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ORIGINAL ARTICLE – Conservation of Nature

Predicting Species Distribution and Conserving Rosewood Tree Under Global Climate Change Scenarios

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Abstract

Aniba rosiodora Ducke, an Amazonian species, is valued for its essential oil rich in linalool, which is widely used in fine perfumery. Due to this, it has been overexploited and recognized as a threatened species. Despite efforts to maintain their genetic variability, there are few quotes about their behavior in the face of climate change. This study uses species distribution modeling (SDM) to project its geographic distribution in future scenarios (2009-2019) with projections for SSP245 (less pessimistic) and SSP585 (more pessimistic) for 2041-2060, 2061-2080 and 2081-2100, based on 19 bioclimatic and 14 edaphic variables in South America. The results indicate that the distribution of rosewood trees is mainly influenced by temperature and precipitation, and the analyzed scenarios indicate a reduction of the areas with environmental suitability, especially in the Amazon, Caatinga, and Atlantic Forest. Strategies should be planned to ensure the conservation and genetic variability of the species.

Keywords: habitat suitability, vulnerability of forest species, Amazon.

1. INTRODUCTION

Tropical forests are critical ecosystems for maintaining Earth's climate and its biodiversity, as well as its chemical and water cycles, carbon regulation, and even people's livelihoods. Greenhouse gas emissions from anthropogenic activities cause a gradual process of global warming and climate change, which directly impact biodiversity and forest ecosystems (IPCC, 2022; Lapola et al., 2023).

According to data from the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), extreme weather events such as floods, landslides and droughts are occurring more frequently and are expected to intensify (IPCC, 2022). For South America, an increase of 1.5 °C in temperature and a reduction of 1.44% of rainfall is estimated to occur during the period from 2030 to 2049 and, for the Amazon, a process of savannization of the tropical forest is foreseen (Tanure et al., 2020; IPCC, 2022). The impacts on forest biodiversity due to the effects of long-term climate change present worrying figures (Tanure et al., 2020) and suggest economic losses that could reach up to US$ 7.7 trillion over a 30-year period (Lapola et al., 2023).

The impact on forest biodiversity will reduce forest areas and the natural distribution of some species, especially native ones. It is also expected that the genetic diversity of these species will decrease significantly due to the eventual reduction of their number of populations (Tomaz et al., 2022). This is because increasing the distance between individuals of the same species decreases gene flow, thus resulting in a reduction of genotypes and altering the phenology of forest species (Sharma et al., 2020).

Among these species that need attention regarding their behavior in the face of climate change, *Aniba rosiodora* Ducke stands out. It is an arboreal, perennial species that is native to the Central Amazon, which grows abundantly in the Amazon rainforest and occurs in tropical and subtropical regions. It belongs to the Lauraceae family and is commonly known in Brazil as "pau-rosa", "pau-rosa-itaúba", "pau-rosa-mulatinho" or "pau-rosa-imbaúba" (Tales et al., 2021; Lopes & Borges, 2024; Santos et al., 2024).

Rosewood produces an essential oil with a high content of linalool (80–97%) primarily in its trunk wood (Tales et al., 2021; Santos et al., 2024). Other parts of the plant may contain linalool in lower concentrations. The species is used in the cosmetics and perfumery industry, as well as having medicinal and ornamental uses (Singh et al., 2022; Santos et al., 2024). Commercial exploitation began in the interior of the state of Pará around the 1930s and the indiscriminate cutting of trees caused genetic erosion, preventing populations from regenerating naturally. This has resulted in a drastic reduction in the natural populations of the species in the states of Pará, Amapá and in other parts of the Amazon (Tales et al., 2021; Torrez et al., 2022).

Due to the increasing risk of extinction of several plant species, it is necessary to accurately predict how biological systems will be distributed and composed. In this context, several techniques have been developed in recent years in the field of species distribution modeling. Currently, there are several methods available, among them, species distribution modeling (SDM), which is often referred to in literature as ecological niche modeling, although conceptually distinct (Silva & Rocha, 2024), a methodology that can demonstrate the impacts of climate change on plant species and which has been employed in studies of adaptation and conservation of species (Borges et al., 2023; Cordeiro et al., 2023; Marques et al., 2024).

Thus, this work aimed to predict the present-day and future geographic distributions of *Aniba rosiodora* using species distribution modeling (SDM), based on environmental predictors, to identify areas of high suitability for its conservation.

2. MATERIALS AND METHODS

Data on the occurrence points of rosewood trees (*Aniba rosiodora* Ducke.) were obtained from the database of the Environmental Information Reference Center, on the SpeciesLink platform (CRIA, 2024), and the Global Biodiversity Information Facility (GBIF, 2024) and delimited for South America. Data from virtual herbaria, bibliographic searches of scientific articles, natural populations and collections of the Federal University of Amazonas and the National Institute for Amazonian Research were also used. These data were used to model and generate spatial layers representing the potential distribution and create layers related to the distribution of the species in South America and were collected in 2024.

Only occurrence records from the period 2009 to 2019 were retained, to ensure consistency with the reference climate period used in the present-day projections. Older records were excluded to reduce potential temporal mismatch with current environmental conditions.

To ensure accuracy of the data, consistency analyses were performed to exclude duplicates, outliers and incomplete information. Coordinate verification was conducted using the "tidyverse" package in R software (Wickham & Wickham, 2017; R Core Team, 2024). Additionally, to avoid sampling bias and reduce data autocorrelation, occurrences with a proximity of less than a 5 km radius were excluded using the spThin package in R software, with 100 repetitions performed to ensure consistency and reproducibility of the thinned dataset (Aiello-Lammens et al., 2015).

