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UNIVERSIDADE FEDERAL DE MINAS GERAIS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS
Departamento de Botânica
Programa de Pós-Graduação em Biologia Vegetal

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PATRÍCIA FERRAZ DE OLIVEIRA

FLORISTIC COMPOSITION AND EVOLUTIONARY DIVERSITY OF TREE COMMUNITIES IN THE ESPINHAÇO RANGE BIOSPHERE RESERVE, SOUTHEASTERN BRAZIL

Dissertação apresentada ao Programa de Pós-Graduação em Biologia Vegetal do Departamento de Botânica do Instituto de Ciências Biológicas da Universidade Federal de Minas Gerais, como requisito parcial à obtenção do título de Mestre em Biologia Vegetal.

Área de Concentração: Ecologia vegetal

BELO HORIZONTE – MG

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Orientador: Prof. Dr. Danilo Rafael Mesquita Neves
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Coorientador: Dra. Leila Meyer
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FOLHA DE APROVAÇÃO

“Floristic composition and evolutionary diversity of tree communities in the Espinhaço Range Biosphere Reserve, southeastern Brazil”

Dissertação defendida por PATRÍCIA FERRAZ DE OLIVEIRA e aprovada, em 27 de agosto de 2021, pela banca examinadora constituída pelos professores:

Dr. Danilo Rafael Mesquita Neves (UFMG), Dra. Lívia Echternacht Andrade (Universidade Federal de Ouro Preto), Dra. Vanessa Leite Rezende (Universidade Federal de Lavras).

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“Crescemos pensando que éramos seus proprietários e dominadores, portanto, autorizados a saqueá-la. Esquecemos que somos terra.”

(Papa Francisco)

Resumo

Investigar os padrões de distribuição da biodiversidade ao longo dos gradientes ambientais é um dos principais desafios da biogeografia e um importante pano de fundo para estratégiasde conservação da biodiversidade. Aqui, nós investigamos a influência dos gradientes climáticos e edáficos sobre duas dimensões da biodiversidade: composição florística e diversidade filogenética, ao longo da Reserva da Biosfera da Serra do Espinhaço (RBSE), um importante território brasileiro para conservação localizado em um ecótono de dois *hotspots* da biodiversidade, Cerrado e Mata Atlântica. Nós compilamos a distribuição de 1.897 espécies de árvores em 171 sítios amostrais utilizando um banco de dados sem precendentes e verificamos se a distribuição geograficamente disjunta dos tipos de vegetaçãoao longo da RBSE seria recuperada e quais seriam os principais fatores ambientais na condução dessa distinção florística. Para calcular a diversidade filogenética, usamos uma filogenia a nível de gênero que abrangeu > 90% dos nossos dados e, usando modelos de modelos generalizados de quadrados mínimos, avaliamos a relação entre a diversidade de linhagem e os preditores ambientais selecionados e a categoria dos tipos de vegetação. Além disso, verificamos se os locais com alta diversidade evolutiva dentro do Espinhaço estavamprotegidos pela atual rede de proteção ambiental. Nossos resultados recuperaram sete gruposflorísticos distintos com um importante papel do gradiente das condições edáficas dedisponibilidade de água na diferenciação florística dentro do Espinhaço. O tipo de vegetaçãoem si foi a variável que melhor explicou os padrões gerais de diversidade de linhagens. Nossa análise sobre estado de conservação mostrou que, dentro da RBSE, comunidades com alta diversidade evolutiva estão, em sua grande maioria, desprotegidas. Nossos resultados destacam que a relação solo-vegetação é fundamental para estruturar e manter a heterogeneidade florística dentro do Espinhaço. Além disso, considerando que as Reservas da Biosfera delimitam e dão visibilidade para potenciais áreas de proteção, nosso estudo pode subsidiar tomadas de decisões para proteção da biodiversidade, potencializando os ganhos marginais ao incluir, juntamente com uma alta riqueza de espécies, o legadoevolutivo da comunidade, especialmente no atual contexto de mudanças climáticas globais.

Palavras-chave: Florestas tropicais, cerrado, *campos rupestres*, diversidade filogenética, gradientes ambientais, analises de ordenação

Abstract

Investigate biodiversity distribution patterns along environmental gradients are one of the major issues in biogeography and an important background for conservation strategies of biodiversity. Here, we investigate the influence of climatic and edaphic gradients on two biodiversity dimensions: floristic composition and phylogenetic diversity, in the EspinhaçoRange Biosphere Reserve (ERBR), an important Brazilian territory for conservation locatedin an ecotone between two of the most diverse global biodiversity hotspots, Cerrado and Mata Atlântica. We compiled the distribution of 1.897 tree species in 171 sites using a robust database and investigated whether the geographically disjunct distribution of vegetation types along ERBR would be recovered and which are the major environmental factors in drivingthis floristic distinction. To calculate the phylogenetic diversity, we used a recent genera phylogeny that covered > 90% of our data and, using generalized least squares models, evaluated the relationship between lineage diversity and the selected environmental predictors and vegetation type category. In addition, we verified whether sites with high evolutionary diversity within the Espinhaço were protected by the current protection network. We recognized seven distinct floristic groups with a clear role in the gradient of edaphic conditions of water availability in floristic differentiation within the Espinhaço. Vegetation type category was the variable that most explained overall patterns of lineage diversity. Our analysis of conservation status showed that, within ERBR, highly evolutionarily diverse communities were mostly unprotected. Our results highlight that soil-vegetation relationship is fundamental for structuring and maintaining the floristic heterogeneity within the Espinhaço. Furthermore, considering that the Biosphere Reserves delimit and give visibility to potential protection areas, our study can support decision- making to protect biodiversity, enhancing marginal gains by including, together with a highspecies richness, the evolutionary legacy of the community, especially in the current contextof global climate change.

Keywords: Tropical forests, savannas, *campos rupestres*, phylogenetic diversity, environmental gradients, ordination analyses

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Sumário

1. Introduction

A central task in biogeography is to investigate biodiversity patterns along spatial and environmental gradients, and understand the processes controlling these patterns (Brown, 2014; Fine, 2015). This knowledge is of fundamental importance in the current context of global climate and land-use change and increasing biodiversity loss, as it can inform conservation strategies. Many studies have described consistent patterns of species richness along gradients of temperature and precipitation for different taxonomic groups (e.g., plants: Gentry, 1988; Kreft; Jetz, 2007; Esquivel-Muelbert *et al.* 2017; ter Steege 2003;birds: Hawkins *et al.*, 2012; fungi: Tedersoo *et al.*, 2014; and mammals: Badgley; Fox, 2008.), showing higher species richness in warmer and wetter regions. Even so there is still no consensus about the mechanisms that structures species richness gradients.

Historically, studies on the distribution of biodiversity along gradients ofprecipitation and temperature have focused on the taxonomic dimension of biodiversity (e.g., species or generic richness), while other important dimensions of biodiversity, such as the phylogenetic and functional diversity, were relatively less explored (Ricklefs, 2006). There isan increasing interest in investigating the distribution of evolutionary diversity along environmental gradients, once maintaining evolutionarily diverse communities may, for example, maximize the ecosystem services that these communities provide (Forest *et al.*, 2007; Coelho de Souza *et al.*, 2019).

Some studies have investigated the relationship and congruence between taxonomicand phylogenetic diversities (Brown *et al.*, 2020; Coronado *et al.*, 2015). However, the spatial distribution patterns obtained from these metrics can be complex and less direct than expected, e.g. sometimes places with high taxonomic diversity might not, necessarily, have greater phylogenetic diversity (Forest *et al.*, 2007), creating challenges for conservation strategies. Further, a recent study on the distribution of phylogenetic diversity across lowland tropical biomes in South America (Neves *et al.*, 2020) showed that a considerable number of angiosperm tree communities with high phylogenetic diversity are currently unprotectedand found in areas of high anthropogenic pressure (arc of deforestation, or *arco do desmatamento* in Portuguese). These results might indicate that current conservation strategies may be ineffective in protecting phylogenetic diversity, especially in heterogeneous regions and front of global environmental changes. The integrated use of assorted metrics can maximize the potential gains of the protected area (Forest *et al.*, 2007), since the survival opportunities of species and lineages can be enhanced when including a greater variety of characteristics and possibilities for evolutionary rescue (Bell, 2017) in front of global environmental changes

(González-Caro *et al.*, 2014, Cavender-Bares *et al.*, 2009), especially in places with high floristic heterogeneity inserted in anthropized landscapes.

The Espinhaço Range, in southeastern Brazil (Fig. 1), is renowned for being one of the seven UNESCO's biosphere reserves in Brazil (henceforth, Espinhaço Range Biosphere Reserve; ERBR) (UNESCO, 2020). Different from the other six biosphere reserves, the ERBR is located in an ecotone of three biodiverse ecoregions (or biomes; IBGE, 2012) (Andrade *et al.*, 2018), including two biodiversity hotspots: the Cerrado and the Mata Atlântica (Myers *et al.*, 2000), and the Caatinga, which is the largest continuous seasonally dry tropical forest in South America (Pennington *et al.*, 2006; Werneck, 2011; Pennington *et al.*, 2001). The ERBR region spans the major climatic realms of tropical and subtropical environments, ranging from everwet to seasonally dry, and from warm temperatures to seasonally cold with freezing temperatures (Kamino *et al.*, 2008; Andrade *et al.*, 2018).

While recent studies have shown the importance of seasonal drought in shaping diversity gradients in tropical tree communities (Esquivel-Muelbert *et al.* 2017; Araujo; Santos, 2019; Engelbrecht *et al.*, 2007), with reduced evolutionary diversity under extremely dry, stressful conditions (Neves *et al.*, 2020), little is known about the relative importance of other climatic and edaphic factors for diversity gradients. The ERBR houses multiple vegetation types known to have their distribution driven by edaphic conditions, such as the dystrophic cerrado (i.e., savannas in nutrient-poor soils) and *campos rupestres* (rocky montane scrublands; Rodrigues *et al.*, 2018; Baldeck *et al.*, 2013; Echternacht *et al.*, 2011).Nonetheless, the contribution of soil fertility and rockiness to patterns of evolutionary diversity in tropical tree communities remains poorly explored.

In this study, we evaluated how floristic composition and evolutionary diversity in tree communities are influenced by gradients of climatic and edaphic conditions throughout the ERBR. We also assessed the effectiveness of current conservation strategies in protecting tree communities with high evolutionary diversity. We used a comprehensive dataset on the distribution of 1.897 tree species across 171 sites of the ERBR, combined with climatic and edaphic variables for these sites. We also used a timescaled phylogeny comprising all major clades of angiosperms in our dataset. Specifically, we addressed four main questions: (Q1) Which are the main vegetation types in the ERBR? We expect that previously recognized vegetation types in the Mata Atlântica (e.g., cloud and rain forest; Oliveira-Filho; Fontes, 2006; Neves *et al.*, 2017), Cerrado (savannas; Bueno *et al.*, 2018) and Caatinga (dry forests;Neves *et al.*, 2015) will be floristically consistent in the ERBR. (Q2) What is the importance of climatic and edaphic factors in driving floristic distinction across the ERBR? We expect that gradients of climatic and edaphic water availability will be the most important in driving floristic differentiation in the ERBR; (Q3) What is the influence of climatic and edaphic factors in shaping patterns of evolutionary diversity across the ERBR? We predict that the variation of water stress gradient of the ERBR plays an important role in the distribution of biodiversity;(Q4) How well protected are sites with high evolutionary diversity in the ERBR by the current network of protected areas there? Given the known mismatch between evolutionarydiversity and species richness in plant communities (e.g., Forest *et al.*, 2007; Neves *et al.*, 2020) and considering that protected areas are commonly designed to protect species-rich sites and endemic or endangered species, we expect that the current network of protected areas in the ERBR might not be effective in protecting tree communities of high evolutionarydiversity.

