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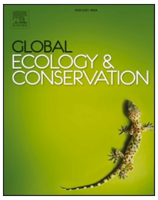

The effects of land use and climate change on diameter of *Dipteryx alata* (Leguminosae) in the Brazilian Cerrado

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ABSTRACT

Diameter at breast height (DBH) is related to various other plant attributes (e.g., height, fruit number, age), and as such, it can indicate important characteristics for species management and conservation. In this study, we aimed to investigate how the DBH of *Dipteryx alata* Vogel (Leguminosae) varies spatially across the Cerrado biome. Additionally, we examined how environmental factors and land use can influence the variation in DBH of the *D. alata*. Furthermore, we estimated the current and future potential distribution of *D. alata* to assess the impact of global climate change on the species' distribution. We utilized a database with 253 records of DBH for *D. alata* distributed across the Cerrado. For each sample unit, we determined the environmental suitability of *D. alata* using niche modeling, and land use was characterized and classified into different types (from pasture to remnant vegetation). Our results revealed that the DBH of *D. alata* ranged from 5 to 75 centimeters, and there was no discernible spatial pattern. Environmental suitability could not predict the spatial variation in DBH. Nonetheless, plants with larger DBH were found in regions classified as pasture in terms of land use. Factors such as reduced competition soil management and age of plants (old plants) may help explain why DBH was greater in pasture areas. It is worth noting that although pasture areas can serve as a refuge for some trees, proper management is essential to promote individuals' recruitment, ensuring population regeneration and the maintenance of diversity in long time. Climate projections anticipate significant loss of climatically suitable areas for *D. alata* in future scenarios.

1. Introduction

The Diameter at Breast Height (DBH) of trees is a morphological characteristic of great importance for environmental research, as it is associated with age, height, volume, fruit productivity, biomass, conservation of areas, forest mortality, among others (Morgenroth et al., 2020). Furthermore, various factors can influence the spatial variability of the diameter population of native species, such as genetic, regional environmental factors, local landscape factors, and management (Nabeshima et al., 2010; Basnet et al., 2024).

Factors such as land use, soil type, and management can influence the early stages of plant growth, leading to variations in diameter

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(e.g. Nunes et al., 2015). Additionally, the removal of vegetation for pasture or crop planting often spares certain native plants, such as *Dipteryx alata* (*baru* tree), due to their utility. In this case, the fruits of *D. alata* are valued as a food source for cattle (Sano et al., 2004), which contributes to its presence in both Cerrado and pasture areas. This selective removal can alter species interactions, potentially influencing the morphological attributes of plant species (Esquivel et al., 2008).

Climatic factors are widely recognized as determinants of species' geographical distribution. These factors, such as climate tolerances, make up the species' climatic niche. Niche modeling tools have been used to map the potential distribution of species (Peterson et al., 2011). In the case of Cerrado plants, the combination of climatic and edaphic factors has been employed to understand species distribution (Ferreira et al., 2022). Furthermore, niche models can be used to predict local population attributes, such as genetic diversity (Collevatti et al., 2011; Soares et al., 2015; Diniz-Filho et al., 2015) and population density (VanDerWal et al., 2009; Kulhanek et al., 2011; Nabout et al., 2011; Nabout et al., 2016; Weber et al., 2017). Therefore, utilizing niche modeling tools to assess their capacity to explain local variations in morphological attributes is one of the frontiers of biogeography and ecology. Moreover, niche models have been employed to predict suitable locations for species occurrence in future scenarios of climate change (Terribile et al., 2012; Velazco et al., 2019; Lorençone et al., 2024; Bonifácio-Anacleto et al., 2024).