In all, 19 bioclimatic and 14 edaphic variables were used, totaling 33 environmental variables in the context of species distribution modeling (SDM) to estimate the potential geographic distribution of the target species. Bioclimatic variables were obtained from WorldClim – Global Climate Data, using the 30 arc-seconds (~1 km²) spatial resolution dataset, which provides interpolated monthly climate data globally (Fick & Hijmans, 2017). Edaphic variables from SoilGrids were also obtained at a spatial resolution of 250 meters, and both sets of variables were resampled to a common resolution of 1 km² to ensure consistency during modeling.

It is important to note that the temporal mismatch between climate data (1970–2000) and occurrence records (2009–2019) may introduce uncertainties in the projections. However, due to the absence of high-resolution climate surfaces that fully cover the recent decades and are compatible with model training, WorldClim remains a valid and widely adopted climatic baseline for SDMs.

To control the multicollinearity between the environmental variables used, a principal component analysis (PCA) was performed, and the principal components (PCs) that contributed the most to the analysis were selected, i.e., those responsible for at least 95% of the total variability of the data (Evangelista-Vale et al., 2021). After the analysis of main components (PCA), were selected for the training of models the variables that presented the highest values of eigenvector, being: seasonal temperature (Bio4), annual precipitation (Bio12), rainfall in the humid quarter (Bio16), in addition to the edaphic elevation variable. These variables were considered because they explain most of the environmental variability of the data (Table 1).

Table 1. Eigenvector values of the six principal components (PCs) of the bioclimatic and edaphic variables used in the process of species distribution modeling (SDM) of *Aniba rosiodora* Ducke.

	Principal Components					
Variable	PC22	PC23	PC24	PC26	PC27	PC28
Bio1	−0.08	−0.01	0.01	0.17	−0.31	−0.12
Bio2	0.18	−0.19	0.11	0.25	−0.27	−0.07
Bio3	0.24	0.49	−0.15	−0.14	0.10	0.03
Bio4	−0.07	0.63	−0.10	0.10	−0.23	−0.07
Bio5	−0.07	0.06	−0.13	−0.23	0.39	0.17
Bio6	−0.04	0.01	−0.05	0.06	0.00	0.05
Bio7	0.00	0.04	−0.04	−0.29	0.35	0.08
Bio8	0.07	−0.13	0.16	−0.12	0.13	0.04
Bio9	−0.28	0.09	0.15	−0.10	0.12	0.02
Bio10	−0.11	0.24	−0.09	0.14	−0.27	−0.11
Bio11	−0.04	−0.18	0.02	0.07	−0.10	−0.05
Bio12	−0.11	−0.21	−0.72	−0.08	−0.02	−0.38
Bio13	−0.13	0.13	0.43	0.37	0.35	−0.31
Bio14	−0.02	−0.05	0.33	−0.44	−0.14	−0.35
Bio15	0.12	0.01	−0.13	0.00	0.03	−0.01
Bio16	−0.09	0.00	0.13	−0.32	−0.44	0.56
Bio17	−0.06	−0.07	−0.14	0.50	0.17	0.50
Bio18	0.19	0.06	0.01	−0.03	0.07	0.02
Bio19	0.21	−0.05	0.05	0.00	0.01	−0.01
CEC	0.09	−0.03	0.04	0.00	−0.03	0.00
CFV	0.26	0.01	−0.02	−0.02	0.01	0.00
Clay	0.00	−0.01	−0.03	−0.02	0.01	0.00
Elevation	−0.62	0.17	0.00	−0.04	0.01	0.01
Nitrogen	−0.10	0.13	−0.01	−0.01	0.01	0.01
OCD	−0.22	−0.12	−0.06	−0.03	0.02	0.00
OCS	0.20	0.09	0.00	0.02	−0.01	−0.01
pH of the soil in H_2O	−0.33	−0.24	0.02	0.00	−0.02	0.01
Sand	0.00	0.01	0.00	0.00	0.00	0.00
Silt	−0.01	−0.01	0.03	0.02	−0.01	0.00
Slope	0.02	−0.04	0.02	0.01	−0.01	0.00
SOC	−0.02	0.03	0.02	0.00	−0.01	0.00
CP	0.00	−0.01	0.00	0.00	0.01	0.00
AD	0.02	0.02	−0.02	0.00	0.00	0.00

Bio1 = annual average temperature (°C); Bio2 = monthly average of daily temperature change (°C); Bio3 = isothermality; Bio4 = temperature seasonality; Bio5 = maximum temperature in the hottest month (°C); Bio6 = minimum temperature in the coldest month (°C); Bio7 = annual temperature change (°C); Bio8 = average temperature in the wettest quarter (°C); Bio9 = average temperature in the driest quarter (°C); Bio10 = average temperature in the hottest quarter (°C); Bio11 = average temperature in the coldest quarter (°c); Bio12 = accumulated rainfall in the year (mm); Bio13 = rainfall accumulated in the wettest month (mm); Bio14 = rainfall accumulated in the driest month (mm); Bio15 = rainfall seasonality; Bio16 = rainfall accumulated in the wettest quarter (mm); Bio17 = rainfall accumulated in the driest quarter(mm); Bio18 = rainfall accumulated in the warmest quarter (mm)and; Bio19 = rainfall accumulated in the coldest quarter (mm); CEC = cation exchange capacity at pH 7; CFV = coarse fragments volumetric; OCD = organic carbon densities; OCS = soil organic carbon stock; SOC = soil organic carbon content; CP = classes and probabilities "World Reference Base" and AD = Apparent density.

For the present-day and future projections, the CNRM-CM6-1 atmospheric circulation model of the CNRM-CERFACS (National Center for Meteorological Research and European Center for Research and Advanced Training in Scientific Calculation) was used. In the construction of the models for future projections, the PCs and the algorithms selected for the present-day models were maintained. The CNRM-CM6-1 general circulation model (GCM) was selected due to its robust performance in simulating precipitation and temperature patterns in tropical regions, particularly over South America, as demonstrated in previous climate modeling studies. Additionally, this GCM is one of the CMIP6 models most frequently used in ecological and environmental studies involving the Amazon region. The decision to use only one GCM aimed to maintain methodological consistency and reduce the complexity of the ensemble analysis, focusing on a model with reliable representation of the study region's climate patterns.

