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Climatic niche as a modeler of the distribution pattern of *Schinopsis brasiliensis* in the Neotropical

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Abstract

Schinopsis brasiliensis Engl. (Anacardiaceae) is a woody medicinal plant interesting to research and conservation due to timber extraction, high pharmacological potential and cultural value in the Brazilian semi-arids. In this research, we modeled the potential distribution of the species in the Neotropical, identified the climate limiting factors of its distribution and measured the percentage of adequate protected areas. The model was generated in the Maxent software, through the combination of 469 registers of the species occurrence and nine climate variables from the WorldClim data base and presented good development (AUC = 0.976). The potentially adequate areas were estimated along the dry diagonal in South America, in addition to fragmented areas at the coast of Peru and Ecuador. Precipitation, temperature and atmospheric humidity were the most influential variables on the prediction of climatically viable areas for the species. The results indicate low representation of protected areas (0.003%) in highly adequate areas, which demonstrates the necessity of expansion, implementation of measures of conservation and management of *S. brasiliensis*. The findings in this study, therefore, can be used for scientific support on delineating these measurements.

Keywords: Conservation, dry forests, ecological niche modeling.

Nicho climático como modelador do padrão de distribuição da *Schinopsis brasiliensis* no Neotrópico

Resumo

Schinopsis brasiliensis (Anacardiaceae) é uma planta lenhosa e medicinal de interesse para pesquisa e conservação em virtude da extração de madeira, elevado potencial farmacológico e valor cultural no semiárido brasileiro. Neste estudo, foi modelada a distribuição potencial da espécie no Neotrópico, identificados os fatores climáticos limitantes da sua distribuição e mensurada a porcentagem de áreas adequadas protegidas. O modelo foi gerado no software Maxent, a partir da combinação de 469 registros de ocorrência da espécie e nove variáveis climáticas da base de dados WorldClim e apresentou um bom desempenho (AUC = 0.976). As áreas potencialmente adequadas foram estimadas, ao longo da diagonal seca da América do Sul, além de áreas fragmentadas na costa do Peru e Equador. Precipitação, temperatura e umidade atmosférica foram as variáveis mais influentes na predição de áreas climaticamente viáveis para a espécie. Os resultados indicaram uma baixa representação de áreas protegidas (0,003%) dentro das áreas de alta aptidão, o que demonstra a necessidade de ampliação, implementação de medidas de conservação e manejo da *S. brasiliensis*. Os achados deste estudo, portanto, podem ser úteis como suporte científico no delineamento dessas medidas.

Palavras-chave: Conservação, florestas secas, modelagem de nicho ecológico.

Introduction

Many factors determine the geographic distribution of species (*e.g.* abiotic and biotic conditions, and habitat access) (Peterson & Soberón, 2012). Among them, climate is highlighted as one of the main determinant factors. Thus, to understand where these species occur and the climate conditions they are adapted to is fundamental for scientific basis in effective plans for biodiversity conservation (Peterson & Soberón, 2012).

The advance in studies regarding geographic distribution is mainly due to the need generated by the accelerated increase in phenomena, such as extinction, habitat loss, climate changes (Alves et al., 2020; Lima, Scariot & Sevilha, 2020) which have direct consequences on species distribution. Therefore, it is necessary to accomplish studies which search information in a fast and fundamental way, that help identifying strategic areas for preservation and conservation of species (Lima et al, 2020).

Modeling ecological niche is a tool that has been widely used with this aim, being applied to different scenarios, scales and taxa. The models are elaborated through the computer combination of occurrence data from a determined species and environmental conditions, aiming to predict the adequacy of the environments for the occurrence of the species (Elith & Leathwick, 2009; Peterson & Soberón, 2012).