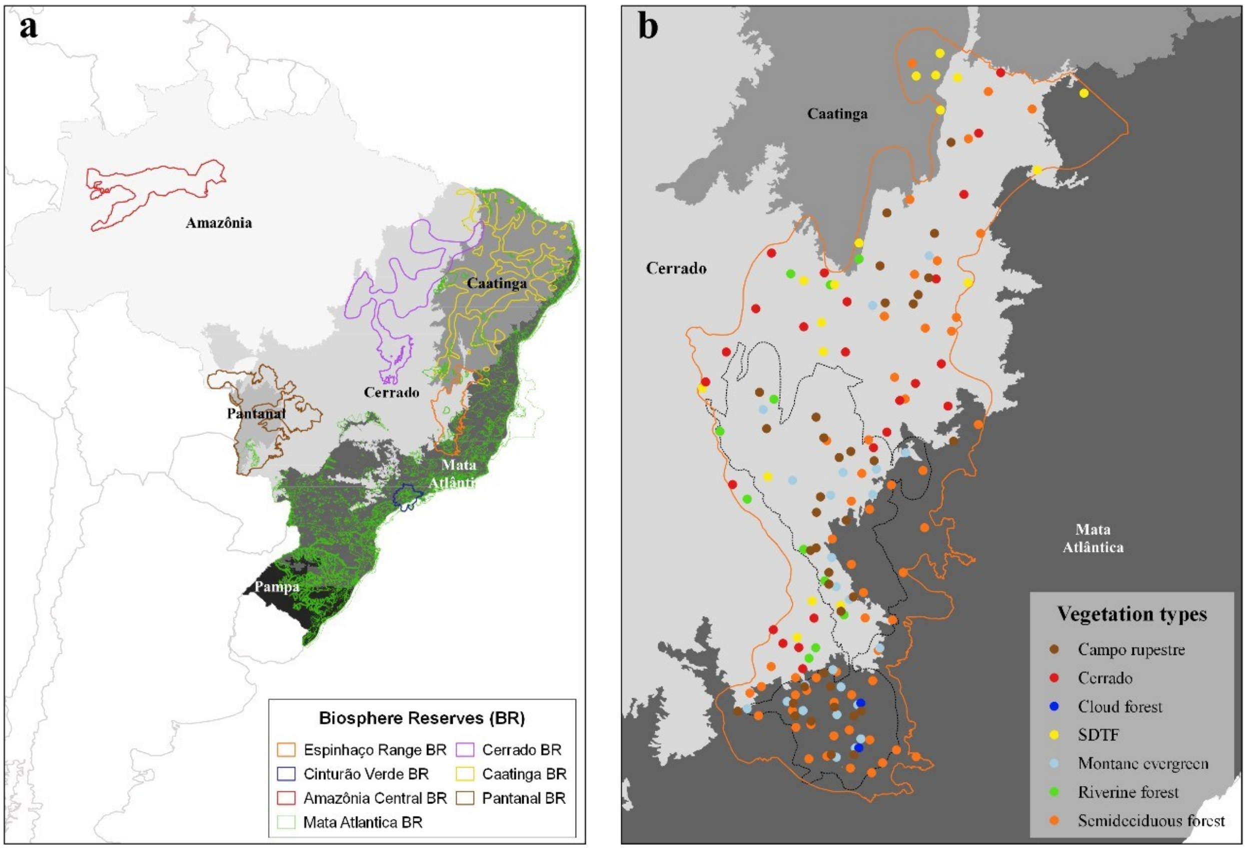

Figure 1. Map of the study area. At the left, the representation/delimitation of the seven Brazilian Biosphere Reserve. At the right, orange delimitation represents the expanded limits of the Espinhaço Range Biosphere Reserve in 2015 with the vegetation types distributions, covering the three biomes: Caatinga, Cerrado and Mata Atlântica. Black dotted lines represent the first delimitation of the reserve in 2005. Different tonalities of gray delimit the biomes in both maps.

2. Methods

2.1 Study area

The Espinhaço Range emerged during the Gondwana formation (c. 640 Mya) and represents the largest orogenic belt in Brazil, spanning c. 1.200 km latitudinally, from southern Minas Gerais state to Northern Bahia state, in eastern Brazil (UNESCO, 2020; Fig. 1). The floristic composition varies according to the local abiotic and geomorphological conditions, resulting in considerable floristic heterogeneity (Kamino *et al.*, 2008). The altitudinal variation (i.e. 700-1.100 m.a.s.l.) across the ERBR, together with a heterogeneous configuration of climatic, topographic and edaphic conditions allow the occurrence of distinct vegetation types over short distances (Fig. 1; Kamino *et al.*, 2008). Indeed, the ERBR is recognized as a biodiversity refuge due its high species richness of multiple, phylogenetically unrelated groups of plants (Echternacht *et al.*, 2011).

The southern portion of the Espinhaço Range was designated as a biosphere reservein 2005 by UNESCO to increase conservation attention in the region, given the widespreadthreat from mining companies and agriculture there, despite its unique biodiversity (Andradeet *al.*, 2018). In 2015, there was a proposal to expand the limits of the biosphere reserve (from 3.2 million ha to 10.2 million ha) to include seasonally dry ecosystems (Caatinga biome) from northern Minas Gerais state (Andrade*et al.*, 2018).

The flora composition in ERBR varies throughout local climatic and edaphic conditions resulting in considerable floristic heterogeneity (Kamino et al., 2008). The different altitudinal strata along the Espinhaço Range allow a high diversity of conditions for vegetation. In higher portions we find the vegetations associated with rocky outcrops, the montane altlantic forests and the unique savanna's domain, the *campo rupestre*. This vegetation has remarkable plant diversity occupies less than 1% of all Brazilian territory and is home to around 15% of all the country's species plant biodiversity. In the intermediate altitudes, the semideciduous vegetation is found in places with adequate moisture and infiltrates the cerrado dry matrix along riparian forests. The north portion, in Bahia state, the vegetation is influenced mostly by the Caatinga domain.

2.2 Dataset

We obtained floristic data from the *NeoTropTree* (NTT; Oliveira-Filho, 2017), a database with ~6,000 geo-referenced sites with tree species checklists compiled fromfloristic surveys, forest inventories, published articles, and unpublished specialized literature(e.g. PhD theses, consultancy reports), spanning all biogeographical domains from southern Florida (USA) and Mexico to Patagonia. Trees are defined here as free-standing woody plants higher than 3m. Each site corresponds to a circular area of 10-km in diameter with itsvegetation type defined following the classification system proposed by Oliveira-Filho (2015). Areas with high habitat heterogeneity (i.e. where two or more vegetation types co-occur in the same 10-km area) can have overlapping sites in the NTT database, with each one corresponding to a single vegetation type. All species and their occurrence records were checked regarding current taxonomic and geographical circumscriptions, as defined by the team of specialists from the online project Flora do Brasil (available at http://floradobrasil.jbrj.gov.br/). For the ERBR, we extracted 1,897 tree species distributed in 171 sites from seven vegetation types: 55 semideciduous forests, 37 *campos rupestres*, 24 cerrado *sensu stricto* (hereafter *cerrado* savannas), 21 montane evergreen dwarf-forests, 18seasonally dry tropical forests (STDF), 11 riverine forest, and five cloud forests (see Table S1 in Supplementary Information).

The NTT database also includes environmental variables for all its sites, derived from multiple sources (at a 30 arc-second resolution), including: altitude at the NTT site center, extracted from Google Earth and given by the Shuttle Mission (SRTM); variables representing average climate (mean annual precipitation and temperature) as well as climateextremes (e.g. precipitation and temperature in driest month) and seasonality (e.g. precipitation seasonality) obtained from WorldClim 1.4 bioclimatic layers (Hijmans *et al.*, 2005); frost frequency (days) and cloud interception (mm) obtained from interpolating known values from meteorological stations as response variables (data collected in the 135 and 57 Brazilian Meteorological Stations, respectively) with elevation, latitude and the WorldClim layers as predicting variables; soil coarseness (% sand), soil fertility (% base saturation) and surface rockiness (% exposed rock) obtained from the Harmonized World Soil Database v 1.2 (available at http://www.fao.org/soils-portal/soil-survey/soil-maps-and- databases/harmonized-world-soil-database-v12/en/) and ranked afterwards by mid-classpercentage to prevent that the high local soil heterogeneity make raw figures unrepresentative; and soil water storage capacity (%) obtained from the International Soil Moisture Network (available at www.ipf.tuwien.ac.at/insitu/). For a detailed description of all environmental variables, see http://www.neotroptree.info/ and Table S2 in Supplementary Information.

2.3 Data analyses

Floristic patterns

We assessed overall patterns of floristic differentiation in the ERBR by applying a Nonmetric Multi-Dimensional Scaling (NMDS) using the Simpson distance as the floristic dissimilarity metric, which minimizes the effect of differences in species richness among sites

(Kreft; Jetz, 2010). Beforehand, we excluded all unicates (i.e., species found in only one site; 288 (15%) out of 1,897 species), as they increase statistical noise in ordination analyses without necessarily contributing information (Lepš; Šmilauer, 2003). We then tested whether the previously defined vegetation types were congruent with the floristic groups observed in the NMDS by performing an Analysis of Similarity (ANOSIM) using the Simpson dissimilarity matrix.

Exploratory ordination analysis revealed that three out of five sites of cloud forests were deeply nested within a montane evergreen dwarf-forest group (ANOSIM $R = 0.27$, $p = 0.07$; Supplementary Fig. S1), and we thereby reclassified them as montane evergreen dwarf-forest for subsequent analyses. This analysis also showed a clear segregation of *campos rupestres* in two groups, with 11 sites clustering with *cerrado* savannas (ANOSIM $R = 0.70, p = 0.001$; Supplementary Fig. S1). These sites were then reclassified and treated as *cerradorupestre* for downstream analyses.

We used the major axes of compositional variation summarized by the ordination analysis to evaluate whether the observed patterns of floristic differentiation in the ERBR are underpinned by variation in climatic and edaphic conditions. First, we selected a subsetof significant environmental variables for each of the major NMDS axes through an AIC- based forward selection procedure for generalized linear models. We then performed an additional and progressive elimination of collinear variables based on their variance inflationfactor (VIF), informed by their ecological relevance, until maintaining only those with VIF < 4 (Quinn; Keough, 2002). We tested the significance of the selected environmental variables by applying ANOVA permutation tests (999 permutations). We explored the results visually by fitting the values of the most important environmental variables in the NMDS ordination space.

Because presence of spatial autocorrelation (SAC) in model residuals can inflate typeI error of statistical tests (Legendre, 1993), we used Moran's I correlograms to check for the presence of SAC in the major NMDS axes (i.e. before the forward selection) and in the model residuals including the environmental variables (i.e. after the forward selection). Dueto a significant spatial structure in the NMDS axes, we included spatial filters as additional predictors to perform the forward selection of the environmental variables. We used Principal Coordinates of Neighbour Matrices as descriptors of the spatial structure (PCNMs;Borcard *et al.*, 2004). We first computed the PCNMs following Borcard and Legendre (2002), keeping only those with positive eigenvalues. We selected the PCNMs by using thesame AIC-based forward selection procedure and ANOVA permutation tests used to selectthe environmental variables (described above). The residuals of the models for the major NMDS axes including only the environmental variables (i.e. after the forward selection) showed no significant spatial structure. These analyses were conducted in the R Statistical Environment (R Core Team, 2019) using the packages "fields" (Nychka *et al.*, 2021), "letsR"(Vilela; Villalobos, 2020), "recluster" (Dapporto *et al.*, 2020), "usdm" (Naimi, 2017), and "vegan" (Oksanen *et al.*, 2020).

Phylogenetic diversity

We calculated phylogenetic diversity of tree communities in the ERBR using a recently published phylogeny of 1.100 angiosperm genera found in lowland tropical South America (Neves *et al.*, 2020). This phylogeny includes 445 out of 487 genera found in our community matrix. We computed the phylogenetic diversity of each community by summing its total phylogenetic branch lengths (PD; Faith, 1992), creating a null model thatrandomly shuffled the tips of the phylogeny 999 times, and then standardizing PD for the genus-level richness in this community (standardized effect size or sesPD; Kembel *et al.*, 2010), a metric we refer to as lineage diversity (*sensu* Neves et al., 2020). To test for differences in lineage diversity among the floristic groups recovered in the NMDS, we usedthe Kruskal-Wallis non-parametric test, followed by a post-hoc pairwise Dunn test.