Climate projections were carried out for the periods 2041–2060, 2061–2080, and 2081–2100 under two contrasting *Shared Socioeconomic Pathways* (SSPs), namely SSP2-4.5 and SSP5-8.5. SSP2-4.5 (hereafter SSP245) represents an intermediate stabilization scenario in which socioeconomic trends follow historical patterns, and climate mitigation policies are implemented with moderate effectiveness. This pathway assumes stabilization of radiative forcing around 4.5 $W \cdot m^{-2}$ by 2100, resulting in an estimated global mean temperature increase of approximately 2.7 °C above pre-industrial levels. Conversely, SSP5-8.5 (SSP585) characterizes a high-emission trajectory dominated by rapid economic development, intensive energy demand met predominantly by fossil fuels, and minimal implementation of climate mitigation policies. This scenario leads to radiative forcing levels near 8.5 $W \cdot m^{-2}$ and a projected temperature rise exceeding 4.4 °C by the end of the century (IPCC, 2022). The inclusion of these two SSPs—representing intermediate and extreme emission futures—follows established recommendations for ecological and biodiversity modeling (Thuiller, 2024), as it enables the assessment of species' vulnerability across a wide range of plausible climatic conditions and informs adaptive conservation strategies under divergent global change trajectories. To construct the consensus model, we used five algorithms: Bioclim - BIO (Nix, 1986), Maximum Entropy - MXD (Philips et al., 2006; Anderson & Gonzalez, 2011), Random Forests - RDF (Prasad et al., 2006), Support Vector Machine - SVM (Prasad et al., 2006) and Generalized Linear Models – GLM (R Core Team, 2024), which allowed us to generate a consensus model in order to select the algorithm with the best predictive quality. Although Bioclim is known for its simplicity and lower predictive performance, it was included for comparative purposes, allowing the evaluation of performance differences across algorithms. Algorithms requiring pseudo-absence data (GLM, SVM, RDF) were trained using 10,000 randomly sampled pseudo-absences, while Maxent and Bioclim, which use background points. The consensus map was built by harmonizing outputs from each modeling approach, respecting their data specifications to minimize bias. Each algorithm was trained with 10,000 data points, background for Maxent and Bioclim, and pseudo-absence points for GLM, SVM, and RDF, randomly sampled across the study area excluding known presences.

These models were evaluated using five statistical metrics: the Area under the Curve (AUC) (Fielding & Bell, 1997), Kappa (Cohen, 1968), True Skill Statistic (Allouche et al., 2006), Jaccard (Leroy et al., 2018), Sorensen (Leroy et al., 2018). Following widely accepted standards in species distribution modeling, we considered models with metric values above 0.7 to be acceptable for robust performance (Fielding & Bell, 1997; Allouche et al., 2006; Leroy et al., 2018). This threshold is frequently used to ensure a balance between model sensitivity and specificity across different evaluation criteria. It is important to note that the temporal mismatch between climate data (1970–2000) and occurrence records (2009–2019) may introduce uncertainties in the projections. However, due to the absence of high-resolution climate surfaces that fully cover the recent decades and are compatible with model training, WorldClim remains a valid and widely adopted climatic baseline for SDMs. For this purpose, the ENMTML package (Andrade et al., 2020) in R software (R Core Team, 2024) was used. Based on these models, binary maps were generated for the target species using the consensus of the models that presented good evaluation metrics and considering the maximum sensitivity and specificity values (MX_TSS). We acknowledge that the final consensus maps represent presence/absence outputs derived from thresholded suitability values, which is characteristic of species distribution modeling (SDM), not ecological niche modeling (ENM). Therefore, this work is framed entirely within the SDM approach. We emphasize that in this study we consider the "rest of the Amazon" to be all the other countries that are part of the biome except Brazil, and the Brazilian Amazon to be the part contained in its entirety in Brazil.

3. RESULTS

After analyzing the consistency of the points of presence and reduction of collinearity, a final occurrence matrix was obtained with 107 occurrence points of *Aniba rosiodora* Ducke, distributed in South America, covering the Amazon and Brazilian phytogeographic domains (Figure 1).