Due to the good quality of the wood, the *Schinopsis brasiliensis* Engl. have been target of a historic intensive exploration. The species is a woody, resinous, heliophyte plant, reaching 15 meters in height and 60 centimeters in diameter in adults individuals, that belongs to the Anacardiaceae botanic family. It can be known as “braúna”, “baraúna”, and “quebracho” (Medeiros, Alencar & Felismino, 2018). It has an elevated social-cultural importance, since its non-woody resources are historically used in traditional medicine in the Brazilian semi-arids for treating many illnesses (Medeiros et al., 2018; Santos et al., 2018).

The unsustainable timber extraction from this species resulted in its acknowledgement as a threatened species in Brazil, specially, in the Cerrado and Caatinga biomes (Brasil, 2008). Recently, has been classified as “Least Concern” (LC), which removes it from the new list of threatened species in Brazil (Martinelli & Moraes, 2013; Brasil, 2014).

However, as a result of the wide pharmacological potential of its leaves and bark (Santos et al., 2018), as well as its ecological importance, considering its resin and fruits are a fundamental and/or alternative nutritional source, during the dry season for primates and avifauna, and its branches act as nesting sites for stingless bees (Lima, Tenório, Gomes, 2014). *Schinopsis brasiliensis* is characterized as, therefore, a key-species, interesting to medicine, research and conservation (Martinelli & Moraes, 2013).

According to this scenario, this research has the following objectives: (1) to estimate the potential distribution of *S. brasiliensis* in the Neotropics, (2) to comprehend the climate factors limiting to the species distribution, and (3) to measure the percentage of protected areas existing inside highly adequate areas.

Materials and Methods

The coordinates of occurrence of the species were obtained through the speciesLink platform (http://www.splink.org.br), a project of the Reference Center for Environmental Information (Centro de Referência em Informação Ambiental - CRIA, 2011), 650 registers were obtained, which were evaluated, eliminating data with georeferencing errors that were redundant, widely out of the known distribution of the target species and cultivated. By the end, 469 registers were maintained.

Abiotic data were compiled through the WorldClim 2.0 platform (Fick & Hijmans, 2017), in a 2.5 arcsecond resolution; the variables were cut out and the respective values were extracted to the Neotropical region. The variable selection was developed through the results of the Principal Component Analysis (PCA) and Pearson correlation. We selected nine non-correlated variables (Tab 1) that best represent the environmental variability of the study area.

Table 1. Bioclimatic variables selected for ecological niche modeling. World Clim 2.0 climate data are averaged over the years 1970-2000.

Bioclimatic Variable	Variable Description
Bio 1	Annual Mean Temperature (ºC)
Bio 3	Isothermality (ºC)
Bio 4	Temperature Seasonality (ºC)
Bio 7	Temperature Annual Range (ºC)
Bio 12	Annual Precipitation (mm)
Bio 14	Precipitation of Driest Month (mm)
Wind_avg	Mean Annual Wind Speed ($m\ s^{-1}$)
Vapr_avg	Mean Annual Water Vapor Pressure (kPa)
Srad_avg	Mean Annual Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)

Source: Author (2021) based on World Clim 2.0 (Fick & Hijmans, 2017).

The model was estimated through the MaxEnt algorithm for predictive modeling (Phillips, Anderson, Schapired, 2006), in which the environmental sheets were combined to the known registers of the species. Thus, the parameters used were: 1.000 background points, 10 replicates, test, and division of the occurrence points for the calibration (70%) and test of the model (30%). The efficiency of the model was tested through the calculation of the Area Under the Curve (AUC) (Phillips et al., 2006).

To evaluate the level of conservation in the highly adequate areas for *S. brasiliensis*, the model was overlapped by a sheet with data regarding coverage of protected areas and we calculated the total area (Km^2) of climatically adequate areas delimited by protected areas. The protected areas data were obtained through the Environment Ministry (MMA) (https://mma.gov.br).

