Ecological Niche Model for *Palicourea jambosioides* (Schltdl.) C.M. Taylor in the State of Bahia, Brazil

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The Atlantic Forest is a complex of ecosystems of great importance, as it is home to a significant portion of Brazilian biodiversity. The Rubiaceae family is the fourth largest in number of species among the Angiosperms, presenting its most remarkable diversity in the phytogeographic domains of the Amazon and the Atlantic Forest. This study aimed to model the ecological niche of *Palicourea jambosioides* (Schltdl.) C.M. Taylor in the state of Bahia. Georeferenced occurrence data were obtained from the online databases SpeciesLink and GBIF, as well as consultations with physical herbaria and scientific articles, and were combined with climate information from WorldClim. The statistical validation of the models was performed considering AUC values ≥ 0.7 and TSS ≥ 0.4. The variables that most contributed to the modeling were BIO5 (26.1%), BIO15 (22.6%), BIO10 (15.8%), and BIO3 (15.0%). It was observed that *P. jambosioides* occurs mainly in areas of seasonal forest and restinga, with temperature and precipitation being the environmental variables with the most significant influence on its distribution. Thus, this study contributes to advancing knowledge about the distribution of the species and can offer subsidies for conservation actions in the state of Bahia.
Keywords: Biodiversity. Geographic Distribution. Atlantic Forest.

The Rubiaceae family was initially described by Jussieu in 1789 and has since been studied by researchers worldwide [1]. The species have high plasticity of habit and morphological characteristics. They are easily recognized by the interpetiolar stipules, rarely interpetiolar, opposite leaves, androecium isostemonous, and usually infectious ovary.

Rubiaceae is the fourth family of several species in the Angiosperms, after Orchidaceae, Asteraceae, and Leguminosae [2]. They occur in all regions of the world, but mainly in the tropics [3]. According to [4], the family has about 14,000 species, distributed in 600 genera, with great species richness in tropical regions.

The Atlantic Forest is the second-largest tropical rainforest on the American continent. It originally extended continuously along the Brazilian coast, penetrating as far east as Paraguay and northeastern Argentina in its southern portion [5]. The Atlantic Forest domain is home to many endemic plant species, many of which are threatened with extinction due to alarming rates of habitat loss [6,7].

A considerable factor is that many species have not yet been cataloged in these areas, resulting in the loss of much data, mainly related to geographic distribution. A strategy that can mitigate the effect of this space in the study of biodiversity is to estimate the actual or potential distribution of a species, characterize the environments with favorable environmental conditions, and identify where and how these places are distributed in space [8].

According to Flora and Funga do Brasil (2024) [9], the most incredible diversity of Rubiaceae occurs in the phytogeographic domains of the Amazon and Atlantic Forest. In the Brazilian territory, the family is present in all the domains represented, having 128 genera distributed in 1,416 species, 704 of which are considered endemic. In the northeast region, the family is cited among the most diverse and is represented by 424 species. Bahia is the second Brazilian state with the highest diversity of Rubiaceae, with about 375 species,

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second only to Amazonas, with about 532 species. Palicourea Aubl., has about 230 species [10]. According to Flora and Funga do Brasil (2024) [9], the genus has about 175 species and is distributed in the Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa, and Pantanal phytogeographic domains. The genus is characterized by presenting flowers with a tubular corolla, without odor, with intense colors and pollinated mainly by hummingbirds, and fleshy, blue to purple fruits, usually dispersed by birds [11]. The genus is closely related to Psychotria, differing from it by the gibbous corolla flowers [12].

Palicourea jambosioides (Schltdl.) C.M. Taylor is an endemic species of Brazil, occurring only in Bahia and Espírito Santo. According to Souza and colleagues [13], it is characterized by a shrubby habit up to 3 m high, persistent stipules bipartite at least at the apex, triangular, acute apex, glabrous; Opposite leaves, chartaceous, oblong, apex acute to acuminate, margin flat; Paniculate, subterminal, multi flower, white or lilac inflorescences; Monocline, heterostylous, sessile flowers; toothed calyx; lilac corolla, tubular, gibbous base, stamens inserted in the median portion of the tube; bifid stigma; Drupaceous fruit, purple to green, when immature, glabrous.

Modeling species' environmental requirements and mapping their distributions in space and time are important aspects of many biological analyses, especially in support of conservation and management interventions [14]. Thus, ecological niche models (ENMs) are empirical or mathematical approximations of a species' ecological niche [15]. They are a technique used to estimate actual or potential distribution ranges or sets of habitats favorable for a given species based on their observed presence and sometimes absence [16].

Understanding geographic distribution is crucial to supporting several research projects, especially ecology. This study sought to map the distribution of *Palicourea jambosioides* in Bahia using species distribution modeling and examine the climatic variables that influence the species' occurrence.