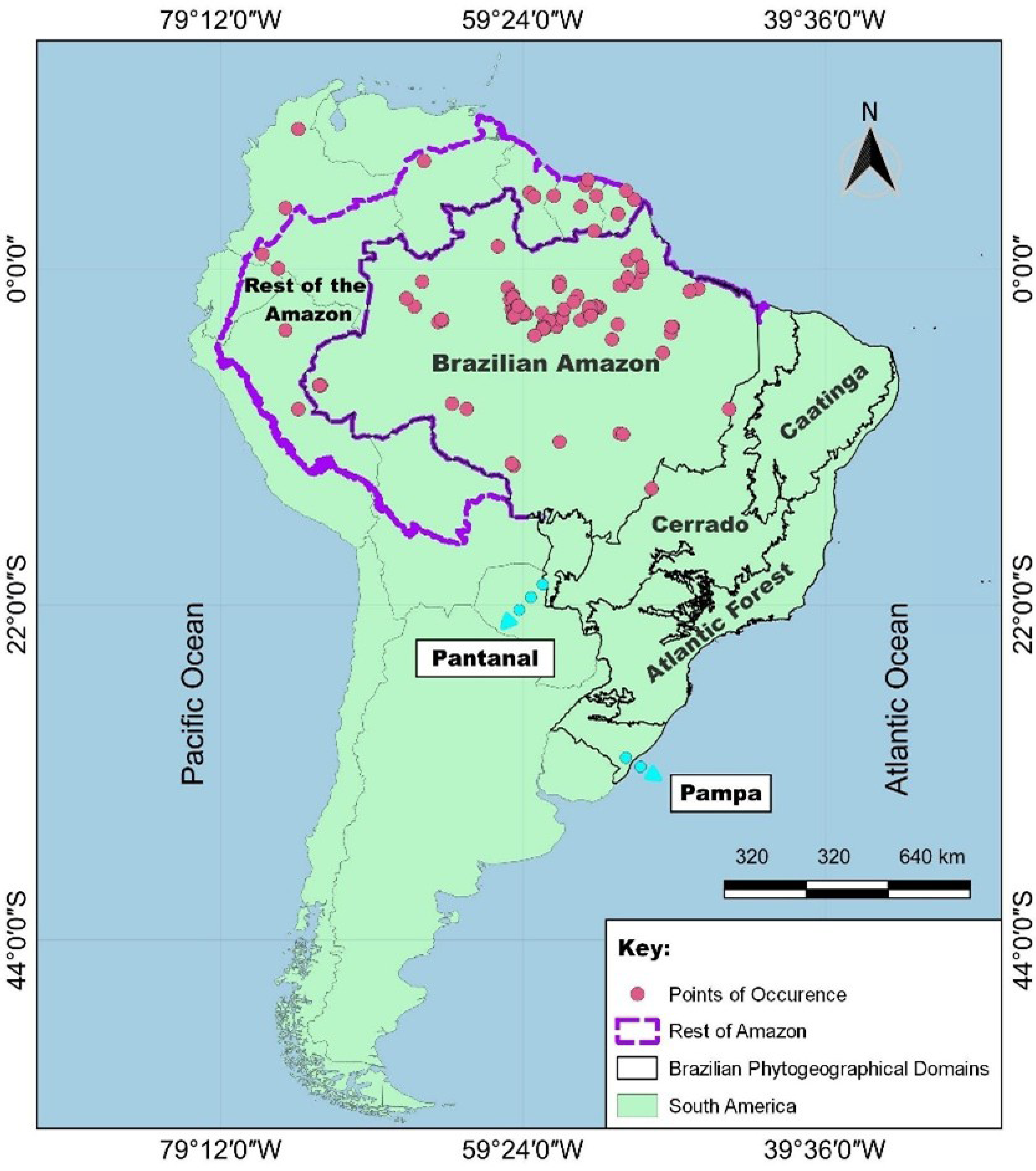

Figure 1. Points of occurrence of *Aniba rosiodora* Ducke in South America, after analysis of collinearity and spatial reduction.

The modeling performed based on five indicator variables (AUC, Kappa, TSS, Jaccard and Sorensen) and five algorithms (BIO, GLM, MXD, RDF and SVM), provided satisfactory metric results in all evaluation indices, with values greater than 7.0 (Table 2). The Jaccard metric versus the BIO algorithm presented a value close to 1.0 and a low standard deviation (0.98±0.02) (Table 2).

Table 2. Indicator variables and standard deviation (SD) for validation of five models for the prediction of the potential area of occurrence of *Aniba rosiodora* Ducke.

	Algorithms				
Metrics	BIO[1]	GLM[2]	MXD[3]	RDF[4]	SVM[5]
AUC[6]	0.90±0.03	0.80±0.06	0.80±0.06	0.80±0.06	0.89±0.04
Kappa	0.88±0.03	0.76±0.06	0.76±0.06	0.78±0.06	0.87±0.04
TSS[7]	0.94±0.04	0.78±0.08	0.78±0.08	0.81±0.06	0.90±0.04
Jaccard	0.98±0.02	0.87±0.06	0.87±0.06	0.88±0.06	0.93±0.03
Sorensen	0.96±0.02	0.80±0.06	0.80±0.06	0.82±0.04	0.90±0.03

[1]BIO = Bioclim; [2]GLM = Generalized Linear Models; [3]MXD = Maximum Entropy Default; [4]RDF = Random Forests; [5]SVM = Support Vector Machine; [6]AUC = Area under the Curve and [7]TSS = True Skill Statistics.

For the reference period (2009-2019), *Aniba rosiodora* presents a high environmental suitability in the Amazon, covering the Brazilian phytogeographic domains such as Amazonia, Caatinga and Cerrado. The domain Amazonia stands out as the region with the highest environmental suitability for *A. rosiodora* (Figure 2). Despite this, it is possible to observe that in some areas in the domain, mainly in the south, west and north, have a low environmental suitability of the species (Figure 2). Also based on the projection, the Pampa and Pantanal domains have a low environmental suitability of rosewood trees (Figure 2).