The pre-analysis, preparation of biotic and abiotic data for modeling and overlapping ecological niche were accomplished in the QGIS 3.4.14 software (QGIS Development Team, 2019). The multivariable analysis above were calculated using the packages “corrplot”, “vegan” and “factoextra” respectively in the R software 3.3.3 version (R Core Team, 2017).

Results and Discussion

The resulting model exhibits a great performance (AUC = 0.976) predicting high climate adequacy areas for *S. brasiliensis*, along the dry diagonal of South America, emphasizing the areas in Caatinga and Cerrado, as well as fragmented areas, in the coast of the Pacific ocean, in typical environments of Seasonally Dry Tropical Forests (SDTF) (Figure 1).

The estimated potential distribution comprehends areas of SDTF of the Neotropics distributed along with the 'Dry Diagonal' of South America, an aisle formed by the phytogeographic domain of Caatinga, Cerrado and Chaco. They are, therefore, deciduous and semi-deciduous forests of wide distribution and fragmented along the Neotropics, associated with fertile soils and a climate regime with high levels of evaporation and transpiration, annual precipitation inferior to 1600 mm, dry season with 2 to 7 months of duration (<100 mm) (Murphy & Lugo, 1986).

The model exhibits a distribution pattern peripheral to Amazon of *S. brasiliensis***,** along the dry diagonal of South America and, in contrast to the known distribution, small fragmented areas in the coast of the Pacific ocean, where there can be found sister taxa of the species. The model supports, therefore, the classification of *S. brasiliensis* as a species typical of formations in semiarid regions associated with deciduous and semi-deciduous forests of the Neotropics (Martinelli & Moraes, 2013;Medeiros et al., 2018).