Understanding the spatial variation of morphological attributes in plants becomes particularly important for species occurring in the Cerrado Biome. This biome covers approximately 25 % of Brazil's territory, encompassing about 2.5 million square kilometers (Silva et al., 2021), and is considered the savanna with the highest floristic diversity in the world. Moreover, this biome is among the most threatened on the planet due to high conversion rates and limited protected areas (Trigueiro et al., 2020; Gonçalves et al., 2020; Barbosa et al., 2023). Additionally, future scenarios of climate change have indicated that Cerrado plants may lose extensive geographical distribution areas (Nabout et al., 2011; Velazco et al., 2019; Ferreira et al., 2021). Given these circumstances, understanding the influence of local land use and regional climate processes, as well as estimating the potential distribution of plant species in current and future climate scenarios, is of paramount importance for biodiversity management and conservation (e.g. Ford et al., 2017).

The aim of this article is to assess the spatial variation of the Diameter at Breast Height (DBH) of *Dipteryx alata* in Brazilian Cerrado and determine the importance land use and environmental suitability in the variation of *D. alata* DBH. Furthermore, we evaluate the impact of global climate change on potential geographical distribution. We used *D. alata* as a model species due to its widespread occurrence in the Cerrado, with records in various landscapes (natural and anthropized). Additionally, as a species of economic interest, there are records of occurrence and DBH data across different regions of the Cerrado, allowing investigations on a broad spatial scale. As expected, we anticipate that DBH will be greater in areas with higher environmental suitability, since more suitable areas are located in regions more favorable to the species' climatic niche (Colwell and Rangel, 2009), which would allow for greater plant development. For land use, our expectation is that plants with larger DBH will be found in pasture areas. This may occur because *D. alata* is spared from removal in pasture areas, as it provides food and shade for livestock. Therefore, local factors such as soil productivity and the absence of competitors may cause plants occurring in pasture areas to have larger DBH.

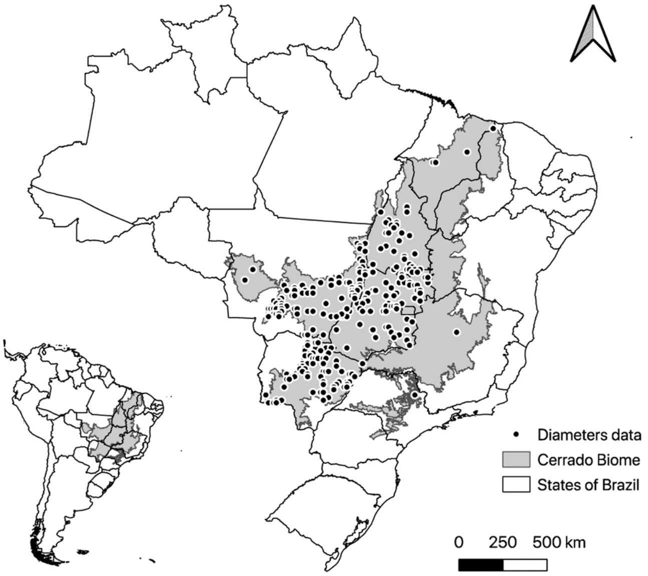

Fig. 1. Map showing the geographic distribution of the 253 sampling sites (grid cells) used in the present study, where the average diameter at breast height (DBH) of *Dipteryx alata* was recorded.

2. Material and methods

2.1. Data collection

The data related to DBH and the location of individuals were obtained through the Brazilian Forest Inventory (Inventário Florestal Nacional - IFN), which is a project coordinated by the Brazilian Forest Service (Serviço Florestal Brasileiro - Brasil, 2021). In this project, a DBH survey was carried out between 2008 and 2021. This data was made available on the SFP website and was obtained by us in 2023. The IFN sampling system is based on a distribution established by the Brazilian Forest Service. Sampling points are spaced at 20 km intervals, forming a standard national 20 × 20 km grid cell (for grid variations, see IFN documentation - https://www.gov.br/florestal/pt-br/assuntos/ifn/metodologia).

For each cell in the IFN grid, a detailed collection of *D. alata* individuals was conducted by a team from the Brazilian Forest Service (SFB), ensuring standardized sample size and effort. In each grid-cell, four rectangular subunits of fixed area (insert area), arranged perpendicular to a central point and oriented in the cardinal directions, were established. These subunits were numbered from 1 to 4. The DBH measurements for each individual of *D, alata* were taken within these subunits. To estimate the DBH for each grid-cell (the unit of analysis), the average DBH from the subunits was calculated.