We used generalized least squares (GLS) models to evaluate the relationship between lineage diversity and the climate and soil variables selected as significant in driving the floristic distinction of tree communities in the ERBR. We also included vegetation typesas a predictor in the GLS. To assess the contribution of each set of variables (i.e. climate, soilor vegetation types) or combinations among them in explaining patterns of lineage diversityin the ERBR, we first summarized the climate and soil variables separately using principal component analyses (PCA), retaining the first principal component (PC) of each PCA as explanatory variables. Climate and soil PCs accounted for 84% and 70% of the variation inthe climate and soil matrices, respectively. We then built seven models with single variables(i.e. climate PC, soil PC, and vegetation type), as well all possible combinations among them. Because spatial autocorrelation can inflate type I error in traditional statistical tests and affect parameter estimates, we accounted for it by performing generalized least squaresanalyses with five different spatial structures: exponential, Gaussian, linear, quadratic ratio and spherical. Model selection was based on the minimization of AIC values; i.e., ΔAIC relative to the null model without spatial autocorrelation. Given a low variation of ΔAIC values (< 2) for the different spatial structures (see Table S3 in Supplementary information), for comparative purposes we chose the exponential structure, which was also used in other studies of evolutionary diversity in neotropical tree communities (Neves *et al.*, 2020; Rezende *et al.* 2017). We did not include cloud and riverine forests in these analyses because cloud forests had only a few sites, and riverine forests showed a low degree of floristic identity (see Results). We performed the phylogenetic analyses using the packages "dunn.test" (Dinno, 2017), "nlme" (Pinheiro *et al.*, 2021), "picante" (Kembel *et al.*, 2010), and "vegan" (Oksanen *et al.*, 2020) in R.

Conservation status

We assessed the protection status (protected or unprotected) of the top 10% tree communities (i.e. 16 sites with highest values of lineage diversity out of 158 sites) by overlaying their distribution onto the coverage of protected areas within ERBR (Appendix 2). We used the delimitation of protected areas from the Cadastro Nacional de Unidades deConservação (MMA; available in: http://mapas.mma.gov.br/i3geo/datadownload.htm). We also evaluated whether the extended delimitation of ERBR including the northern region ofMinas Gerais state includes sites with high lineage diversity across the ERBR. For these analyses we used the packages "raster" (Hijmans *et al.*, 2021), "rgdal" (Bivand *et al.*, 2021),"rgeos" (Bivand *et al.*, 2020) and "SpatialEco" (Evans *et al.*, 2021) in R.

3. Results

3.1 Floristic patterns

Variation in tree community composition summarized by the first two ordination axis (stress value = 0.15; Fig. 2) supports the floristic distinction of seven previously defined vegetation types for the Espinhaço Range Biosphere Reserve (ERBR), namely semideciduous forest, *campo rupestre*, *cerrado rupestre*, cerrado *sensu stricto*, montane evergreen dwarf-forest, seasonally dry tropical forest (SDTF), and cloud forest (ANOSIM $R = 0.87$, $p = 0.001$). Riverine forests showed higher floristic affinity with semideciduous forests and remained nested with these sites (ANOSIM $R = 0.25$ $p = 0.003$).

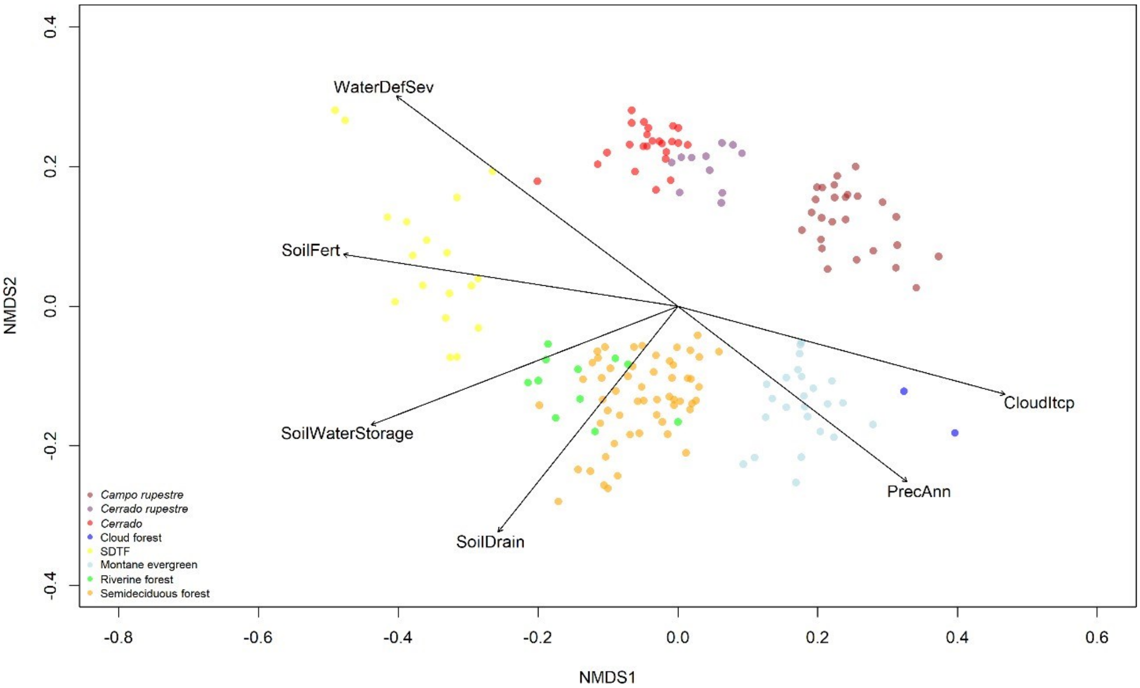

Figure 2. Ordination of 171 tree communities in the Espinhaco Range Biosphere Reserve inferred from non-metric multidimensional scaling of their species composition. Arrows reflect relationships of climatic and edaphic variables with the variation in community composition summarized by the first two ordination axes. CloudItcp = cloud interception; PrecAnn = annual precipitation; SoilDrain = soil drainage restriction; SoilFert = soil fertility; WaterDefSev = severity of the water deficit period; SoilWaterStorage = soil water storage capacity.

The first axis of the NMDS ordination distributes the vegetation types over a deciduousness gradient, segregating the STDF in the negative values and Atlantic evergreen formations in the positive values, with the semideciduous forest in a floristically transitional position. Soil fertility together with cloud interception and soil water storage capacity werethe most important predictors in the first axis. Further, the second axis segregates the open (positive values) and forest (negative values) formations, with the STDF in the transition position. Here, soil drainage restriction was the most important variable for this segregation.The STDF positive sites distribution in the second axis represents areas geographically distant, floristically closer to savannas and *campo rupestres*.

The selected environmental predictors account for 84% and 36% of the variation in community composition summarized by the first two NMDS axes, respectively (Table S4 in Supplementary information). Higher values of soil fertility and severity of the water deficit period were congruent with the floristic differentiation of SDTF communities from all other vegetation types. Higher cloud interception (or horizontal precipitation) was effective in segregating cloud forests and montane evergreen dwarf-forests from all other vegetation types, with higher horizontal precipitation in cloud forests. Variation in mean annualprecipitation segregated montane evergreen dwarf-forests from semideciduous forest, whilehigher soil water storage capacity and soil drainage restriction (i.e. a proxy of soil waterlogging) were consistent with the segregation of semideciduous and riverine forests from *campo rupestre*, *cerrado rupestre* and *cerrado* savannas.

3.2 Lineage diversity

We found significant differences in lineage diversity (i.e. standardized effect size or sesPD, *sensu* Neves *et al.*, 2020) among the vegetation types (Kruskal-Wallis $\chi^2 = 76$, $p < 0.001$). The STDF showed significantly lower values of lineage diversity, given the null expectation, than the other vegetation types, except for the *campo rupestre* (Fig. 3). In turn,the semideciduous forest had significantly higher values of lineage diversity in comparisonto the other vegetation types, except for the *cerrado rupestre* and *cerrado* savanna. In GLSmodels, vegetation type alone was the most effective variable explaining variation in lineage diversity (*pseudo*-R^2 = 55%) when compared to climate and soil. There was a negligible minimization of AIC (i.e. $\Delta AIC < 2$) in more complex models, either those including two variables or all variables.

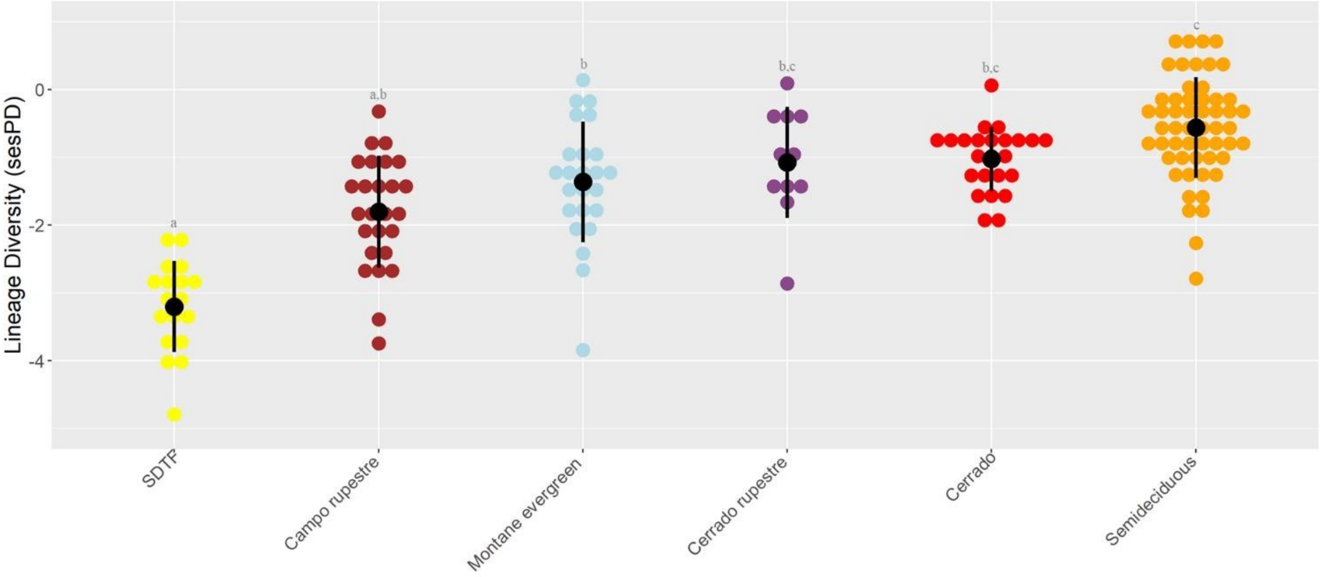

Figure 3. Distribution Lineage Diversity (i.e. standardized effect size of phylogenetic diversity - sesPD) in vegetation types of the ERBR. Black points in the center of the distribution indicate the mean values of sesPD. Different letters indicate significant differences ($p < 0.05$) in sesPD between vegetation types, while letters in common indicate no significant differences.

3.3 Conservation status

Our conservation status assessment showed that from the 10% of tree communities within the ERBR with the highest values of lineage diversity (i.e. 16 out of 158 sites), 13 of them belong to the semideciduous forest, while each one of the remaining three sites belong to a different vegetation type: montane evergreen dwarf-forest, *cerrado rupestre,* and cerrado *sensu stricto*. Only six of these sites (37,5%) are located within protected areas, all of them belonging to the semideciduous forest. Eleven of the more evolutionarily diverse tree communities in the ERBR are found in the expanded ERBR area, with seven of them currently unprotected (Fig. 4).