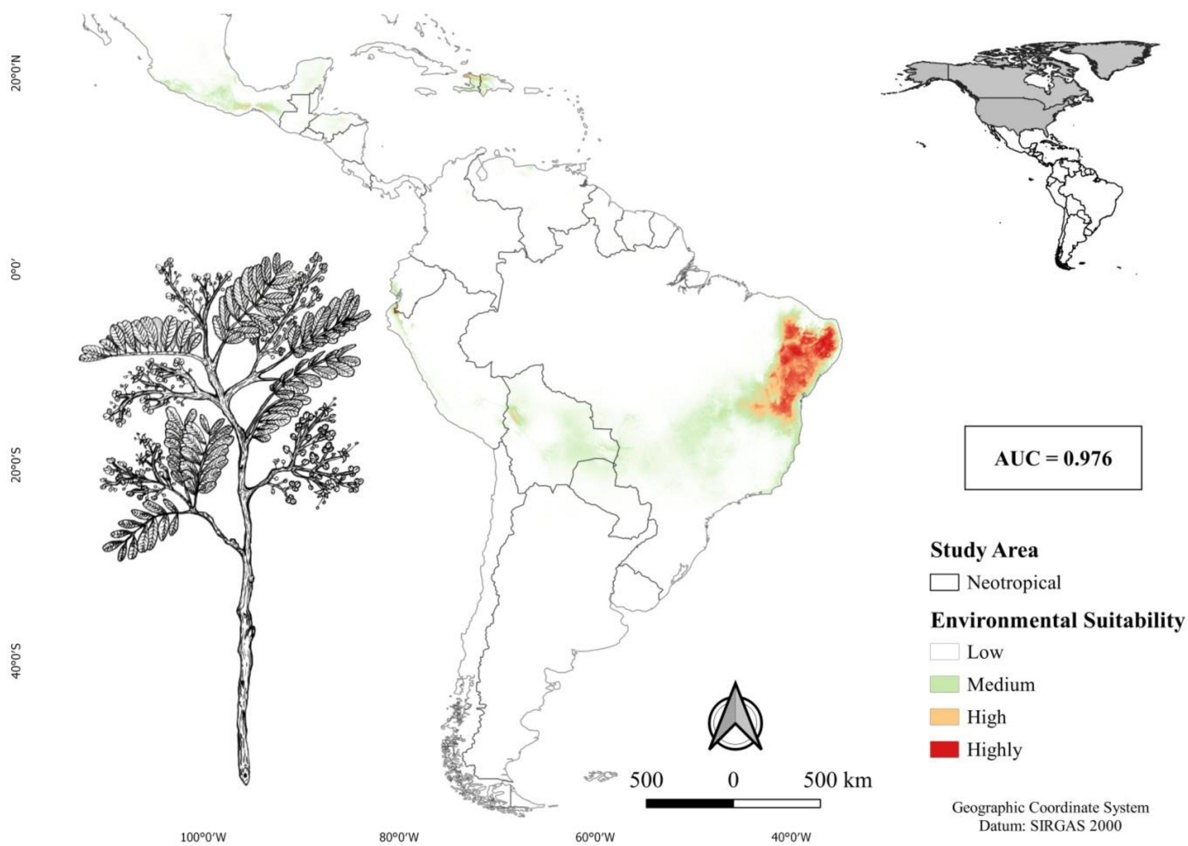

Figure 1. Ecological niche model for *S. brasiliensis* in the Neotropics. The red tones indicate areas with a high probability of occurrence and climatic conditions suitable for the species.

In general, the genus *Schinopsis* includes eight species which have their distribution associated with neotropical dry woods environments and subtropical forests from the Argentinian chaco (Mogni, Prado & Oakley, 2017). The genus *Schinopsis* emergence, in the flora of the Andes Mountain Range region, is documented from the Middle Eocene (45 Myr), as an indicator of the presence of xeric environments in this region (Posadas & Ortiz-Jaureguizar, 2011). A recent research in phylogenetics and ancestral niche reconstruction of the Anacardiaceae family proposed by Weeks et al. (2014), demonstrates that the diversification event which originated *S. brasiliensis* took place during the Pliocene (5.3 – 2.5 Myr), through an ancestral also from a dry tropical climate niche.

Accordingly, the estimated potential distribution for *S. brasiliensis* suggests biogeographic relations with the evolution of the Andes Range biota and with the continuous ancestral distribution theory of open formations in South America, as suggested by Prado & Gibbs (1993) in the Pleistocene Arc Theory, once orogenic events, marine transgressions and climate changes, during Pliocene and Pleistocene, provided environmental variations which contributed to the expansion of open and dry environments of South America and to the diversification of the associated taxa in these environments in the Andean region, as well as the genus *Schinopsis* (Posadas & Ortiz-Jaureguizar, 2011).

However, analysis of ancestral area and climate niche, as well as paleomodelings, are essential approaches for a better understanding of the biogeographic history of this taxon, once each component of a biota can respond differently to past conditions and events.

Temperature and precipitation frequently are considered the climate factors that influence the most, in large scale, distribution and dispersion of plants (Punyasena, Eshel & McElwain, 2008). The variables which most contributed, for the PCA (Figure 2), were the precipitation of the driest month (Bio 14) and annual precipitation (Bio 12) and, for the MaxEnt tests (Tab 2), the average of the water vapor pressure (Vapr_avg), annual precipitation (Bio 12) and temperature seasonality (Bio 4).