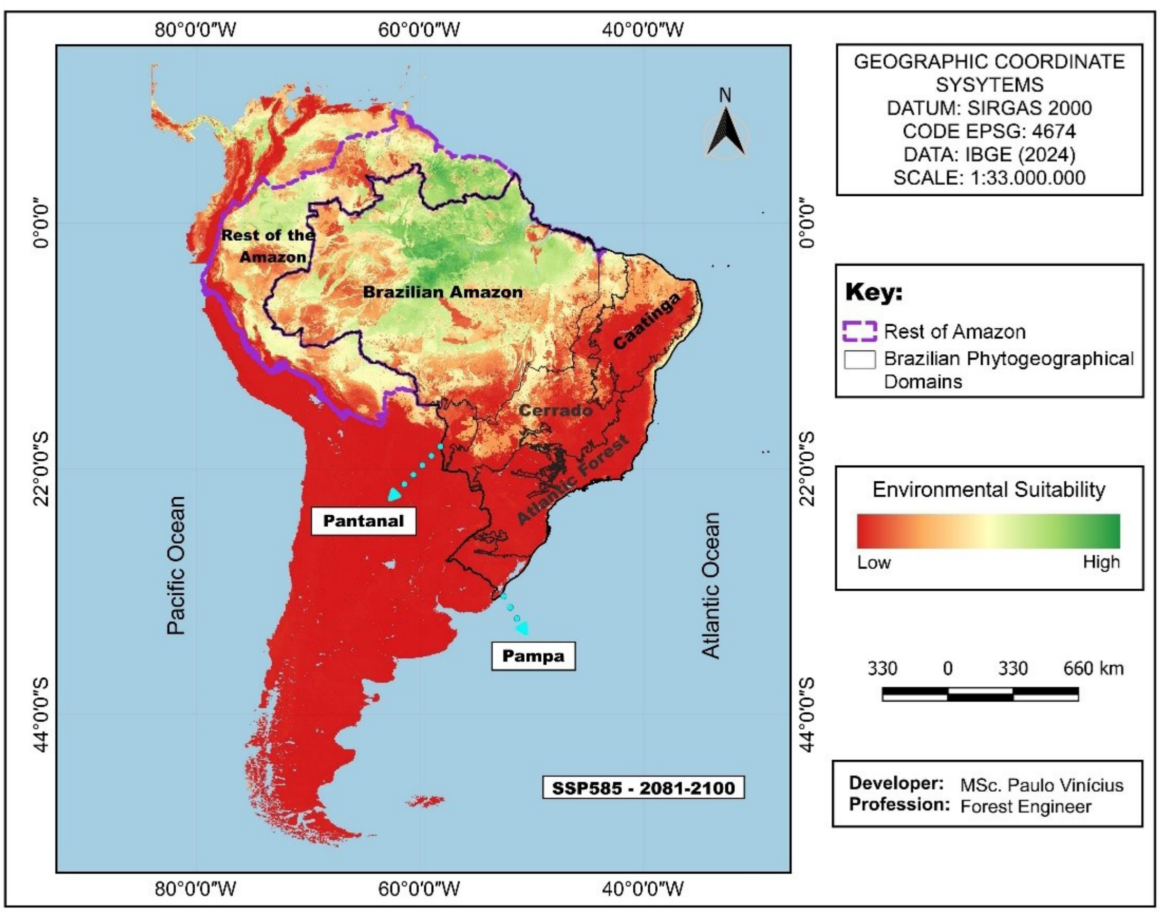

Figure 2. Projection for the present-day (2009-2019) for the species *Aniba rosiodora* Ducke in South America.

Future projections for the least pessimistic scenario (SSP245) indicate significant losses of areas with climatic suitability of *A. rosiodora* across all six Brazilian phytogeographic domains. For instance, when comparing to the reference period (2009-2019), the Amazon domain is projected to lose up to 22.8% of suitable area in 2041-2060, while the Caatinga domain is expected to experience 100% loss as early as this first interval (Table 3). These results confirm a strong contraction of suitable habitats, particularly at the edges of the Amazon domain (Figure 3A, B, C), emphasizing the urgent need for targeted conservation strategies.

Table 3. Projections of increase in (+) or loss (−) of areas of environmental suitability (%) in the scenarios SSP245 and SSP585 for the time intervals 2041-2060, 2061-2080 and 2081-2100, compared to the current period, in South America, for the species *Aniba rosiodora* Ducke.

		SSP245			SSP585		
Area (km^2)		2041–2060	2061–2080	2081–2100	2041–2060	2061–2080	2081–2100
Brazilian Amazon	2,235.218.70	−22.8	−19.4	−17.6	−21.0	−24.2	−62.5
Rest of the Amazon	1,231.030.28	−25.8	−24.8	−27.4	−29.7	−31.0	−42.3
Caatinga	16,460.97	−100.0	−100.0	−100.0	−100.0	−100.0	−100.0
Cerrado	276,554.66	−87.2	−83.9	−85.7	−84.9	−85.5	−96.3
Atlantic Forest	31,081.36	−95.7	−96.3	−97.5	−98.6	−99.8	−99.9
Pampa	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pantanal	138.91	+812.5	+2,000.0	+987.5	+1525.0	+750.0	−94.1
Total	3,790,484.877	−29.4	−26.8	−26.8	−29.4%	−31.8	−58.9%

In the more pessimistic scenario (SSP585), it is evident that there is climatic suitability to the north and southwest of the Amazonia domain, with a greater probability of occurrence of rosewood trees (Figure 3D, E, F). In the same scenario, it is also observed that there is a severe reduction of areas from the edges to the center of the domain, which is intensified in the interval 2081-2100 (Figure 3F).

In percentage terms, the projection of increase in or loss of areas with environmental suitability for the occurrence of rosewood trees indicates area losses in the two scenarios analyzed SSP245 (less pessimistic) and SSP585 (more pessimistic) and in the three-time intervals for the study areas (Table 3). Except for the Pantanal domain, which despite having a smaller reference area (km^2), showed significant gains in area, both in the SSP245 scenario and in the SSP585 scenario; reaching +2,000% in the SSP245 scenario in 2061-2080 (Table 3). In the SSP585 scenario in 2081-2100, the Cerrado, Atlantic Forest and Caatinga domains presented the highest percentages of losses, with 96.3, 99.9 and 100%, respectively. In 2041-2060, in the SSP 245 scenario, the Caatinga domain has already reached its totality for loss of areas with climatic suitability (Table 3). The Amazonia domain presents the largest area with climatic suitability for the occurrence of rosewood trees and, despite this in the SSP585 scenario in 2081-2100, there is a loss of 62.5% of areas when compared to the reference period (Table 3). Amazon presented the lowest loss of area (-43.3%) when compared to the other locations (Table 3).