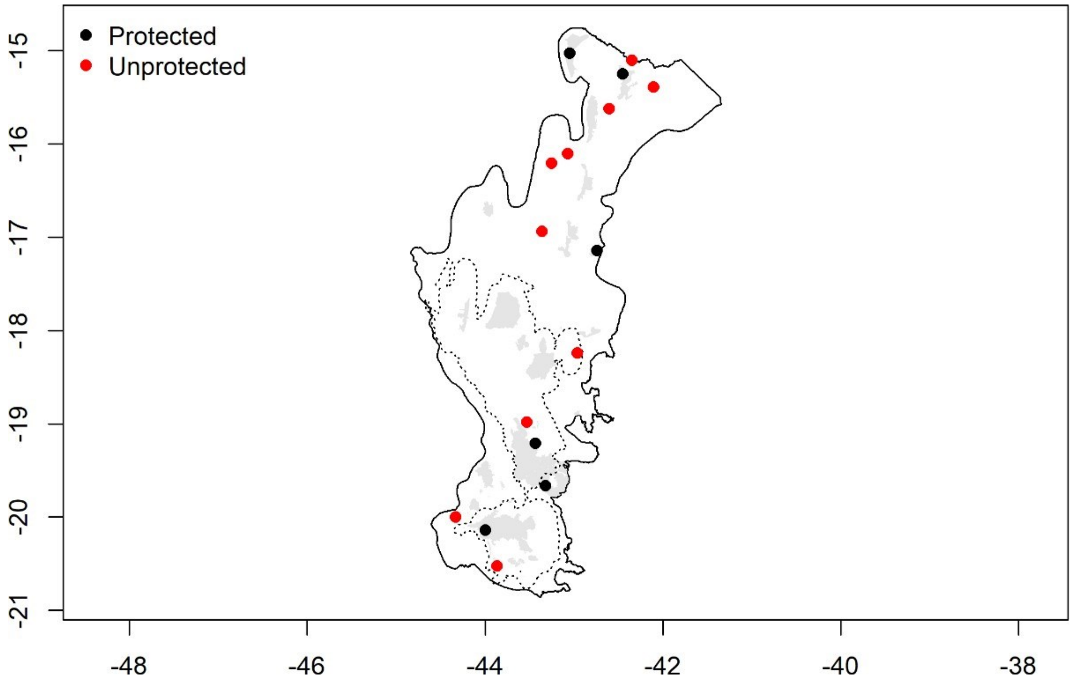

Figure 4. Conservation status (protected or unprotected by protected areas) of the top 10% tree communities (16 sites) with the highest values of lineage diversity (i.e. standardized effect size or ses.PD) across the Espinhaço Range Biosphere Reserve (ERBR). Black dotted line represents the initial boundaries of the ERBRdefined in 2005, solid black line represents the expanded limits proposed in 2015, and the gray polygons are area covered by protected areas.

4. Discussion

4.1 Floristic differentiation of the ERBR flora

Our results confirmed the compositional identity of eight vegetation types that co- occur along Espinhaço Range Biosphere Reserve (ERBR), an ecotonal region comprising portions of the *Mata Atlântica* and the Cerrado biodiversity hotspots and of the Caatinga biome. Gradients of edaphic conditions, which are often neglected in large-scale biogeographical studies, are at least as important as climatic conditions in explaining the floristic differentiation and maintenance of the heterogeneity of these vegetation types.

The evergreen vegetation of the *Mata Atlântica* is replaced with the increase of water deficit severity by semideciduous forests, that have a species composition able to resist in longer dry seasons (Oliveira-Filho; Fontes, 2006; Silva de Miranda *et al.*, 2018; Scarano, 2009) and where smaller amounts of precipitation occur (e.g., mean annual precipitation of 1.474 mm in montane evergreen forests, and 1.309mm in semideciduous forests). Soil drainage restriction, for instance, is one of the most important edaphic conditions in our models and enables these species to expand their distribution in driest environments throughriverine forests, explaining the compositional similarity of semideciduous and riverine forests.

Compositional similarity is much lower between evergreen forests and *cerrado* savannas, which are often adjacent to semideciduous forest (i.e., similar precipitation conditions; Dexter *et al.*, 2018), but are found under higher local water shortage due to highersoil drainage. That same gradient of soil water restriction played an important role in the floristically segregation of sites previously defined as *campos rupestres* into those that occurin more similar conditions and features more floristic influence of the cerrado savannas (cerrado rupestre), and to those of wet elevation vegetation. This result is in agreement withfloristic studies showing that *campo rupestre* vegetation does not constitute a unique woodyfloristic group, but distinct groups influenced by the surrounding vegetation (Neves *et al.*, 2017; Zappi, 2008). So, the maintenance of the floristic heterogeneity in this remarkable plant diversity vegetation also depends, beyond the protection *per se*, on the protection of the surrounding vegetation.

4.2 Patterns of lineage diversity across ERBR vegetation types

Lineage diversity values were significantly different among vegetation types. The SDTFs, which are found under the driest conditions of the ERBR, show the lowest levels of lineage diversity amongst vegetation types in our analyses, with all its tree communities being assembled from a phylogenetically clustered subset of angiosperm communities. Lineage diversity in the ERBR, however, does not increase linearly with the gradient of water availability, which would implicate in highest values across moist and evergreen forests. Instead, highest amounts of lineage diversity in the ERBR are found in semideciduous forests, which occur under intermediate conditions of the precipitationgradient sampled in our study.

These patterns found here support recent findings, on a largerscale, of high lineage diversity values in sites located in environments with intermediate precipitation conditions of the tropical portion of lowland South America (Neves *et al.*, 2020). This pattern reflects that semideciduous forests are assembled from lineages that represent the major clades of angiosperms, including those that are endemic to extremes of the precipitation gradient, but coexist under intermediate precipitation conditions.

The convergence of different lineages in regions with intermediate precipitation suggests that extremes of this gradient (dry-wet) establish a limit of occurrence for the lineages within ERBR. Here, in wet Atlantic sites, we found endemic lineages of uplands, such as *Weinmannia*, *Drymis*, *Podocarpus* and *Hedyosmum* that are adapted to different conditions, such as the occurrence of horizontal precipitation and occasional frost events (Oliveira-Filho; Fontes, 2000; Giulietti; Pirani, 1988). In dry areas, we also found endemic genera, such as *Mimosa*, *Piptadenia* and *Schinopsis* (Oliveira-Filho; Fontes, 2000; Pennington *et al.*, 2001). These lineages confined to the extreme share similar environmental conditions and abiotic mechanisms over evolutionary time scales (Pennington et al., 2009; Segovia *et al.*, 2020; Neves *et al.*, 2020), and together with highest values of lineage diversityin intermediate conditions, influence and structure the biogeographical changes in the communities along ERBR.

Despite the clear role of water availability gradients in shaping patterns of lineage diversity across tree communities in the ERBR (this study) and on larger scales in tropical South America (Neves *et al.*, 2020), vegetation type alone is the most effective variable predicting overall patterns of lineage diversity across the ERBR, with negligible contributions of climate and soil conditions. The distribution of vegetation types in the ERBR are highly congruent with edaphic and climatic conditions, but unmeasured factors affecting their distribution, and not included in our models, such as fire and herbivory (Simon *et al.*, 2009; Bueno *et al.*, 2018), might also be shaping patterns of lineage diversity.

These findings are of important implications for conservation, as we can predict the amount of evolutionary diversity in tree communities of the ERBR by identifying the vegetation typeto which it belongs. Here we argue that this approach can be relevant for defining conservation strategies in the Espinhaço Range as a whole, not only in the area delimited asthe Biosphere Reserve. Our results indicate that in regions under high anthropogenic pressure, but where information on their tree community composition is lacking for decision- makers, conservation priorities can be defined to some degree of confidence based on the identity of the vegetation types found across that region.

In this study, the herbaceous component of the vegetation was not considered. However, we emphasize the importance that future studies include this component of vegetation in analysis of evolutionary diversity and floristic composition, helping decision makers in the development of strategies to protect this biodiversity.

4.3 Conservation implications

This complex network of co-occurrence between vegetations in ecotonal regions calls attention to the importance of discussion about construction of broad conservation strategies that aim to maintain the heterogeneity and the services provided by these vegetations. Recent studies have shown that areas with high evolutionary diversity also havegreater ecosystem functionality, increasing the resilience of these communities in the face of global environmental changes (Cadotte *et al.*, 2008; Coelho de Souza *et al.*, 2019; Lavergne *et al.*, 2013). Our analysis of conservation status revealed that within ERBR the evolutionarily diverse communities are mostly unprotected. This result illustrates the traditional conservation policies in Brazil, where protection areas are defined only using thespecies richness metric and endemic or endangered species.

Studies in hotspots of diversity have demonstrated that geographic distribution between areas with great species richness and those with great evolutionary diversity are notcongruent (Forest *et al.*, 2007). Through a similar analysis for the ERBR, our study highlights areas of high evolutionary diversity distributed between two hotspots of biodiversity that are unprotected. Our analysis showed that the top 10% highly evolutionarilydiverse communities belong to semideciduous and montane evergreen dwarf-forest, vegetation types representing the *Mata Atlântica*, as well as *cerrado rupestre* and cerrado sensu stricto, with only semideciduous sites included in protected areas. However, the reserve's recent expansion was important to increase visibility for conservation in the ERBR.Our results highlight that the key areas with distinct flora and evolutionary legacies, such ascerrados and evergreen forest, are now included within the ERBR, reinforce the importance of rating several biodiversity metrics for conservation, identifying not only rich-sites, but also places with favorable perspectives of the survival front of global environmental changes.

5. Conclusion

Here, we used a robust database and identified the main floristic groups and principal factors that shape species composition and patterns of lineage diversity across the Espinhaço Range Biosphere Reserve. The high floristic heterogeneity of the ERBR is maintained and structured mainly by the soil-vegetation relationship, specially by the water availability in the system. In turn, vegetation type was the best variable predicting overall patterns of lineage diversity across the ERBR. The current conservation policy in ERBR does not protect the sites with high lineage diversity, which likely resulted due the fact that most protection areas have been determined taking into account only few dimensions of biodiversity. The potential gains for conservation can be greater when evolutionary legacy of the community is considered for decision making, as it, even in an unknown future, would allow greater coverage of the genetic variety and, thus, more survival possibilities for species. Therefore, future studies in vegetation mosaics need, in addition to understanding the general patterns of biodiversity, to assess how this biodiversity has been protected by the existing network of protected areas, mainly in the current context of global climate and increasing biodiversity loss.

References

Andrade, M.A.; Drummond, G.M.; Domingues, S.A.; Martins, C.S.; Franco, A.R. (Org.) et. al. *Reserva Da Biosfera Da Serra Do Espinhaço Fase 2*. Reserva da Biosfera da Serra do Espinhaço, MaB-UNESCO. Belo Horizonte, Minas Gerais, Brasil. 2018.

Araújo, F. D. C.; Santos, R. M. (2019). Different degrees of water-related stress affect evolutionary diversity in a seasonally dry biome. *Oecologia*, 189, 795–802.

Badgley, C.; Fox, D. L. (2000). Ecological biogeography of North American mammals: species density and ecological structure in relation to environmental gradients. *Journal of Biogeography* 27: 1437–1467.

Baldeck, C.A.; Harms, K.E.; Yavitt, J.B.; John, R.; Turner, B.L.; Valencia, R.; Navarrete, H.; Davies, S.J.; Chuyong, G.B.; Kenfack, D.; Thomas, D.W.; Madawala, S.; Gunatilleke,N.; Gunatilleke, S.; Bunyavejchewin, S.; Kiratiprayoon, S.; Yaacob, A.; Supardi, M.N.N.; Dalling, J.W. (2013) Soil resources and topography shape local tree community structurein tropical forests. *Proc R Soc B* 280: 20122532.