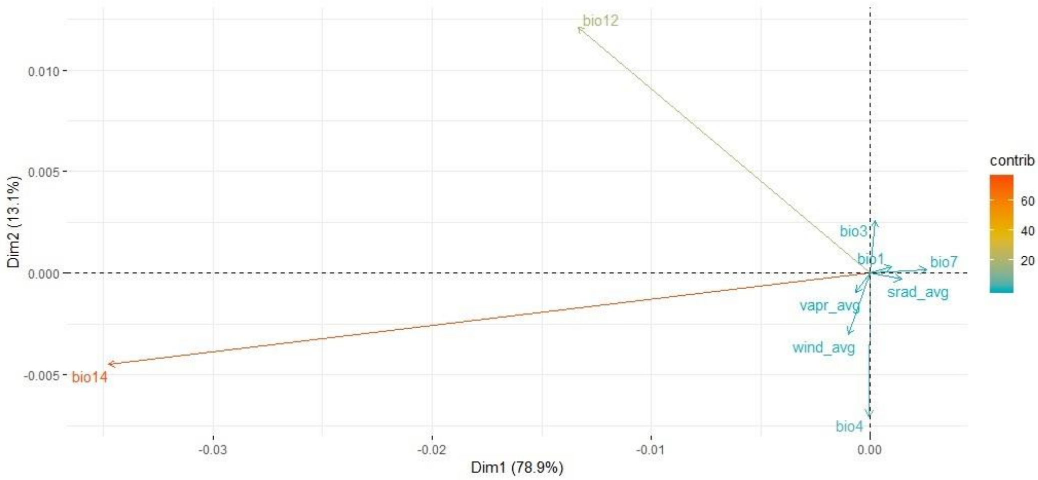

Figure 2. Principal Component Analysis (PCA). The arrow colors range from red with high contribution variables to blue with a low contribution.

In general, temperature and rainfall regime directly influence the phenological processes (i.e., flowering, fructification, leaves fall and production) of the plants, so that the typical species of semiarid regions have many strategies for regulating metabolic activities to resist conditions of water stress and high temperatures (Borchert, 1994).

Dendrochronological and phenological studies emphasize, for instance, the strategy of fast return to the phenological activities of the species, at the first sign of water in the environment, so there is high contribution of sporadic rains, while in the dry period, for the secondary growth of the species (Barbosa, Barbosa &, Lima 2003). The same chronological sensibility to sporadic rains has been proved for *S. brasiliensis*, which justifies the high contribution of the precipitation variables in the driest month (Bio 14, figure 1) to the survival of the plant in the predicted environments, mainly, in the period with the highest water deficit (Nogueira, Pagotto, Roig, Lisi & de Souza Ribeiro, 2017).

In the literature, *S. brasiliensis* is a tree, frequently classified as deciduous, which totally loses its leaves in the dry season (Medeiros et al., 2018). However, Barbosa et al. (2003) and in personal observation in field, suggest that the species is, more precisely, a optional deciduous, that can remain with its leaves along the whole year, specially when it is distributed next to watercourses or more humid sites located inside semiarid regions (e.g., altitude swamps).

Thus, it is possible to infer that the influence of variables on the distribution of the species occurs, on a wide scale as well as in microenvironment level, conditioning variables in vegetative and reproductive processes of the species in face of seasonality of semirad regions. In addition, the adequacy of environments predicted by the model is a result of, therefore, the set of mechanisms of physiological plasticity of the species in face of the climate fluctuations and water disponibility in these areas, which guarantee the survival of the species in these environments (Barbosa et al., 2003; Nogueira et al., 2017).

Table 2. Contribution percentage of variables to the model. The values are normalized averages of each revaluation replica of the model and the result of losses in the AUC value, after permutations of each variable, evaluating the gains and losses attributed by each to the model performance.

Variables	Percent Contribution
Vapr_avg	36.6
Bio 12	20
Bio 4	15.3
Bio 3	8.8
Wind_avg	7.3
Bio 7	6.3
Srad_avg	2.5
Bio 14	2.4
Bio 1	0.8

Source: Maxent (2021).

The planning of the studies and conservation plans have as basis areas with high aptitude for survival of a given species. The model generated in this study enabled us to identify the range of climatically viable habitats for *S. brasiliensis*, emphasizing that environments of dry forests in Neotropical, located along the dry diagonal in South America, are priority areas for conservation and reintroduction of the species.

The overlap of the model with protected areas indicates a small representation of protected areas. From the 56.833.400.000 km^2 total of potentially adequate areas for the species predicted in this model, only around 0.003% (1.730,61 km^2) are protection areas (Fig 3).