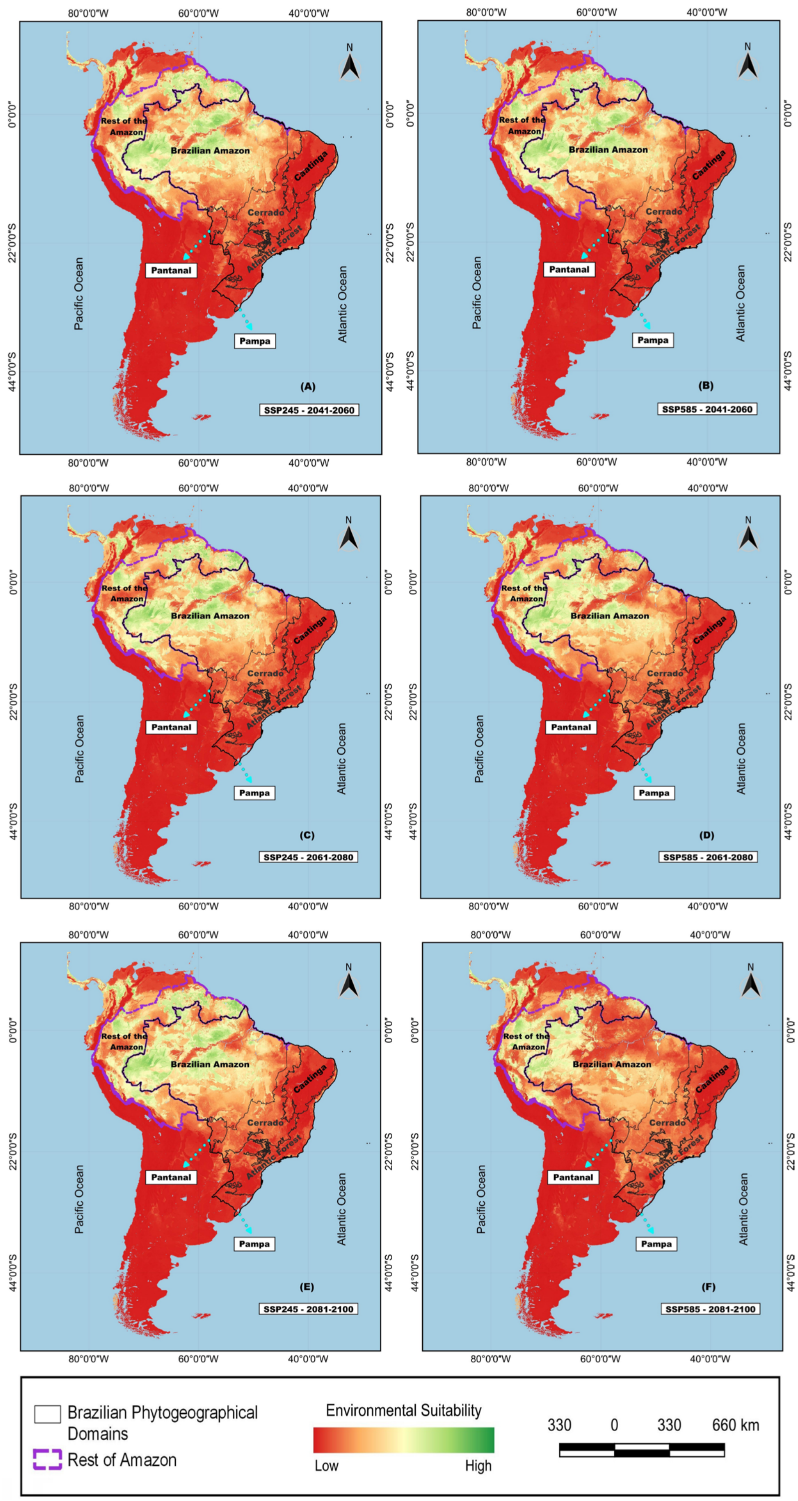

Figure 3. Projection for the species *Aniba rosiodora* Ducke in the time intervals 2041-2060, 2061-2080 and 2081-2100, in the least pessimistic (SSP 245) and most pessimistic (SSP 585) scenarios.

The modeling carried out for the protected areas of the Brazilian Amazon indicate a low probability of occurrence of the species in the extreme north and the central portion in the less pessimistic scenario SSP245 (Figure 4A, B, C and Figure 5A, B, C). These losses of area are intensified in the most pessimistic scenario SSP585 and are located mainly in conservation units (Figure 4D, E, F and Figure 5D, E, F).