Materials and Methods

Bahia is the fifth largest state in Brazil, with 564,733,081 km² [17]. Due to its territorial extension and climatic and geographic variation, it is home to a great diversity of vegetation. Some of the main domains present are the Atlantic Forest, Caatinga, and Cerrado (Figure 1).

According to Giulietti and Pirani [17], "*formations of dense ombrophilous forests (Hiléia baiana), vegetation with marine influence (restinga, dunes), and vegetation with fluvial-marine influence (mangrove) are found in coastal areas; seasonal semideciduous forest in most of the areas bordering the dense ombrophilous forest and in the central plateau regions; savannas (cerrado), mainly west of the São Francisco River, but with disjunctions in the Chapada Diamantina and in the north of the state; seasonal deciduous forest and steppe savannas (caatingas) mainly in the interplanaltic depressions and western slope of the central mountain systems; and rupestrian fields, in areas above 900 m of the Chapada Diamantina*." Thus, they reflect rich and vast biodiversity, have endemic species, and offer environmental mechanisms.

The climate of Bahia is diversified due to the state's territorial extension and its different physiographic regions. In general, these climates can be considered mega thermal tropicals, with marked differences in rainfall [17]. The average annual rainfall varies from 363 mm in the northern and northeastern portions of the state to 2,000 mm recorded in the coastal plain of the municipality of Ilhéus [18].

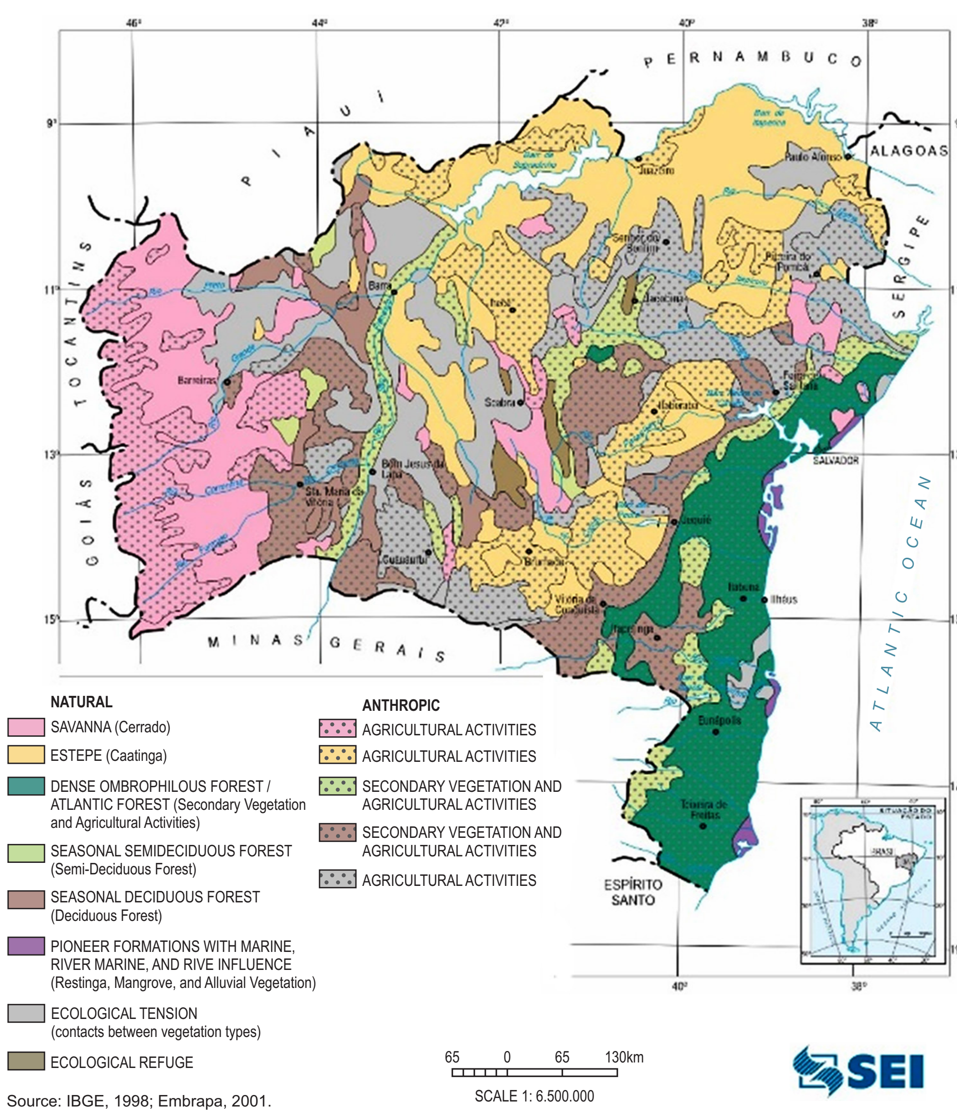
The occurrence data of *Palicourea jambosioides* were obtained based on the research platforms SpeciesLink (www.specieslink.net) and Global Biodiversity Information Facility (GBIF - www.gbif.org), consultation of the published data and the visits to the physical collections of the Herbarium of the State University of Bahia (HUNEB), Herbarium Alexandre Leal Costa (ALCB), Herbarium of the State University of Feira de Santana (HUEFS). Data on the geographic distribution of the species were obtained based on the literature and the labels of the specimens analyzed. The spelling of the scientific name and authorship of the taxon was used [19].