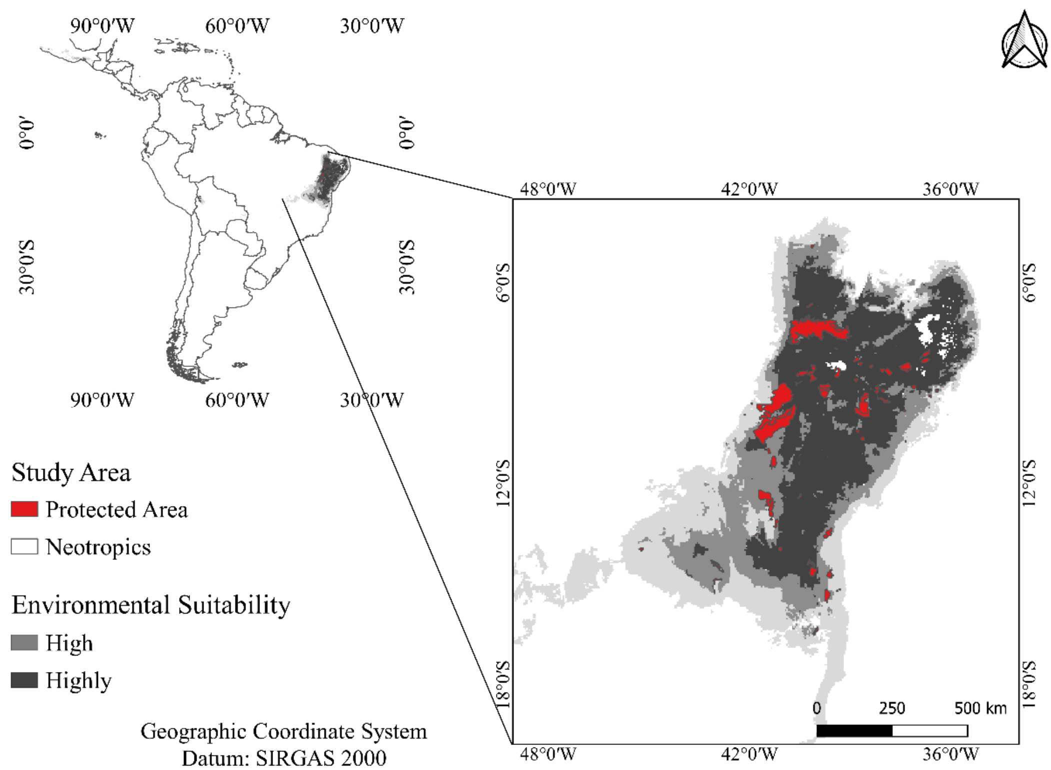

Figure 3. Overlap of protected areas and areas of high climatic suitability for *S. brasiliensis*. The percentage of protected areas that overlap areas of high environmental suitability for the species was estimated.

Knowing that one of the main protection strategies of biodiversity and management of ecosystem services are protected areas and that the high diversity and endemism of dry forests are still poorly studied in relation to humid woods in the Neotropics, therefore the protection levels of these ecosystems are insufficient (Banda et al., 2016). Nowadays, less than 10% of the original expansion of these formations is intact in several countries, being considered a strongly threatened environment (Banda et al., 2016).

A recent study points a good regeneration potential of populations of *S. brasiliensis* in face of the historical exploration to which it was submitted in the past, in the Brazilian Northeast, as well as that the distribution of the species in this region, in future scenarios of climate changes will tend to suffer little impact (Alves et al., 2020). Due to the small scale of Alves et al. (2020) study, the model generated in this study increases and corroborates the priority areas for species conservation, in a current scenario, also emphasized by the authors mentioned.