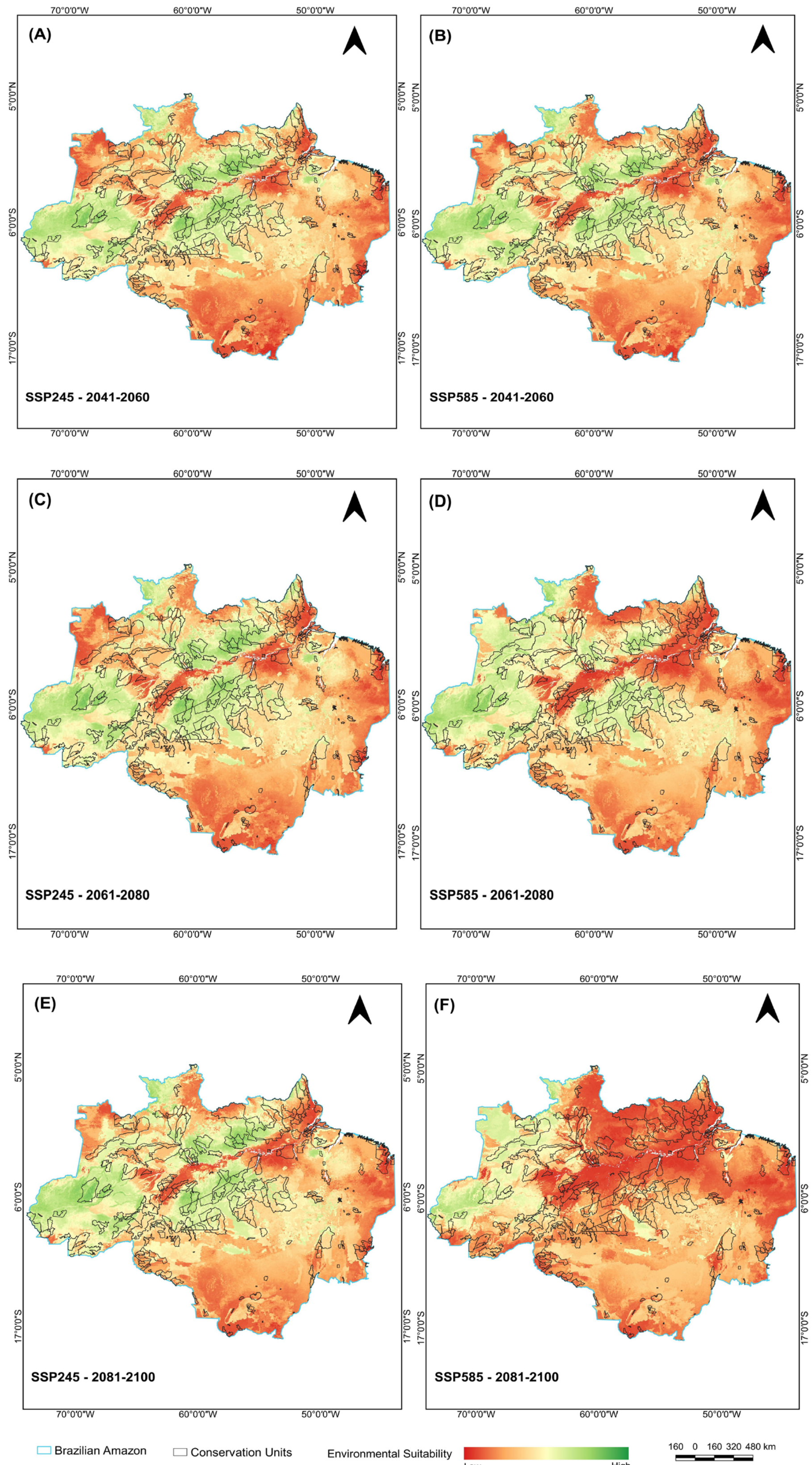

Figure 4. Projection for the species *Aniba rosiodora* Ducke in the time intervals 2041-2060, 2061-2080 and 2081-2100 in a less pessimistic (SSP 245) and more pessimistic (SSP 585) scenarios in conservation units of the Brazilian Amazon.

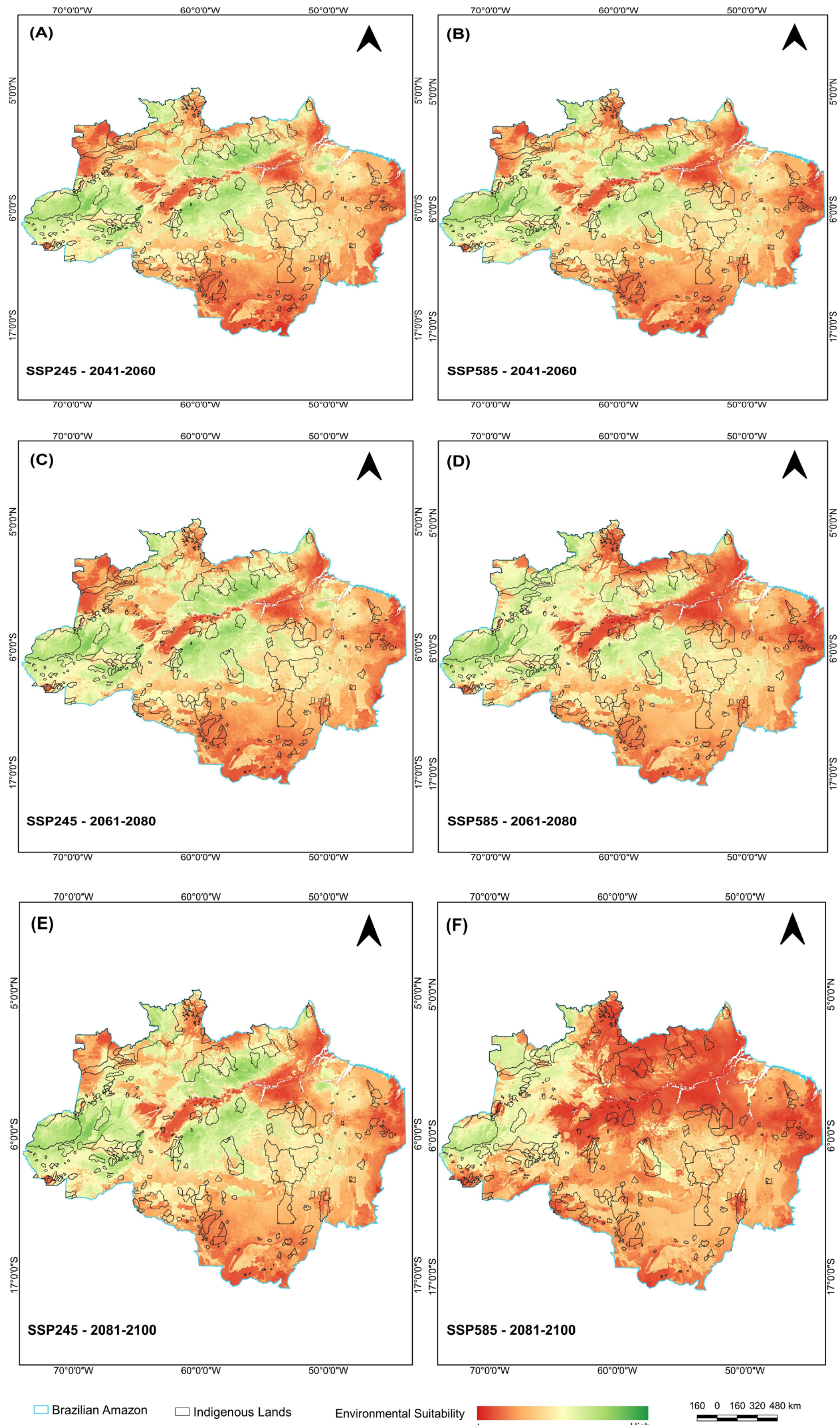

Figure 5. Projection for the species *Aniba rosiodora* Ducke in the time intervals 2041-260, 2061-2080 and 2081-2100 in the less pessimistic (SSP 245) and more pessimistic (SSP 585) scenarios in indigenous lands of the Brazilian Amazon.