Data on species occurrences were included in Excel spreadsheets, and specimens that were not identified by experts or had inaccurate geographic data were excluded from the analyses. Duplicates, wrong and/or missing coordinates, and occurrences without location data were removed. The tidyverse package [20] refined such data.

With the aid of the earth and tidyverse packages, the bioclimatic variables were obtained through the Worldclim (http://www.worldclim.org/) database in version 2.1 [21]. The 19 variables derived from monthly values of temperature and precipitation are presented in GeoTiff (.tif) format at the spatial resolution of the 2.5 arc-minute layers. The study area was delimited to Brazil and later to Bahia. The projections were combined through the methodology of ensembling [22].

The environmental variables selected through Pearson's correlation (with a cut-off value of 0.8) were BIO5 (Maximum temperature of the hottest month), BIO15 (Seasonality of precipitation), BIO10 (Average temperature of the hottest room), BIO3 (Isothermality), BIO4 (Seasonality of temperature), BIO9 (Temperature of the driest room), BIO8 (Average temperature of the wettest room), BIO13 (Precipitation in the wettest month),

Figure 1. Vegetation map of Bahia.



BIO 18 (Precipitation in the hottest room). To minimize the effects of multicollinearity in the models, the environmental variables were evaluated based on the calculation of the Variance Inflation Factor (VIF), thus resulting in the elimination of redundant variables, i.e., only the variables with the lowest degree of collinearity of the set were used. The generated models used the AUC and TSS metrics to be evaluated, whose AUC values ≥ 0.7 and TSS ≥ 0.4 [23]. All procedures were performed in R 4.4.1 [24] through the usdm package [25]. The model was trained for the states of Bahia and Espírito Santo using the Maxent 3.4.4 algorithm [26], with 10 replicates and a cross-validation method with 5 data partitions (k = 5). This algorithm is justified because it is notably useful for species in which the records of points of occurrence have a low number [27] and because it requires only points of presence [28].