Bell, G. (2017). Evolutionary rescue. *Annual Review of Ecology, Evolution, and Systematics*.48, 605–627

Bivand, R.; Keitt, T.; Rowlingson, B.; Pebesma, E.; Sumner, M.; Hijmans, R.; Baston, D.; Rouault, E.; Warmerdam, F.; Ooms, J.; Rundel, C. (2021). *rgdal: Bindings for the 'Geospatial' Data Abstraction Library.* R package version 1.5-23. Available at https://cran.r-project.org/web/packages/rgdal/index.html

Bivand, R.; Rundel, C.; Pebesma, E.; Stuetz, R.; Hufthammer, K.O.; Giraudoux, P.; Davis, M.; Santilli, S. (2020). *rgeos: Interface to Geometry Engine - Open Source ('GEOS')*. R package version 0.5-5. Available at https://cran.r-project.org/web/packages/rgeos/index.html

Borcard, D.; Legendre, P. (2002). All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. Ecological Modelling 153, 1–2, 51-68.

Borcard, D.; Legendre, P.; Avois-Jacquet, C.; Tuomisto, H. (2004). Dissecting the spatial structure of ecological data at multiple scales. *Ecology* 85, 1826–1832

Brown, J. H. (2014). Why are there so many species in the tropics?. *Journal of biogeography*, 41(1), 8-22.

Brown, J. L., Paz, A., Reginato, M., Renata, C. A., Assis, C., Lyra, M., Caddah, M. K., Aguirre-Santoro, J., d'Horta, F., Raposo do Amaral, F., Goldenberg, R., Lucas Silva- Brandão, K., Freitas, A. V. L., Rodrigues, M. T., Michelangeli, F. A., Miyaki, C. Y., & Carnaval, A. C. (2020). Seeing the forest through many trees: Multi-taxon patterns of phylogenetic diversity in the Atlantic Forest hotspot. *Diversity and Distributions*, 26(9), 1160–1176.

Bueno, M.L.; Dexter, K.G.; Pennington, R.T.; Pontara, V.; Neves, D.M.; Ratter, J.A.; Oliveira-Filho, A.T. (2018). The environmental triangle of the Cerrado Domain: Ecological factors driving shifts in tree species composition between forests and savannas. *J Ecol.* 106:2109–2120.

C. C.; Armesto, J. J.; Olivera-Filho, A. T.; Dexter, K. G. (2020). Freezing and water availability structure the evolutionary diversity of trees across the Americas. *Sci. Adv.* 6,eaaz5373

Cadotte, M.W., Cardinale, B.J. & Oakley, T.H. (2008) Evolutionary history and the effect of biodiversity on plant productivity. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 17012–17017.

Cavender-Bares J. et al. (2009). The merging of community ecology and phylogenetic biology, *Ecol. Lett.*, 12 (pg. 693-715)

Coelho de Souza, F. et al. (2019). Evolutionary diversity is associated with wood productivity in Amazonian forests. *Nature Ecology & Evolution*, 3, 1754–1761.

Coronado, E.N.H. et al. (2015). Phylogenetic diversity of Amazonian tree communities. *Diversity and Distributions*, 21, 1295–1307.

Dapporto, L.; Ramazzotti, M.; Falttorini, S.; Talavera, G.; Vila, R.; Dennis R.L.H. (2020). *recluster: Ordination Methods for the Analysis of Beta-Diversity Indices*. R package version 2.9. Available at https://cran.r-project.org/web/packages/recluster/index.html

Dexter, K.G; Pennington, T.R.; Oliveira-Filho A.T.; Bueno M.L.; Silva de Miranda, P.L.; Neves D.M. (2018). Inserting tropical dry forests into the discussion on biome transitionsin the tropics. *Frontiers in Ecology and Evolution.* 6, 104

Dinno, A. (2017). *Dunn.test: Dunn's test of multiple comparisons using rank sums*. R package version 1.3.5. Available at https://cran.r-project.org/web/packages/dunn.test/index.html.

Echternacht, L.; Trovó, M.; Oliveira, C.T.; Pirani, J.R. (2011). Areas of endemism in the Espinhaço Range in Minas Gerais, Brazil. *Flora* 206:782–791

Engelbrecht, B. M. J. et al. (2007). Drought sensitivity shapes species distribution patterns in tropical forests. *Nature* 447, 80–82

Esquivel-Muelbert et al. (2016). Seasonal drought limits tree species across the Neotropics. *Ecography* 40, 618–629

Evans, J.S.; Murphy, M.A.; Ram, K. *spatialEco: Spatial Analysis and Modelling Utilities*. (2021). R package version 1.3-7. Available at https://cran.r-project.org/web/packages/spatialEco/index.html

Faith, D.P. (1992). Conservation evaluation and phylogenetic diversity. *Biol. Conserv*. 61, 1–10.

Fine, P. V. (2015). Ecological and evolutionary drivers of geographic variation in species diversity. *Annual Review of Ecology, Evolution, and Systematics*, 46, 369-392.

Forest, F.; Grenyer, R.; Rouget, M.; et al. (2007). Preserving the evolutionary potential of floras in biodiversity hotspots. *Nature* 445, 757–760.

Gentry, A.H. Changes in plant community diversity and floristic composition on environmental and geographical gradients. (1988). *Annals of the Missouri Botanical Garden* 75, 1–34.

Giulietti, A.M.; Pirani, J.R. (1988). Patterns of geographic distribution of some plant species from Espinhac¸ o Range, Minas Gerais and Bahia, Brazil. *In:* Vanzolini, P.; Heyer, W.R. (org.). *Procceedings of a workshop on neotropical distribution patterns*. Academia Brasileira de Ciências, Rio de Janeiro, pp. 39–69.

González-Caro, S.; Umaña, M.N.; Álvarez E.; Stevenson, P.R.; Swenson, N.G. (2014) Phylogenetic alpha and beta diversity in tropical tree assemblages along regional scale environmental gradients in northwest South America. *J Plant Ecol* 7:145–53.

Hawkins, B.; Field, R.; Cornell, H.; Currie, D.; Guegan, J.; Kaufman, D.; Kerr, J.; Mittelbach, G.; Oberdorff, T.; O'Brien, E. et al. (2003). Energy, water, and broad-scale geographic patterns of species richness. *Ecology* 84, 3105–3117

Hawkins, B.A. et al. (2012). Different evolutionary histories underlie congruent species richness gradients of birds and mammals. *Journal of biogeography*, 39(5), 825-841.

Hijmans, R. J. et al. (2021). *raster: Geographic data analysis and modeling*. R package version 3.4-13. Available at https://cran.r-project.org/web/packages/raster/index.html

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25, 1965–1978.

Instituto Brasileiro de Geografia e Estatística (IBGE) Ed. (2012). *Manual técnico da vegetação brasileira*. 2º edição. Rio de Janeiro.

Kamino, L.H.Y.; Oliveira-Filho, A.T.; Stehmann, J.R. (2008). Relações florísticas entre as fitofisionomias florestais da Cadeia do Espinhaço, Brasil. *Megadiversidade* 4, 78–98.

Kembel, S. W.; Cowan, P. D.; Helmus, M. R.; Cornwell, W. K.; Morlon, H.; Ackerly, D. D.; Blomberg, S. P. Webb, C. O. (2010). Picante: R tools for integrating phylogenies andecology. *Bioinformatics*, 26, 1463-1464.

Kreft, H.; Jetz, W. Global patterns and determinants of vascular plant diversity. (2007). *Proc. Natl Acad. Sci*. USA 104, 5925–5930.

Lavergne, S.; Evans, M. E.; Burfield, I. J.; Jiguet, F; Thuiller, W. (2013). Are species' responses to global change predicted by past niche evolution? *Phil. Trans. R. Soc. B.* 368,20120091.

Legendre, P. (1993). Spatial autocorrelation: trouble or new paradigm? *Ecology* 74:1659– 73

Lepš, J., & Šmilauer, J. P. (2003). *Multivariate analysis of ecological data using CANOCO*. Cambridge, UK: Cambridge University Press.

Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; Fonseca, G.A.B..; Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature* v. 403 24

Naimi, B. (2017). *usdm: Uncertainty Analysis for Species Distribution Models*. R package version 1.1-18. Available at https://cran.r-project.org/web/packages/usdm/index.html

Neves, D.M.; Dexter, K.G.; Baker, T.R.; de Souza F.C.; Oliveira-Filho, A.T.; Queiroz, L.P.; Lima, H.C.; Simon, M.F.; Lewis, G.P.; Segovia, R.A et. Al. (2020). Evolutionarydiversity in tropical tree communities peaks at intermediate precipitation *Sci. Rep*. 10 1–7

Neves, D.M.; Dexter, K.G.; Pennington, R.T. et al. (2017). Dissecting a biodiversity hotspot:The importance of environmentally marginal habitats in the Atlantic Forest domain of South America. *Diversity and Distributions*. 23(8):898-909.

Neves, D.M.; Dexter, K.G.; Pennington, R.T; Bueno, M.L.; Miranda, P.L.S.; Oliveira-Filho, A.T. (2017). Lack of floristic identity in campos rupestres—A hyperdiverse mosaic of rocky montane savannas in South America. *Flora*, 238, 24– 31

Nychka, D.; Furrer, R.; Paige, J.; Sain, S. (2021). *Fields: Tools for spatial data*. R package version 12.5. Available at https://cran.r-project.org/web/packages/fields/index.html

Oksanen, J.; Blanchet, F. G.; Kindt, R.; Legendre, P.; Minchin, P.R.; O'Hara, R.B.; Simpson, G.L.; Solymos, P.; Stevens, M. H. H.; Wagner, H. (2020). *Vegan: Community Ecology Package*. R package version 2.5-7. Available at https://cran.r-project.org/web/packages/vegan/index.html

Oliveira-Filho, A. T. (2015). Um Sistema de classificação fisionômico-ecológica da vegetação Neotropical. In P. V. Eisenlohr, J. M. Felfili, M. M. R. F. Melo, L. A. Andrade& J. A. A. Meira-Neto (Eds.), *Fitossociologia no Brasil: Métodos e estudos de casos*, Vol. 2 (pp. 452–473). Viçosa, Brazil: Editora UFV

Oliveira-Filho, A. T.; Fontes, M. A. L. (2000). Patterns of floristic differentiation among Atlantic forests in southeastern Brazil and the influence of climate. *Biotropica* 32, 793– 810.

Oliveira-Filho, A. T.; Jarenkow, J. A.; Rodal, M. J. N. (2006). Floristic relationships of Seasonally Dry Forest of eastern South American based on tree species distribution patterns. *In:* Pennington, T.R.; Lewis, G.P.; Ratter, J.A. (org.). *Neotropical Savannas andDry Forests: Plant Diversity, Biogeography and Conservation*. CRC Press; 1ª edição, 159–192

Oliveira-Filho, A.T. (2017). *NeoTropTree, Flora arbórea da Região Neotropical: Um bancode dados envolvendo biogeografia, diversidade e conservação*. Universidade Federal deMinas Gerais. Disponível em http://www.neotroptree.info

Pennington, R.T.; Lavin, M.; Oliveira–Filho, A. (2009). Woody plant diversity, evolution and ecology in the tropics: Perspectives from seasonally dry tropical forests. *Ann Rev Ecol Evol Syst* 40:437–457

Pennington, R.T.; Prado, D.E.; Pendry, C.A. (2001). Neotropical seasonally dry forests and Quaternary vegetation changes. *Journal of Biogeography* 27: 261-273.

Pennington, R.T.; Richardson, J. E.; Lavin, M. (2006). Insights into the historical construction of species-rich biomes from dated plant phylogenies, neutral ecological theory and phylogenetic community structure. *New Phytol.*, 172, 605– 616.

Pinheiro, J.; Bates, D.; DebRoy, S.; Sarkar, D.; R Core Team. (2021). *nlme: linear and nonlinear mixed effects models*. R package version 3.1-152. Available at https://cran.r-project.org/web/packages/nlme/index.html

Quinn, G.P.; Keough, M.J. (2002). *Experimental design and data analysis for biologists*. Cambridge University Press, Cambridge

R Core Team. (2019). R: A language and environment for statistical computing. Version 3.6.1. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/.