The DBH data for *D. alata* were obtained from the Forest Inventory of Brazil website, and each grid-cell in the present study corresponded to unity of analysis (Fig. 1). In total, information was obtained for 253 sampling cell-grid, and 748 individuals of *D. alata* were measured.

We used two sets of predictors to explain the spatial variation of DBH: i) Environmental suitability obtained from niche models; ii) Land use classification based on satellite imagery and field classification.

To niche modeling, the records of *D. alata* were obtained in GBIF (Global Biodiversity Information Facility), Species Link, Reflora and data of forest inventory (i.e. the clusters – Fig. 1). A total of 834 records were obtained and arranged into the gridded Neotropical region with a resolution of 0.1666667 × 0.1666667 degrees of latitude and longitude (∼ 18 km; 10 arcmins). Thus, we ended up with a total of 654 non-duplicated and filtered unique points that were posteriorly used for modeling (supplementary material – Fig. 1).

We downloaded the climate data as bioclimatic variables for the present and future scenarios in the Worldclim online database (https://www.worldclim.org, version 2.1; Hijmans et al., 2005). We selected an intermediate (Representative Concentration Pathways - RCP 4.5) and pessimist (RCP 8.5) future carbon emission scenario projected to 2070. These two scenarios were chosen to capture a range of potential future climate conditions, from moderate to extreme emissions trajectories. The scenario used is based on the Global Climate Models (GCM) of the Community Climate System Model (CCSM4). This model and scenarios have been used in other studies with Cerrado plants, allowing for comparisons between different papers (Ribeiro et al., 2019; Ferreira et al., 2022). The environmental layers were selected avoiding collinearity and observing the biological effect of those in the plant's physiology.

We also downloaded pH in H20 at 30 cm depth (Hengl et al., 2017), representing soil characteristics for the plant. We downloaded this variable on the Soil grids website (https://soilgrids.org), and it was used as a stochastic variable since there is no prediction for future scenarios. All environmental variables used had grid cells rescaled to a resolution of 0.166667° longitude and latitude (nearly 18 km) in the Neotropic extension. The variables used for modeling were BIO2 (Mean Diurnal Range), BIO4 (Temperature Seasonality), BIO10 (Mean Temperature of Warmest Quarter), BIO17 (Precipitation of Driest Quarter), and pH (pH in H20 at 30 cm depth). We used a factorial analysis with varimax rotation to remove the statistical collinearity. For this, we used the functions *fa* and *fa.parallel* of the *psych* package (Revelle, 2023) in the R software, version 4.2.3 (R Core Team (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/), to determine the adequate number of non-orthogonal axes. We picked four axes and then selected the variables with the highest loading (- or +) in each axis (see methological details in Ferreira et al., 2021; 2022).

The method used was Maximum Entropy (MaxEnt; Phillips et al., 2006). We used 10,558 points to determine the species distribution (background points and presence points) (∼4.8 % of the entire area; Barbet-Massin et al., 2012), randomly generated throughout the Neotropical region while avoiding cells with presence records. The models were built using the cross-validation approach, with 10 repetitions to account for variability in training/testing partitions. In each repetition, 75 % of the presence/background records were used for training and 25 % for testing, randomly selected. We used the following MaxEnt settings: a maximum of 500 iterations or until convergence, regularization values (linear/quadratic/product: 0.050, categorical: 0.250, threshold: 1.000, hinge: 0.500), and selected environmental layers (BIO2, BIO4, BIO10, BIO17 and pH). We evaluated the models using the AUC (Area Under the "Receiver Operating Characteristic" Curve) (Swets, 1988), a threshold-independent metric that compares predicted and observed values.