It is observed that the greatest loss of areas with climate suitability in protected areas occurs in conservation units in the two scenarios evaluated, with significant losses (-68.1%) in the SSP585 scenario in 2081-2100 (Table 4). The indigenous lands presented greater climatic suitability for the occurrence of rosewood trees, which was confirmed by the lower loss of area (-45.6%) when compared to the conservation units (Table 4).

Table 4. Projections of loss (−) of and increase (+) in areas of climatic suitability (%) in conservation units (CUs) and indigenous lands (ILs) in the scenarios SSP245 and SSP585 for the three assessment periods compared to the reference period (2009-2019).

Area (Km^2)		SSP245			SSP585		
		2041–2060	2061–2080	2081–2100	2041–2060	2061–2080	2081–2100
CU	715,044.949	−21.8	−16.7	−17.2	−21.8	−23.0	−68.1
IL	533,974.315	−8.5	−13.5	−10.4	−6.4	−9.6	−45.6
Total	1,249,019.26	−16.1	−15.4	−14.3	−15.3	−17.3	−58.5

4. DISCUSSION

The distribution pattern of species is affected by climate change at different spatial and temporal scales, which interfere in areas with environmental suitability for the occurrence of plant species (Brandão et al., 2022). This is observed for *Aniba rosiodora*, a species that is native to the Amazon, which is one of the regions that is most sensitive to climate change due to the rich biodiversity it encompasses. In addition, the rosewood trees present economic importance; thus, it is a forest species that is the target of selective overexploitation – so much so that its felling reached 30,000 tons of wood per year between 1945 and 1974 (Brandão et al., 2022; Torrez et al., 2022).

Although some species may respond to climate change through migration or phenotypic plasticity, it remains uncertain whether *A. rosiodora*, a species already classified as endangered, possesses the adaptive capacity to establish viable populations in new environments within a few decades. The rapid pace of projected climate shifts (within 20 to 60 years) may outpace the species' ability to respond, especially considering its low natural regeneration rate and the fragmentation of its current habitat (Gougherty et al., 2021).

For the rosewood tree, it is seen in the literature that the increase in temperature and changes in rainfall indices is causing changes in the habitat considered suitable for the species; thus, it has migrated to regions of higher altitudes and with milder temperatures, i.e., areas with specific edaphoclimatic conditions for its good development. In addition, climate change also affects the phenology of the target species, which is naturally already irregular and has poor flowering synchronization, which are critical factors for its reproduction, resulting in a lower natural regeneration capacity of the species (Torrez et al., 2022).

The species distribution modeling (SDM) developed in this study does not aim to define the fundamental or realized ecological niche of *A. rosiodora*, but rather to predict its potential geographic distribution based on environmental variables. The results indicate that the current environmental suitability for the species in the Amazon is significantly affected by climate change, with a reduction in suitable areas, particularly at the eastern and southern edges of the domain. This area is known as the Brazilian Arc of Deforestation, in which the average precipitation rate is lower and has a greater thermal amplitude, and it is considered more vulnerable due to increasing deforestation and forest fires (Santos et al., 2021).

This methodology was also used in native species of the Amazon region such as *Bertholletia excelsa* Bonpl. (Brazil nut tree), and it was found that its occurrence may decrease in the region by up to 25% by 2050 (Evangelista-Vale et al., 2021). Assessing the migration or adaptation capacity of native species can provide information about the vulnerability of these individuals in relation to global climate change and can help in defining conservation methods for these species through a more comprehensive and meaningful assessment of the risks that populations may face in future climates (Gougherty et al., 2021). Considering the loss of areas with the occurrence of rosewood trees in the Amazon, one of the strategies to contain the advance of deforestation and landscape fragmentation is the creation of protected areas and indigenous lands (Paiva et al., 2020). Despite this, these areas in the Amazon still suffer anthropogenic pressure, making them vulnerable to the effects of climate change (Dobrowski et al., 2021). In the future scenarios, in the modeling for the occurrence of rosewood trees in protected areas, it was observed that although indigenous lands are constantly being affected by deforestation and burning, these are still the best way to maintain these species and ensure the conservation of their plant resources.

5. CONCLUSION

Deforestation has intensified the effects of climate change on areas with climatic suitability for the occurrence of rosewood trees, which increases the risk of possible extinction of the species. Conservation and sustainable management strategies are indispensable to protect rosewood trees and ensure their long-term survival.

Protected areas (conservation units and indigenous lands) are still the best conservation strategy to maintain the occurrence of rosewood trees in these environments and ensure the conservation of their resources and the genetic variability of the species.

To reduce the loss of genetic diversity related to the loss of area in the Brazilian phytogeographic domains, it is necessary to sample the total genetic variability, prior to any changes in the predicted scenario, for the conservation of rosewood trees, introducing genotypes in other places of greater suitability as indicated by the present study.

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DATA AVAILABILITY

The entire data set supporting this study's results is available upon request to the corresponding author, Manuel de Jesus Vieira Júnior. The data used were obtained from public databases (GBIF, SpeciesLink) and research institutions (UFAM, INPA) and organized specifically for this study.

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