Rezende, V.L.; Dexter, K.G.; Pennington, R.T.; Oliveira-Filho, A.T. (2017). Geographical variation in the evolutionary diversity of tree communities across southern South America. *J Biogeogr*. 44: 2365–2375.

Ricklefs RE (2006) Evolutionary diversification and the origin of the diversity-environment relationship. *Ecology* 87:S3–13.

Rodrigues, P.M.S.; Schaefer, C.E.G.R.; de Oliveira, S.J.; Ferreira Júnior, W.G.; dos Santos, R.M.; Neri, A.V. (2018). The influence of soil on vegetation structure and plant diversityin different tropical savannic and forest habitats. *Journal of Plant Ecology*, 11, 2, 226– 236,

Scarano, F. R. (2009). Plant communities at the periphery of the Atlantic rain forest: Rare-species bias and its risks for conservation. *Biological Conservation*, 142, 1201–1208. Segovia, R. A.; Pennington, R. T.; Baker, T. R.; Coelho de Souza, F.; Neves, D. M.; Davis,

Silva de Miranda, P.L.; Oliveira-Filho, A.T.; Pennington, R.T.; Neves, D.M.; Baker, T.R.; Dexter, K.G. (2018). Using tree species inventories to map biomes and assess their climatic overlaps in lowland tropical South America. *Global Ecol Biogeogr.* 27,8:1–14

Simon, M.F.; Grether, R.; de Queiroz, L.P.; Skema, C.; Pennington, R.T.; Hughes, C.E. (2009). Recent assembly of the Cerrado, a neotropical plant diversity hotspot, by in situ evolution of adaptations to fire. *Proceedings of the National Academy of Sciences USA*, 106, 20359–20364.

Tedersoo, L. et al. (2014). Global diversity and geography of soil fungi. *Science* 346: 1256688.

ter Steege, H. et al. (2003). A spatial model of tree α-diversity and tree density for the Amazon. *Biodivers. Conserv*. 12, 2255–2277

UNESCO. 2020. Disponível em: <https://en.unesco.org/biosphere/lac/espinhaco>. Acesso em 07 set. 2020

Vilela, B.; Villalobos, F. (2020). *letsR: Data Handling and Analysis in Macroecology*. R package version 4.0. Available at https://cran.r-project.org/web/packages/letsR/index.html

Webb, C.O.; Ackerly, D.D.; McPeek, M.A.; Donoghue, M.J. (2002). Phylogenies and community ecology. *Annual Review of Ecology and Systematics* v. 33 (1) p. 475-505.

Werneck, F.P. (2011). The diversification of eastern South American open vegetation biomes: historical biogeography and perspectives. *Quaternary Science Reviews*, 30, 1630–1648.

Zappi, D. (2008). Fitofisionomia da Caatinga associada à Cadeia do Espinhaço. *Megadiversidade* 4:34–38

Supplementary Information

Table S1 Complete information of 171 sites distributed in the eight vegetation types.

	Site name	Long	Lat	Altitude	Domain	Vegetation type	Nº genus	Conservation status: PA name
AtlMG018	Itambé do Mato Dentro, floresta semidecídua	-43.2072	-19.4222	578	Atlantic Forest	Semideciduous forest	147	Área De Proteção Ambiental Do Itacuru
AtlMG033	Guaraciaba, floresta semidecídua	-43.0203	-20.5022	496	Atlantic Forest	Semideciduous forest	152	
AtlMG040	Leme do Prado, floresta semidecídua	-42.7033	-17.0336	900	Atlantic Forest	Semideciduous forest	165	
AtlMG044	Aricanduva, floresta semidecídua	-42.5294	-17.8792	860	Atlantic Forest	Semideciduous forest	164	
AtlMG046	Rio Vermelho, floresta semidecídua	-42.9661	-18.2422	719	Atlantic Forest	Semideciduous forest	165	
AtlMG048	Guanhães, floresta semidecídua	-42.9544	-18.6939	916	Atlantic Forest	Semideciduous forest	153	
AtlMG050	Carmésia, Aldeia Pataxó, floresta semidecídua	-43.1225	-19.0478	739	Atlantic Forest	Semideciduous forest	137	
AtlMG054	São Gonçalo do Rio Abaixo, floresta semidecídua	-43.3633	-19.9019	775	Atlantic Forest	Semideciduous forest	186	
AtlMG059	Diogo de Vasconcelos, floresta semidecídua	-43.1758	-20.4486	739	Atlantic Forest	Semideciduous forest	149	
AtlMG060	Pinheiro Alto, floresta semidecídua	-43.2856	-20.5503	932	Atlantic Forest	Semideciduous forest	150	
AtlMG061	Piranga, floresta semidecídua	-43.3719	-20.6286	777	Atlantic Forest	Semideciduous forest	154	
AtlMG064	Serra do Caraça, Santuário, floresta nebular	-43.4811	-20.0925	1419	Atlantic Forest	Montane evergreen	120	Área De Proteção Ambiental Sul-Rmbh
AtlMG066	Ouro Preto, Itacolomi, floresta nebular	-43.5006	-20.4336	1402	Atlantic Forest	Montane evergreen	138	Parque Estadual Do Itacolomi
AtlMG069	Parque do Rio Preto, nanofloresta nebular	-43.3342	-18.2314	1541	Atlantic Forest	Montane evergreen	95	Parque Estadual Rio Preto
AtlMG070	Serra do Caraça, Carapuça, nanofloresta nebular	-43.4575	-20.0792	1577	Atlantic Forest	Cloud forest	NI	Área De Proteção Ambiental Sul-Rmbh
AtlMG071	Pico do Itacolomi, nanofloresta nebular	-43.4725	-20.4325	1626	Atlantic Forest	Cloud forest	NI	Parque Estadual Do Itacolomi
AtlMG074	Grão Mogol, nanofloresta rupícola	-42.9186	-16.5469	1068	Atlantic Forest	Montane evergreen	84	Parque Estadual Grão Mogol
AtlMG075	Itacambira, nanofloresta rupícola	-43.3639	-16.9389	1125	Atlantic Forest	Montane evergreen	75	
AtlMG076	Serra do Cabral, nanofloresta rupícola	-44.2278	-17.7608	1087	Atlantic Forest	Montane evergreen	98	Parque Estadual Da Serra Do Cabral
AtlMG077	Serra do Ambrósio, nanofloresta rupícola	-43.1033	-18.1025	1209	Atlantic Forest	Montane evergreen	124	
AtlMG078	Diamantina, nanofloresta rupícola	-43.5969	-18.2575	1116	Atlantic Forest	Montane evergreen	131	
AtlMG079	Conselheiro Mata, nanofloresta rupícola	-43.9961	-18.3197	1020	Atlantic Forest	Montane evergreen	86	
AtlMG080	Pico do Itambé, nanofloresta rupícola	-43.3625	-18.4319	1335	Atlantic Forest	Montane evergreen	85	Área De Proteção Ambiental Águas Vertentes
AtlMG081	Gouveia a Datas, nanofloresta rupícola	-43.695	-18.4375	1267	Atlantic Forest	Montane evergreen	84	
AtlMG082	Conceição do Mato Dentro, nanofloresta rupícola	-43.6864	-18.9289	1295	Atlantic Forest	Montane evergreen	95	
AtlMG083	Serra do Cipó, Lapinha, nanofloresta rupícola	-43.6514	-19.1606	1113	Atlantic Forest	Montane evergreen	140	Área De Proteção Ambiental Morro Da Pedreira

AtlMG084	Serra do Cipó, Juquinha, nanofloresta rupícola	-43.5467	-19.2614	1291	Atlantic Forest	Montane evergreen	120	Área De Proteção Ambiental Morro Da Pedreira
AtlMG085	Pico do Itabiruçu, nanofloresta rupícola	-43.3078	-19.6439	1133	Atlantic Forest	Montane evergreen	70	Área De Proteção Ambiental Piracicaba
AtlMG086	Serra da Piedade, Santuário, nanofloresta rupícola	-43.6778	-19.8156	1381	Atlantic Forest	Montane evergreen	96	
AtlMG087	Serra do Curral, Baleia, nanofloresta rupícola	-43.8972	-19.9358	1020	Atlantic Forest	Montane evergreen	96	Área De Proteção Ambiental Sul-Rmbh
AtlMG088	Gongo Soco, nanofloresta rupícola	-43.6136	-19.9511	1332	Atlantic Forest	Montane evergreen	88	
AtlMG089	Serra do Rola-Moça, nanofloresta rupícola	-44.0378	-20.0664	1207	Atlantic Forest	Montane evergreen	109	Parque Estadual Serra Do Rola Moça
AtlMG090	Serra da Pedra Grande, nanofloresta rupícola	-44.3533	-20.1231	1296	Atlantic Forest	Montane evergreen	109	
AtlMG091	Capitão do Mato, nanofloresta rupícola	-43.9133	-20.1378	1152	Atlantic Forest	Montane evergreen	104	Área De Proteção Ambiental Sul-Rmbh
AtlMG092	Capanema, nanofloresta rupícola	-43.6458	-20.17	1208	Atlantic Forest	Montane evergreen	96	Parque Ciol Da Serra Do Gandarela
AtlMG093	Mariana, nanofloresta rupícola	-43.4567	-20.3608	1260	Atlantic Forest	Montane evergreen	98	
AtlMG094	Serra de Ouro Branco, nanofloresta rupícola	-43.6503	-20.5061	1305	Atlantic Forest	Montane evergreen	80	Parque Estadual Serra Do Ouro Branco
AtlMG095	Montividiu, floresta semidecídua	-43.0514	-15.0278	920	Atlantic Forest	Semideciduous forest	110	Parque Estadual Caminho Dos Gerais
AtlMG096	Rio Pardo de Minas, floresta semidecídua	-42.6083	-15.6231	785	Atlantic Forest	Semideciduous forest	102	
AtlMG097	Riacho dos Machados, floresta semidecídua	-43.0708	-16.1025	880	Atlantic Forest	Semideciduous forest	99	
AtlMG098	Grão Mogol, Rio Itacambiruçu, floresta semidecídua	-42.8539	-16.5867	641	Atlantic Forest	Semideciduous forest	145	
AtlMG099	Adão Colares, Rio Itacambiruçu, floresta semidecídua	-43.0331	-16.6939	750	Atlantic Forest	Semideciduous forest	130	
AtlMG100	Itacambira, Rio Itacambiruçu, floresta semidecídua	-43.2711	-17.0244	843	Atlantic Forest	Semideciduous forest	112	
AtlMG101	Peixe Cru, floresta semidecídua	-42.9486	-17.1181	700	Atlantic Forest	Semideciduous forest	125	
AtlMG102	Acauã, floresta semidecídua	-42.7417	-17.1428	937	Atlantic Forest	Semideciduous forest	137	Estação Ecológica De Acauã
AtlMG103	Planalto de Minas, floresta semidecídua	-43.1906	-17.5069	908	Atlantic Forest	Semideciduous forest	166	
AtlMG104	Abadia, floresta semidecídua	-43.1067	-17.6769	664	Atlantic Forest	Semideciduous forest	134	
AtlMG105	São Gonçalo do Rio Preto, floresta semidecídua	-43.3961	-17.9997	786	Atlantic Forest	Semideciduous forest	166	
AtlMG106	São João da Chapada, Macacos, floresta semidecídua	-43.7256	-18.0064	948	Atlantic Forest	Semideciduous forest	123	
AtlMG107	Mendanha, Rio Jequitinhonha, floresta semidecídua	-43.4494	-18.2656	738	Atlantic Forest	Semideciduous forest	146	Área De Proteção Ambiental Águas Vertentes
AtlMG108	Serra Azul de Minas, floresta semidecídua	-43.2164	-18.3575	771	Atlantic Forest	Semideciduous forest	163	Área De Proteção Ambiental Águas Vertentes
AtlMG109	Milho Verde, Rio Jequitinhonha, floresta semidecídua	-43.5317	-18.4842	947	Atlantic Forest	Semideciduous forest	143	
AtlMG110	Conceição do Mato Dentro, floresta semidecídua	-43.5314	-18.9831	715	Atlantic Forest	Semideciduous forest	183	
AtlMG111	Cabeça de Boi, floresta semidecídua	-43.4231	-19.4061	847	Atlantic Forest	Semideciduous forest	166	Área De Proteção Ambiental Morro Da Pedreira
AtlMG112	Itabira, floresta semidecídua	-43.3194	-19.6625	968	Atlantic Forest	Semideciduous forest	122	Área De Proteção Ambiental Piracicaba
AtlMG113	Esmeraldas, floresta semidecídua	-44.1642	-19.7906	947	Atlantic Forest	Semideciduous forest	188	