The land use was assessed using two data collection approaches: i) Landscape characterization at the time of collection; and ii) Satellite image analysis. At the collection sites, each region was classified into 11 land use and/or physiognomy types. This classification was carried out by the Forest Inventory of Brazil at the time of collection and is available along with the diameter data. The land use/physiognomy classes are: Caatinga, Natural fields, Cerrado, Forest mature, Secondary forest advanced, Secondary forest young, Urban influence, Shrub, Pasture, Small forest fragments, and Soil exposed. In addition to this classification, we obtained cumulative deforestation data through satellite imagery available in the PRODES Cerrado system (Assis et al., 2019; Parente et al., 2021). For each sampling unit, we determined whether the region was classified as "forested" or "deforested" between 2002 and 2019. A sampling unit was considered "forested" if it maintained forest cover throughout the entire period. If deforestation occurred at any point during this time frame, the unit was classified as "deforested," regardless of its forest status in 2002.

2.2. Data analysis

The land use data were summarized using Principal Coordinate Analysis (PCoA), a multivariate technique suitable for categorical data. This involved synthesizing data related to land use (11 types of land use) and the deforestation classification obtained from PRODES Cerrado. PCoA was applied to a dissimilarity matrix computed using the Jaccard distance index, which is appropriate for binary and presence/absence data. The contribution of variables to the formation of the principal axes was assessed by calculating the correlations between the original variables and the principal axes. This allowed us to identify the most influential variables in shaping the overall structure of the data. Two axes were retained, which were subsequently used in the regression analysis.

The spatial structure of *D. alata* DBH was evaluated using Moran`s I correlogram (Legendre and Legendre, 2012), considering the Sturges rule to determine the number of classes of the correlogram.

The importance of predictors land-use and environmental suitability (present climate scenarios) on *D. alata* DBH was tested using the Ordinary-Least Square (OLS) model. All variables were standardized, which scales the mean to zero and standards the deviation to one (except two PCoA axis). The collinearity among all predictors' variables was evaluated using the Variance Inflation Factor (VIF) establishing a VIF equal or higher than 2 as the threshold to consider a variable with high collinearity. We evaluated the assumptions of OLS (linearity, normality and spatial independence) using the residual of the regression model. The spatial independence was evaluated by analyzing the spatial correlogram of residuals (see Hawkins et al., 2007). The significance of predictors was tested using a null model using 999 Monte Carlos simulations (Manly, 2006).

We also used quantile regression since we intended to assess how the predictor variables affect different parts of the diameter distribution. Quantile regression minimizes the sum of absolute deviations of a function from the observed values at a specific quantile (Hao and Naiman, 2007). To perform quantile regression for the diameter, we utilized the quantiles of 20, 50, and 90 %. The 50 % quantile represents the median, reflecting the central tendency of the distribution, while the 20 % and 90 % quantiles provide insights into how the predictor variables influence the lower and upper extremes of the diameter distribution. By comparing the results across these quantiles, we could assess whether the predictors have consistent or varying effects across different parts of the distribution.

The statistical analyses were performed using functions and packages available in the R software, version 4.2.3 (R Core Team, 2024). The OLS model was performed using the lm function in the stats package. The quantilie regression was perfomerd using the function rq in the quantreg packages (Koenker et al., 2018) The VIF was determined using the function vif in the faraway package (Faraway, 2016). The PCoA was performed using the function cmdscale function in the stats package. The Moran's I correlograms were performed using the function correlog in ncf package (Bjornstad, 2022).

2.3. Results

A total of 748 individuals distributed across 254 sampling units in the Cerrado were measured for Diameter at Breast Height (DBH). The average DBH within grid cells ranged from 5 cm (it is worth noting that measurements were taken only from this DBH and above) to 74.4 cm, with a median of 17.6 cm (Fig. 2).