The analysis of the percentage of protected areas located in highly adequate areas (Fig 3) predicted by the model revealed a small efficiency of protection of the species in these areas. Thus, the synergetic effect imposed by the loss of native habitat for agriculture and the low effectiveness of protection pointed in this study reinforce the necessity of expansion and implementation of protection areas and conservation actions in these environments (Banda et al., 2016).

Conclusion

Modeling of ecological niche has been an important tool for studies with conservationist aims. In summary, in this study, we estimated climatically adequate areas for *S. brasiliensis*, which are concentrated along the Dry Diagonal of South America and with fragments in the Pacific coast. The climate variables related to temperature, precipitation and atmospheric humidity were the most influential in the species distribution. Therefore, the results of this study can be an important guiding tool for determining and outlining priority areas for conservation and management of *S. brasiliensis*

There are multiple factors that influence the distribution of plants (*e.g.* edaphic, water, relief, biotic interactions, anthropic activity factors). In this study, only climatic variables were used, thus, the incorporation of new factores, in future studies, is fundamental for evaluating more robustly the potential distribution, as well as other techniques and studies (*e.g.* molecular, evolution, reproductive) are useful and must be associated to this with the aim of providing a more robust scientific basis.

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References

Alves, C. A. B., Leite, A. P., Ribeiro, J. E. da S., Guerra, N. M., Santos, S. da S., Souza, R. S., Carvalho, T. K. N., Lucena, C. M. de, Fonseca, A. M. F. de A., Lins Filho, J. A., Souto, J. S., & Lucena, R. F. P. de. (2020). Distribution and future projections for Schinopsis brasiliensis Engler (Anacardiaceae) in the semi-arid region of Brazil. *Revista Brasileira de Gestão Ambiental e Sustentabilidade*, *7*(17), 1361–1378. https://doi.org/10.21438/rbgas(2020)071721

Banda, K. R., Delgado-Salinas, A., Dexter, K. G., Linares-Palomino, R., Oliveira-Filho, A., Prado, D., Pullan, M., Quintana, C., Riina, R., Rodríguez, G. M., Weintritt, J., Acevedo-Rodríguez, P., Adarve, J., Álvarez, E., Aranguren, A. B., Arteaga, J. C., Aymard, G., Castaño, A., Ceballos-Mago, N., … Pennington, R. T. (2016). Plant diversity patterns in neotropical dry forests and their conservation implications. *Science*, *353*(6306), 1383–1388. https://doi.org/10.1126/science.aaf5080

Barbosa, D. D. A., Barbosa, M. D. A., & Lima, L. D. (2003). Fenologia de espécies lenhosas da Caatinga. In I. R. Leal, M. Tabarelli & J. M. C. Silva, *Ecologia e conservação da Caatinga* (1a ed., Cap.16, pp. 657-694). Recife: Ed. Universitária UFPE.

Borchert, R. (1994). Soil and stem water storage determine phenology and distribution of tropical dry forest trees. *Ecology*, *75*(5), 1437–1449. https://doi.org/10.2307/1937467

Brasil. (2008). Instrução Normativa N° 6, 23 de setembro de 2008. Diário Oficial da União: seção 1, Brasília, DF, p. 75.

Brasil. (2014) . Portaria Nº 443, de 17 de dezembro de 2014. Diário Oficial da União: seção 1, Brasília, DF, p.25.

CRIA (Centro de Referência e Informação Ambiental). (2011). Specieslink - simple search. http://www.splink.org.br/index (Accessed 23 August 2019).

Elith, J., & Leathwick, J. R. (2009). Species distribution models: Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics*, *40*, 677–697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086

Lima, D. M., Tenório, S., & Gomes, K. (2014). Dieta por Anodorhynchus leari Bonaparte, 1856 (Aves: Psittacidae) em palmeira de licuri na caatinga baiana. *Atualidades ornitológicas*, *178*, 50-54. http://www.ao.com.br/download/AO178_50.pdf

Lima, V. V. F., Scariot, A., & Sevilha, A. C. (2020). Predicting the distribution of Syagrus coronata palm: Challenges for the conservation of an important resource in northeastern Brazil. *Flora: Morphology, Distribution, Functional Ecology of Plants*, *269* (July 2019), 151607. https://doi.org/10.1016/j.flora.2020.151607

Martinelli, Gustavo & Moraes, M.A. (2013). Livro Vermelho da Flora do Brasil (1a ed.). Rio de Janeiro: Andrea Jakobsson.