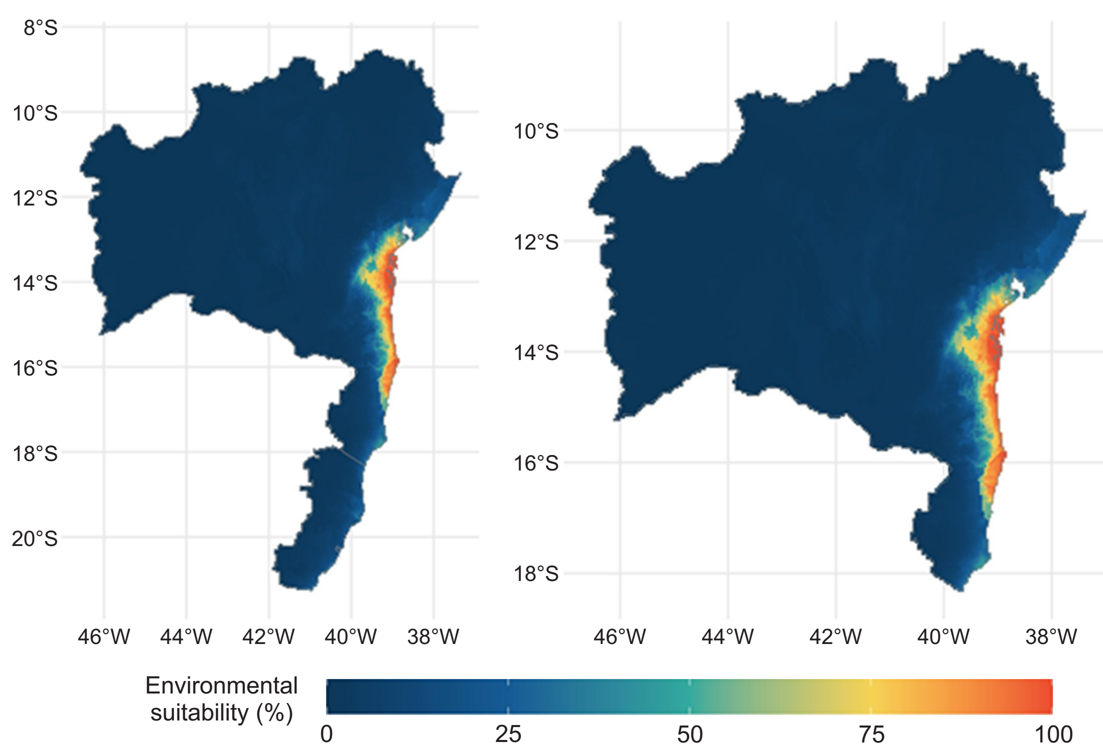
Results and Discussion

The model performed excellently with AUC = 0.93 and TSS ≥ 0.81 values for Bahia. According to the result on the projection map (Figure 2), the occurrence of the species should be concentrated in the coastal region of Bahia in the Atlantic Forest portion. The model suggests that this portion has areas where the occurrence tends to be 100 (%). of chance, that is, the species is found with certainty.

There are also occurrences in regions where the estimated presence is close to 0 (%), which means that the model does not entirely rule out the possibility of occurrences in regions further away from the coast, but they should be rare. In the central region of the distribution map, some occurrences stand out for their distance from their niche and are, therefore, a result generated by the insertion of data that record the occurrence in this remote region.

The values of the most significant variables with a relative contribution to the modeling based on the Pearson Correlation method were: BIO5- Maximum temperature of the hottest month (26.1%); BIO15- Seasonality of precipitation (22.6%); BIO10 -Average temperature of the hottest room (15.8%); BIO3- Isothermality (15%). It was possible to observe that the distribution of *P. jambosioides* in

Figure 2. Ensemble of projections for *Palicourea jambosioides* for the states of Espírito Santo and Bahia projected from the model for Brazilian territory.



Bahia occurs mainly in seasonal forest and resting areas, with temperature and precipitation being the environmental variables with the most significant influence on its distribution.

Climatic variables, especially those related to temperature and precipitation, are important because they directly influence plant development and are responsible for floristic changes along gradients [29,30]. According to reference [9], *Palicourea jambosioides* is distributed by domains of the Atlantic Forest. In a study carried out by [13, 31], the species was found in the Serras da Fumaça chain, previously known only from the coastal Atlantic Forest and resting areas. The Serra da Fumaça corresponds to one of the Jacobina Mountains, which is part of the northern portion of the Chapada Diamantina [17].

The Espinhaço Chain is a mountain formation extending north-south, from Bahia to Minas Gerais, under the phytogeographic influence of the Atlantic Forest, Cerrado, and Caatinga domains [32]. However, the dominant vegetation cover in the spinach chain is the rupestrian grassland [33]. Although these two biomes are separated by 250 km, which does not allow the survival of grassland species; Harley (1995) considers the existence of "intermediate" environments in which some occur [34].

According to Alves and colleagues [34], although the restingas occur at sea level and, on the other hand, the rupestrian fields are above 800 m, and the fields of altitude fields well above 1300 m, these altitude distinctions are not established as significant in the tropics. Thus, based on studies by Giulietti and Pirani 1988; Harley and Simmons 1986 Harley 1988, some species first occurred in Serra da Fumaça and are found along the Brazilian coast.

Palicourea jambosioides is a shrub native to Brazil [9]. It differs from the others through the leaves with inconspicuous secondary veins on both sides, the inflorescence with rachis, thick peduncles, and purple corolla [13]. Studies regarding the geographic distribution of *P. jambosioides* in Bahia are not found. Thus, biogeographic studies, including modeling tools, become extremely important, in addition to floristic and phenological surveys, as they can enrich the knowledge of the local flora and the distribution and conservation situation of the species.

Endemic species, such as *P. jambosioides*, have specific ecological roles that influence the structure and dynamics of plant and animal communities around them. Their presence can also affect vegetation composition and interaction with other species, including pollinators and herbivores. The conservation of *P. jambosioides* is important for the preservation of the biodiversity of the Atlantic Forest, as the biome is threatened by several factors, mainly by anthropogenic actions, thus putting the survival of many species at risk.

Conclusion

The ecological niche modeling allowed the visualization of the areas with the highest probability of occurrences of *P. jambosioides* in the states of Bahia and Espírito Santo, especially in the coastal region of the state of Bahia in the Atlantic Forest portion. The species is distributed mainly in seasonal forests and restingas, influenced by high temperatures and precipitation, whose conditions include humid environments and drier and seasonal ones. Ecological niche modeling is a valuable tool for expanding knowledge about the distribution of the species in the Atlantic Forest, and it can help new collections and intensify the increase in sampling effort in certain areas.

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