The sampling units were distributed across the Cerrado biome, and there is no evidence of a spatial pattern in the DBH (Fig. 3). For instance, plants with higher DBH values (e.g., above the 75th percentile or exceeding 24.4 cm) were recorded in different regions of the

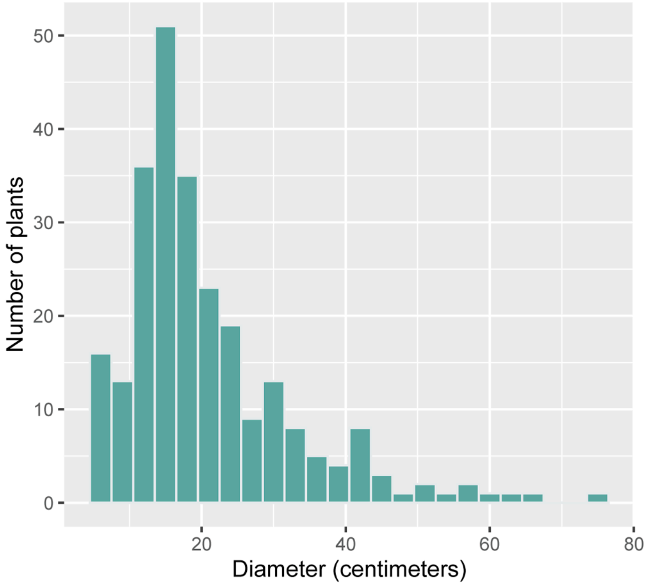

Fig. 2. Histogram of average of Diameter at Breast Height (DBH) of *Dipteryx alata* in sampling sites of Brazilian Cerrado, obtained from "Inventário Florestal Nacional" - IFN.

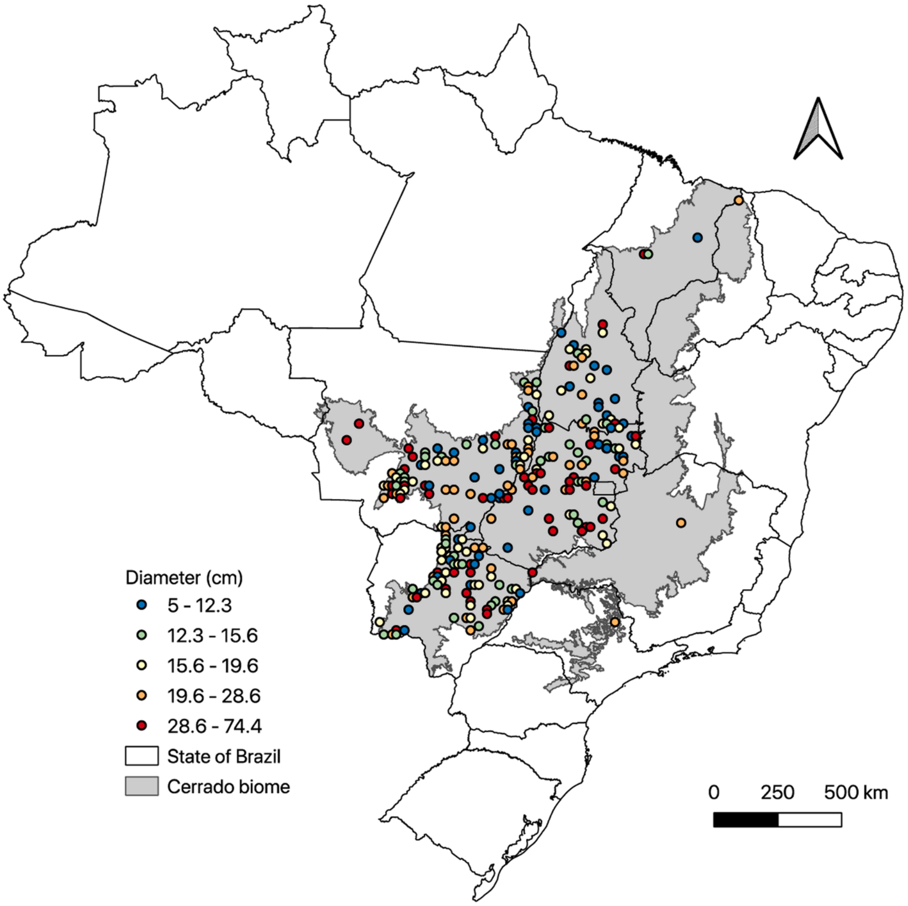

Fig. 3. Spatial distribution of *Dipteryx alata* sampling points, with colors representing different size classes for DBH (as per legend in the figure). There is no spatial pattern, as evidenced by the DBH variable's correlogram (see material supplementary).