Medeiros, A. C. D., Alencar, L. C. B., & Castro Felismino, D. D. (2018). Schinopsis brasiliensis Engl. In U. P. Albuquerque, U. Patil & A. Máthé, *Medicinal and Aromatic Plants of South America* (1a ed., pp. 421-429). Springer, Dordrecht. https://doi.org/10.1007/978-94-024-1552-0_38

Mogni, V. Y., Prado, D. E., & Oakley, L. J. (2017). Notas nomenclaturales en el género Schinopsis (Anacardiaceae). *Boletín de la Sociedad Argentina de Botánica*, *52*(1), 185-191. https://doi.org/10.31055/1851.2372.v52.n1.16918

Murphy, P. G., & Lugo, A. E. (1986). Ecology of tropical dry forest. *Annual review of ecology and systematics*, 67-88. https://doi.org/10.1146/annurev.es.17.110186.000435

Nogueira, F. C., Pagotto, M. A., Roig, F. A., Lisi, C. S., & Ribeiro, A. S. (2017). Responses of tree-ring growth in Schinopsis brasiliensis to climate factors in the dry forests of northeastern Brazil. *Trees - Structure and Function*, *32*(2), 453–464. https://doi.org/10.1007/s00468-017-1642-3

Peterson, A. T., & Soberón, J. (2012). Species distribution modeling and ecological niche modeling: Getting the Concepts Right. *Natureza & Conservação*, *10*(2), 102–107. https://doi.org/10.4322/natcon.2012.019

Phillips, S. J., Anderson, R. P., & Schapired, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, *6*(2–3), 231–252. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Posadas, P & Ortiz-Jaureguizar, E. (2011). Evolução da Região Andina da América do Sul. In: C.J.B. Carvalho & E.A.B. Almeida, *Biogeografia Da América Do Sul Padrões E Processos* (1a ed., Cap. 11, pp. 175-183). São Paulo: Roca.

Prado, D. E., & Gibbs, P. E. (1993). Patterns of Species Distributions in the Dry Seasonal Forests of South America. *Annals of the Missouri Botanical Garden*, *80*(4), 902. https://doi.org/10.2307/2399937

Punyasena, S. W., Eshel, G., & McElwain, J. C. (2008). The influence of climate on the spatial patterning of Neotropical plant families. *Journal of Biogeography*, *35*(1), 117–130. https://doi.org/10.1111/j.1365-2699.2007.01773.x

QGIS Development Team. (2019). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

R Core Team. (2017). R: A Language and Environment for Statistical Computing**.** R Foundation for Statistical Computing, Vienna, Austria, versão 3.3.3.

Santos, C. C. de S., Guilhon, C. C., Moreno, D. S. A., Alviano, C. S., Estevam, C. dos S., Blank, A. F., & Fernandes, P. D. (2018). Anti-inflammatory, antinociceptive and antioxidant properties of Schinopsis brasiliensis bark. *Journal of Ethnopharmacology*, *213*, 176–182. https://doi.org/10.1016/j.jep.2017.11.012

Weeks, A., Zapata, F., Pell, S. K., Daly, D. C., Mitchell, J. D., & Fine, P. V. A. (2014). To move or to evolve: Contrasting patterns of intercontinental connectivity and climatic niche evolution in "Terebinthaceae" (Anacardiaceae and Burseraceae). *Frontiers in Genetics*, *5*(NOV). https://doi.org/10.3389/fgene.2014.00409