AtlMG114	Belo Horizonte, floresta semidecídua	-43.9719	-19.8769	847	Atlantic Forest	Semideciduous forest	205	
AtlMG115	Sabará, Chácara do Lessa, floresta semidecídua	-43.8089	-19.8783	905	Atlantic Forest	Semideciduous forest	142	
AtlMG116	Betim, floresta semidecídua	-44.2419	-19.9478	783	Atlantic Forest	Semideciduous forest	160	
AtlMG117	Nova Lima, Mata do Jambreiro, floresta semidecídua	-43.8842	-19.9789	855	Atlantic Forest	Semideciduous forest	171	Área De Proteção Ambiental Sul-Rmbh
AtlMG118	Mateus Leme, floresta semidecídua	-44.3328	-19.9994	804	Atlantic Forest	Semideciduous forest	154	
AtlMG119	São Gonçalo do Monte, floresta semidecídua	-43.5294	-20.0136	842	Atlantic Forest	Semideciduous forest	158	
AtlMG120	Brumadinho, floresta semidecídua	-44.2647	-20.1778	862	Atlantic Forest	Semideciduous forest	200	
AtlMG121	Mariana, floresta semidecídua	-43.3861	-20.3689	722	Atlantic Forest	Semideciduous forest	203	
AtlMG122	Congonhas do Campo, floresta semidecídua	-43.8675	-20.5192	265	Atlantic Forest	Semideciduous forest	130	
AtlMG124	Serro, floresta semidecídua	-43.3878	-18.5489	1120	Atlantic Forest	Semideciduous forest	177	
AtlMG125	Congonhas do Norte, floresta semidecídua	-43.6822	-18.7819	1144	Atlantic Forest	Semideciduous forest	156	
AtlMG126	Morro do Pilar, floresta semidecídua	-43.4361	-19.2064	1086	Atlantic Forest	Semideciduous forest	184	Área De Proteção Ambiental Morro Da Pedreira
AtlMG127	Serra da Piedade, Penedia, floresta semidecídua	-43.6486	-19.8306	1211	Atlantic Forest	Semideciduous forest	136	
AtlMG128	Serra do Curral, Mutuca, floresta semidecídua	-43.9731	-20.0139	1202	Atlantic Forest	Semideciduous forest	172	Parque Estadual Serra Do Rola Moça
AtlMG129	Serra da Gandarela, floresta semidecídua	-43.6686	-20.0722	1228	Atlantic Forest	Semideciduous forest	176	Parque Ciol Da Serra Do Gandarela
AtlMG130	Serra da Calçada, floresta semidecídua	-43.9967	-20.1369	1077	Atlantic Forest	Semideciduous forest	191	Área De Proteção Ambiental Sul-Rmbh
AtlMG131	Serra de Itabirito, floresta semidecídua	-43.8514	-20.2467	1134	Atlantic Forest	Semideciduous forest	150	Área De Proteção Ambiental Sul-Rmbh
AtlMG132	Serra da Moeda, floresta semidecídua	-43.9694	-20.2703	1136	Atlantic Forest	Semideciduous forest	164	Monumento Tural Estadual Serra Da Moeda
AtlMG133	Ouro Preto, Uaimií, floresta semidecídua	-43.5481	-20.2911	1300	Atlantic Forest	Semideciduous forest	172	Floresta Estadual Do Uaimii
AtlMG134	Cachoeira do Campo, floresta semidecídua	-43.6694	-20.3372	1164	Atlantic Forest	Semideciduous forest	161	
AtlMG135	Ouro Branco, floresta semidecídua	-43.7242	-20.4972	1053	Atlantic Forest	Semideciduous forest	168	
AtlMG136	Catas Altas da Noruega, floresta semidecídua	-43.5394	-20.5922	1279	Atlantic Forest	Semideciduous forest	184	
AtlMG137	Montezuma, nanofloresta semidecídua	-42.4511	-15.2506	971	Atlantic Forest	Semideciduous forest	115	Reserva De Desenvolvimento Sustentável Scentes Geraizeiras
AtlMG138	Indaiabira, nanofloresta semidecídua	-42.1053	-15.3889	868	Atlantic Forest	Semideciduous forest	104	
AtlMG139	Padre Carvalho, nanofloresta semidecídua	-42.5122	-16.3714	733	Atlantic Forest	Semideciduous forest	125	
AtlMG141	Serra Nova, campo rupícola	-42.7456	-15.6517	1017	Atlantic Forest	Campo rupestre	53	Parque Estadual Serra Nova E Talhado
AtlMG143	Grão Mogol, campo rupícola	-42.8756	-16.3706	1136	Atlantic Forest	Campo rupestre	66	Parque Estadual Grão Mogol
AtlMG144	Cristália, Morro do Chapéu, campo rupícola	-42.9214	-16.7208	1207	Atlantic Forest	Campo rupestre	65	
AtlMG145	Botumirim, campo rupícola	-43.0425	-16.9267	1103	Atlantic Forest	Campo rupestre	53	Parque Estadual De Botumirim
AtlMG146	Serra do Cabral, campo rupícola	-44.2564	-17.625	1126	Atlantic Forest	Campo rupestre	78	

AtlMG147	Parque das Sempre-Vivas, campo rupícola	-43.8103	-17.8214	1193	Atlantic Forest	Campo rupestre	56	Parque Ciol Das Sempre Vivas
AtlMG148	Itamarandiba, Serra Negra, campo rupícola	-42.7253	-18.0111	1290	Atlantic Forest	Campo rupestre	74	Parque Estadual Serra Negra
AtlMG149	Diamantina, Biribiri, campo rupícola	-43.6278	-18.14	1019	Atlantic Forest	Campo rupestre	100	Parque Estadual Biribiri
AtlMG150	Parque do Rio Preto, campo rupícola	-43.3522	-18.1658	1224	Atlantic Forest	Campo rupestre	89	Parque Estadual Rio Preto
AtlMG151	Gouveia, campo rupícola	-43.7753	-18.4503	1043	Atlantic Forest	Campo rupestre	73	
AtlMG152	Presidente Kubitschek, campo rupícola	-43.5731	-18.6353	1165	Atlantic Forest	Campo rupestre	58	
AtlMG153	Santana de Pirapama, campo rupícola	-43.8094	-18.8539	1049	Atlantic Forest	Campo rupestre	59	
AtlMG154	Serra do Cipó, Ermo dos Gerais, campo rupícola	-43.7092	-19.0475	1279	Atlantic Forest	Campo rupestre	98	
AtlMG155	Serra do Cipó, Vellozias Gigantes, campo rupícola	-43.5158	-19.24	1264	Atlantic Forest	Campo rupestre	70	Área De Proteção Ambiental Morro Da Pedreira
AtlMG156	Serra de Sabarabuçu, campo rupícola	-43.7469	-19.8414	1144	Atlantic Forest	Campo rupestre	66	
AtlMG157	Morro Vermelho, campo rupícola	-43.6958	-19.9472	1076	Atlantic Forest	Campo rupestre	65	
AtlMG158	Serra do Curral, Mangabeiras, campo rupícola	-43.9014	-19.9492	1161	Atlantic Forest	Campo rupestre	73	Área De Proteção Ambiental Sul-Rmbh
AtlMG159	Itatiaiuçu, campo rupícola	-44.4286	-20.1431	1201	Atlantic Forest	Campo rupestre	82	
AtlMG160	Ouro Preto, Alegria, campo rupícola	-43.5119	-20.1808	1036	Atlantic Forest	Campo rupestre	80	
AtlMG161	Serra do Itabirito, Gata Branca, campo rupícola	-43.8489	-20.2214	1325	Atlantic Forest	Campo rupestre	61	Área De Proteção Ambiental Sul-Rmbh
AtlMG162	Serra de Ouro Branco, campo rupícola	-43.6911	-20.4861	1285	Atlantic Forest	Campo rupestre	69	Parque Estadual Serra Do Ouro Branco
AtlMG163	Lavras Novas, campo campo rupícola	-43.5114	-20.4864	1236	Atlantic Forest	Campo rupestre	67	
AtlMG164	Retiro das Pedras, campo rupícola	-43.9897	-20.0803	1437	Atlantic Forest	Campo rupestre	80	Área De Proteção Ambiental Sul-Rmbh
AtlMG165	Serra da Gandarela, campo rupícola	-43.6656	-20.1106	1584	Atlantic Forest	Campo rupestre	86	Parque Ciol Da Serra Do Gandarela
AtlMG166	Serra do Caraça, Inficionado, campo rupícola	-43.4547	-20.1419	1914	Atlantic Forest	Campo rupestre	64	
AtlMG167	Topo do Mundo, campo rupícola	-43.9753	-20.1803	1506	Atlantic Forest	Campo rupestre	60	Área De Proteção Ambiental Sul-Rmbh
CaaMG001	Montividiu, caatinga quartzítica	-43.02	-15.1278	996	Caatinga	Dry forest	105	Parque Estadual Caminho Dos Gerais
CaaMG002	Santo Antônio do Retiro, caatinga quartzítica	-42.6939	-15.1414	1068	Caatinga	Dry forest	92	
CaaMG003	Espinosa, caatinga alcalina	-42.8325	-14.9481	644	Caatinga	Dry forest	76	
CaaMG004	Monte Azul, caatinga alcalina	-42.8656	-15.1214	698	Caatinga	Dry forest	75	
CaaMG025	Mato Verde, caatinga arbórea	-42.8283	-15.3972	741	Caatinga	Dry forest	93	
CaaMG028	Francisco Sá, caatinga arbórea	-43.4703	-16.4469	734	Caatinga	Dry forest	88	
CaaMG032	Usina de Irapé, floresta decídua	-42.6108	-16.7608	574	Caatinga	Dry forest	71	
CaaMG033	Ninheira, floresta decídua	-41.6964	-15.2633	923	Caatinga	Dry forest	76	
CaaMG035	Taiobeiras, floresta decídua	-42.0656	-15.8703	854	Caatinga	Dry forest	82	