Cerrado (e.g., central, south, or west of the Biome). In fact, the analysis of Moran's I correlogram did not indicate a spatial pattern in DBH, with the first distance class registering a Moran's I of 0.04 ($p > 0.05$).

The geographic distribution model of *D. alata* demonstrated a good fit (AUC = 0.92) and revealed a broad distribution across the entire Cerrado biome, with higher environmental suitability concentrated in the central region of the biome (Fig. 4A). Intermediate future climate projections (Fig. 4B) and pessimistic scenarios (Fig. 4C) indicate a gradual and widespread loss of climatic suitability across the central, northern, and western regions of the Cerrado biome. In particular, the central region, currently characterized by high environmental suitability, is expected to experience significant declines. Conversely, suitable areas are projected to become increasingly concentrated in the southeastern region of Brazil. Notably, no significant gains in new occurrence areas were identified

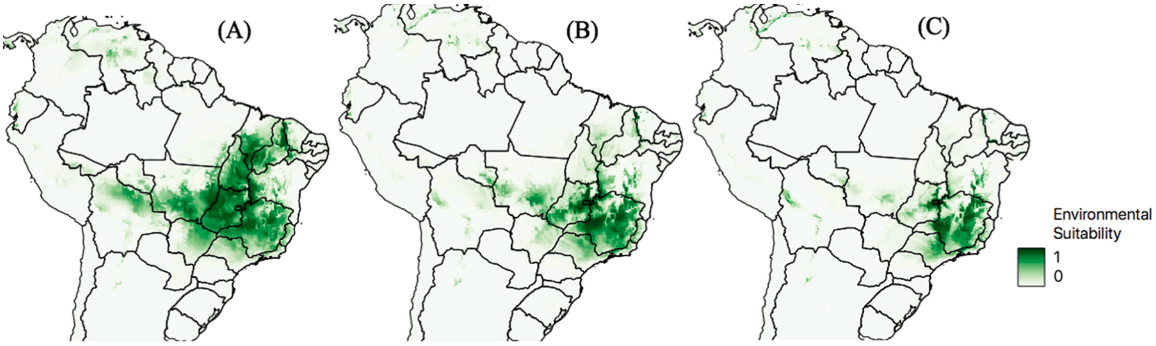

Fig. 4. Species distribution model of *Dipteryx alata* in different climate scenarios: (A) present; (B) future 2070 intermediate and; (C) 2070 pessimistic.

under either scenario, underscoring the restrictive impacts of climate change on the potential distribution of *D. alata*.

The first two axes of PCoA were able to explain 69.57 % of the total data variation. The PCoA axes were used in the linear regression. Negatively along the first axis were the sampling units classified as Cerrado and areas preserved according to the PRODES data, i.e., areas with remaining vegetation. Positively along the first axis were the sampling units classified as pasture and exposed soil. Considering the second axis, the variables Cerrado and Pasture are negatively associated with this axis. The other variables are positively related to the second axis (Fig. 5).

The linear regression indicated that the DBH of the plants was explained by the first axis of the PCoA ($R^2adj = 0.288$; $P < 0.001$, Table 1). The first axis of the PCoA showed a positive relationship with DBH; therefore, areas with the presence of pastures tend to have higher DBH values. In fact, plants with larger DBH values were found in pasture regions, with plants reaching DBH values exceeding 40 cm (mean of 25.4 cm). Conversely, in remnant Cerrado areas, the maximum DBH observed was 40 cm (mean of 17.9 cm) (Fig. 6). Climatic suitability was not significant in explaining the spatial variation of DBH. No spatial autocorrelation was observed in the regression residuals (see Fig. 3 in the supplementary material).