CerMG028	Francisco Sá, floresta ripícola	-43.4706	-16.5725	703	Cerrado	Riverine forest	NI	
CerMG029	Joaquim Felício, floresta ripícola	-44.1433	-17.68	631	Cerrado	Riverine forest	NI	
CerMG030	Santana de Pirapama, Rio Cipó, floresta ripícola	-43.9075	-18.865	613	Cerrado	Riverine forest	NI	
CerMG031	Santana do Riacho, Rio Cipó, floresta ripícola	-43.7411	-19.1133	691	Cerrado	Riverine forest	NI	
CerMG032	Cardeal Mota, Rio Mascate, floresta ripícola	-43.5894	-19.3828	807	Cerrado	Riverine forest	NI	Área De Proteção Ambiental Morro Da Pedreira
CerMG033	Olhos d'Água, floresta decídua	-43.7536	-17.3042	804	Cerrado	Dry forest	95	
CerMG034	Cardeal Mota, floresta decídua	-43.6169	-19.3081	915	Cerrado	Dry forest	87	Área De Proteção Ambiental Morro Da Pedreira
CerMG035	Fruta de Leite, cerradão mesotrófico	-42.6433	-16.0625	853	Cerrado	Cerrado	94	
CerMG037	Senador Modestino Gonçalves, cerradão distrófico	-43.2514	-17.9397	724	Cerrado	Cerrado	86	
CerMG038	Rio Pardo de Minas, cerrado	-42.5275	-15.5792	832	Cerrado	Cerrado	96	
CerMG039	Cristália, cerrado	-42.8631	-16.7306	771	Cerrado	Cerrado	90	
CerMG041	Olhos d'Água, cerrado	-43.5783	-17.3072	785	Cerrado	Cerrado	96	
CerMG042	Turmalina, Veredinha, cerrado	-42.8222	-17.4	886	Cerrado	Cerrado	84	
CerMG043	Carbonita, cerrado	-43.0261	-17.555	797	Cerrado	Cerrado	78	
CerMG044	Abadia, cerrado	-43.15	-17.69	904	Cerrado	Cerrado	82	
CerMG045	Itamarandiba, cerrado	-42.7697	-17.7344	902	Cerrado	Cerrado	82	
CerMG046	São Gonçalo do Rio Preto, cerrado	-43.3569	-18.0622	749	Cerrado	Cerrado	93	
CerMG047	Montezuma, cerrado	-42.3533	-15.1014	1006	Cerrado	Cerrado	76	
CerMG048	Francisco Sá, Catuni, cerrado rupícola	-43.2511	-16.2089	886	Cerrado	Cerrado rupestre	51	
CerMG049	Grão Mogol, Santa Marta, cerrado rupícola	-43.3056	-16.6267	884	Cerrado	Cerrado rupestre	110	
CerMG050	Botumirim, cerrado rupícola	-43.0044	-16.8547	877	Cerrado	Cerrado rupestre	95	
CerMG051	Itacambira, cerrado rupícola	-43.2647	-16.9189	919	Cerrado	Cerrado rupestre	101	
CerMG052	São João da Chapada, Macacos, cerrado rupícola	-43.7489	-17.9842	980	Cerrado	Cerrado rupestre	67	
CerMG053	Mendanha, cerrado rupícola	-43.5364	-18.0919	711	Cerrado	Cerrado rupestre	76	
CerMG054	Santana de Pirapama, cerrado rupícola	-43.8539	-18.8733	717	Cerrado	Cerrado rupestre	56	
CerMG055	Santana do Riacho, cerrado rupícola	-43.7089	-19.14	866	Cerrado	Cerrado rupestre	76	
CerMG056	Cardeal Mota, cerrado rupícola	-43.6136	-19.3544	821	Cerrado	Cerrado rupestre	65	Área De Proteção Ambiental Morro Da Pedreira
CerMG057	Serra do Cabral, cerrado rupícola	-44.2006	-17.9119	736	Cerrado	Cerrado rupestre	91	
CerMG058	Gouveia, cerrado rupícola	-43.8072	-18.5731	1037	Cerrado	Cerrado rupestre	65	
CerMG069	Lassance, floresta ripícola	-44.5683	-17.9339	516	Cerrado	Riverine forest	NI	

CerMG079	Buriti do Campo Santo, floresta ripícola	-44.0097	-16.6894	835	Cerrado	Riverine forest	NI	Parque Estadual Da Lapa Grande
CerMG080	Juramento, floresta ripícola	-43.6983	-16.7772	609	Cerrado	Riverine forest	NI	
CerMG084	Corinto, floresta ripícola	-44.3533	-18.4681	635	Cerrado	Riverine forest	NI	
CerMG091	Lagoa Santa, Rio das Velhas, floresta ripícola	-43.8136	-19.6419	675	Cerrado	Riverine forest	NI	Refúgio De Vida Silvestre Estadual Macaúbas
CerMG092	Santa Luzia, floresta ripícola	-43.8664	-19.7244	679	Cerrado	Riverine forest	NI	
CerMG107	Várzea da Palma, floresta decídua	-44.7072	-17.5922	498	Cerrado	Dry forest	91	
CerMG109	Santo Hipólito, floresta decídua	-44.1906	-18.2914	597	Cerrado	Dry forest	80	
CerMG112	Montes Claros, floresta decídua	-43.9072	-16.7431	838	Cerrado	Dry forest	106	Parque Estadual Da Lapa Grande
CerMG113	Juramento, floresta decídua	-43.6636	-16.775	662	Cerrado	Dry forest	81	
CerMG114	Bocaiúva, floresta decídua	-43.7672	-17.0736	759	Cerrado	Dry forest	76	
CerMG118	Baldim, floresta decídua	-43.8408	-19.2733	914	Cerrado	Dry forest	92	
CerMG119	Lagoa Santa, Lapinha, floresta decídua	-43.9597	-19.56	744	Cerrado	Dry forest	105	Parque Estadual Do Sumidouro
CerMG133	Coração de Jesus, cerradão mesotrófico	-44.1617	-16.5258	847	Cerrado	Cerrado	91	
CerMG134	Montes Claros, cerradão mesotrófico	-43.7453	-16.6819	626	Cerrado	Cerrado	101	
CerMG135	Juramento, cerradão mesotrófico	-43.5656	-16.9097	746	Cerrado	Cerrado	93	
CerMG139	Confins, cerradão mesotrófico	-43.9464	-19.6403	795	Cerrado	Cerrado	79	Área De Proteção Ambiental Carste Da Lagoa Santa
CerMG143	Sete Lagoas, cerradão distrófico	-44.1472	-19.4997	814	Cerrado	Cerrado	93	
CerMG144	Pedro Leopoldo, cerradão distrófico	-44.0714	-19.6075	803	Cerrado	Cerrado	92	
CerMG145	Belo Horizonte, Granja Wernek, cerradão distrófico	-43.9156	-19.8075	787	Cerrado	Cerrado	93	
CerMG147	Jequitaí, cerrado	-44.5183	-17.3072	554	Cerrado	Cerrado	92	
CerMG151	Várzea da Palma, cerrado	-44.6811	-17.5433	510	Cerrado	Cerrado	98	
CerMG167	Claro dos Poções, cerrado	-44.2856	-16.9647	850	Cerrado	Cerrado	90	
CerMG168	Bocaiúva, cerrado	-43.9072	-17.1078	670	Cerrado	Cerrado	90	
CerMG172	Corinto, cerrado	-44.4686	-18.3533	662	Cerrado	Cerrado	94	
CerMG180	São José do Almeida, cerrado	-43.8264	-19.4081	764	Cerrado	Cerrado	92	

Table S2 Detailed description of all environmental variables.

Name code	Variable name	Resource	Description	Proxy

Altitude	Altitude	Google Earth (SRTM)		
TempAnn	Annual mean temperature (°C)	WorldClim P1	Mean of average temperature of each month over twelve months	Energy inputs for the ecosystem
TempDayRng	Annual mean diurnal range (°C)	WorldClim P2	Mean of the monthly temperature ranges (monthly maximum-monthly minimum). Measures the fluctuation within a month to capture diurnal temperature range	
Isotherm	Isothermality (%)	WorldClim P3	Day to night temperature oscillation relative to the summer to winter oscillations. The ratio of the P2 and P7*100	
TempSeas	Temperature seasonality (°C)	WorldClim P4	Measures the temperature change over the course of the year. Standard deviation of the mean monthly temperature	
TempMax	Maximum temperature of the warmest month (°C)	WorldClim P5	The maximum monthly temperature occurrence over a given year	
TempMin	Minimum temperature of the coldest month (°C)	WorldClim P6	The minimum monthly temperature occurrence over a given year	
TempAnnRng	Temperature annual range (°C)	WorldClim P7	Temperature variation over a given period (TempMax-TempMin)	
PrecAnn	Annual precipitation (mm)	WorldClim P12	Sum of all monthly precipitation values	Water inputs for the ecosystem; water availability
PrecWetP	Precipitation of the wettest month (mm)	WorldClim P13	Total precipitation during the wettest month	

PrecDryP	Precipitation of the driest month (mm)	WorldClim P14	Total precipitation during the driest month	
PrecSeas	Precipitation seasonality (%)	WorldClim P15	Measure of the variation in monthly precipitation totals over the year. The ratio of the standard deviation of the monthly total precipitation and mean monthly total precipitation*100	Provides a percentage of precipitation variability. Larger percentages represent greater variability of precipitation
WaterDefDur	Duration of the water deficit period (days)	Walter's climate diagrams (Walter, 1985)	Drought periods duration	
WaterDefSev	Severity of the water deficit period (mm)	Walter's climate diagrams (Walter, 1985)	Precipitation volume in drought periods	
DaysFrost	Number of days with frost (days)	Regressions	Number of days with frost	
CloudItcp	Cloud interception or horizontal precipitation (mm)	Regressions		
Rockiness	Surface rockiness	Google Eath images	Percentage of exposed rocks of surface	
Sandiness	Soil texture class	Harmonized World Soil Database v 1.2	Percentage of sand	
SoilDrain	Soil drainage class	EMBRAPA 2013 Soil Classification System		Soil waterlogging
SoilWaterStorage	Soil water storage	International Soil Moisture Network	((Ranked drainage class)+(100-Ranked surface rockiness)+(100-Ranked percentage sand))/3	Soil water availability
SoilFert	Soil fertility	Harmonized World Soil Database v 1.2	Percentage of base saturation	
Sanility	Soil salinity	Harmonized World Soil Database v 1.2	Classes based on average ECe (Electric conductivity)	

Table S3 Variation of AIC values for different spatial structures used in GLS models.

	Exponential	**Gaussian**	**Linear**	**Ratio**	**Spherical**
Climate	424.545	431.756	431.575	426.251	425.455
Soil	427.038	434.073	453.255	428.781	428.526
Vegetation type	377.959	377.365	377.354	378.725	377.354
Climate and soil	426.995	432.255	432.268	429.433	428.238
Climate and vegetation type	377.458	377.142	377.138	378.114	377.138
Soil and vegetation type	380.535	380.154	380.147	381.106	380.147
All	382.143	381.871	381.867	382.701	381.867

Table S4 Slope values of environmental predictors that explain variation in community composition summarized by NMDS axes.

Environmental variables	NMDS1	NMDS2
Soil fertility	-0.07	-
Cloud interception	0.05	0.01
Soil water storage	-0.05	-
Temperature annual range	0.02	-
Water deficit severity	-0.02	-
Soil drainage class	-	-0.1
Annual precipitation	-	-0.05
Surface rockiness	-	-0.05

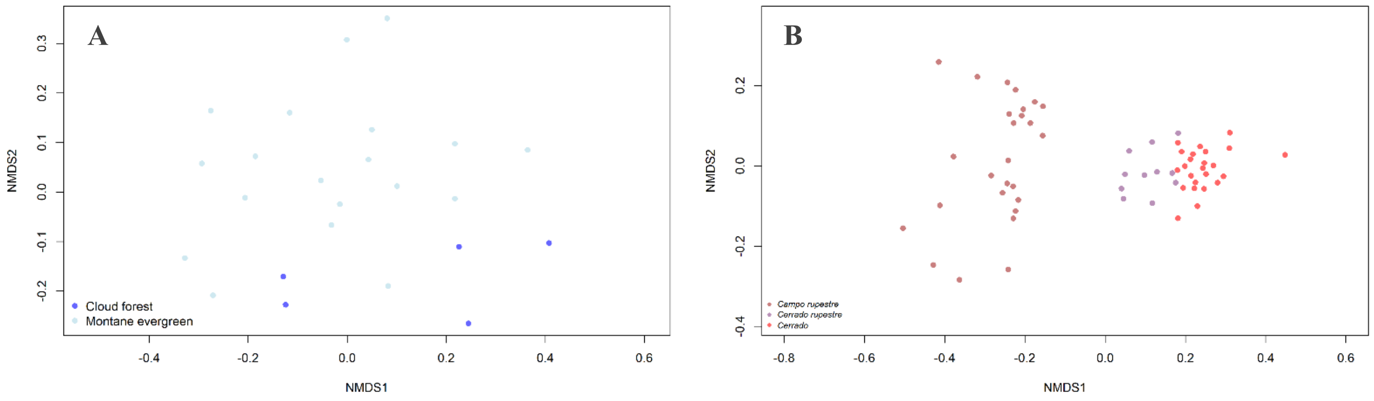

Figure S1 Exploratory ordination analysis. In **A** cloud and montane evergreen dwarf-forest group and, in **B** segregation of *campos rupestres* in two groups.