In the quantile regression for DBH, it was divided into three distinct quantiles (20 %, 50 %, and 90 %) and related to predictors. Overall, the quantile regression showed a similar result to the global regression, where plants with larger diameters were found in regions classified as pasture. This pattern was consistent for plants with small diameters (20th percentile), those up to the median (50th percentile), and even up to the 90th percentile (Table 2).

3. Discussion

The *D. alata* tree exhibited a broad spatial distribution within the Cerrado biome, with the potential to occur throughout the entire biome. Furthermore, the sampled populations showed a wide variation in DBH (ranging from 5 to 74 cm). However, even though plants were geographically close, their DBH values were not similar, indicating an absence of spatial pattern. The lack of spatial structure can be explained by land use factors, as plants with larger DBH were found in regions classified as pasture land. DBH was not related to the environmental suitability indicated by niche models, indicating that the niche model used is not a good predictor for this variable.

Some tree of Cerrado, such as *D. alata*, have been spared from deforestation for land use conversion into pasture. This occurs primarily because the presence of these trees does not hinder pasture or cattle management, and also because animals enjoy the fruit and benefit from the thermal comfort provided by the tree's canopy (Silva Neto et al., 2022). Consequently, it is possible to find individuals of *D. alata* in both Cerrado remnants and pasture areas.

Other studies with a smaller number of observations have also found that plants occurring in pasture areas have a larger DBH (Sano

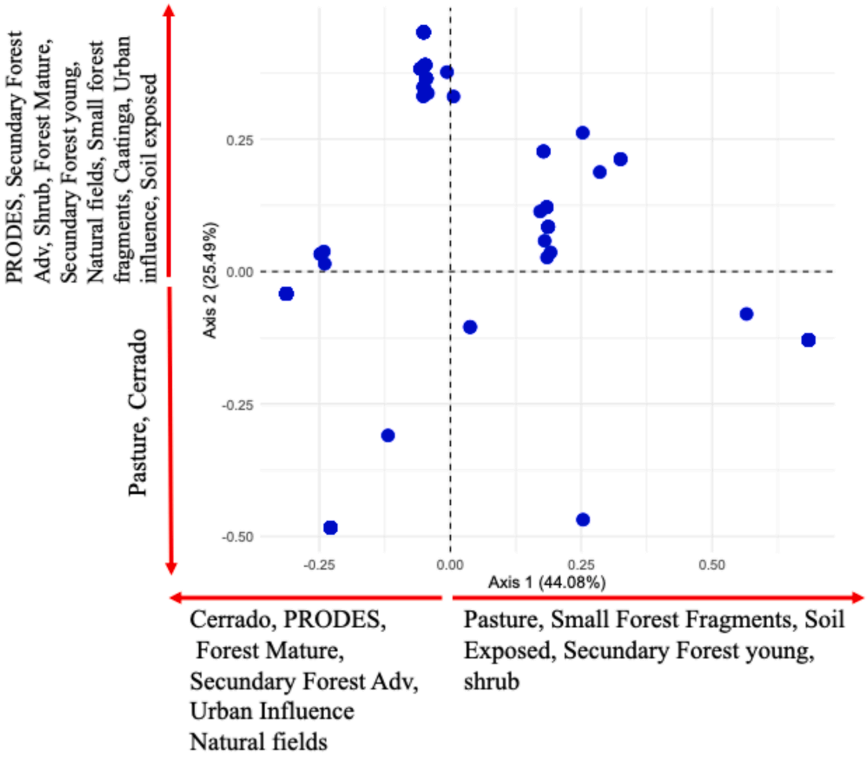

Fig. 5. The first two axes of the Principal Coordinates Analysis (PCoA) based on 11 land-use types and deforestation data obtained from satellite imagery (PRODES data).

Table 1
Summary of linear regression of Diameter at Breast Height in function of environemtnal suitability (indicated by niche modelling) and land use (indicated by two axes of PCoA). The significance was tested used the Monte Carlo procedure (1000 randomizations).

	Diameter	
	Slope standardized	P-Value
Environmental Suitability	−0.085	0.191
PC1	0.546	< 0.001
PC2	−0.389	0.59
R^2	0.288	< 0.001

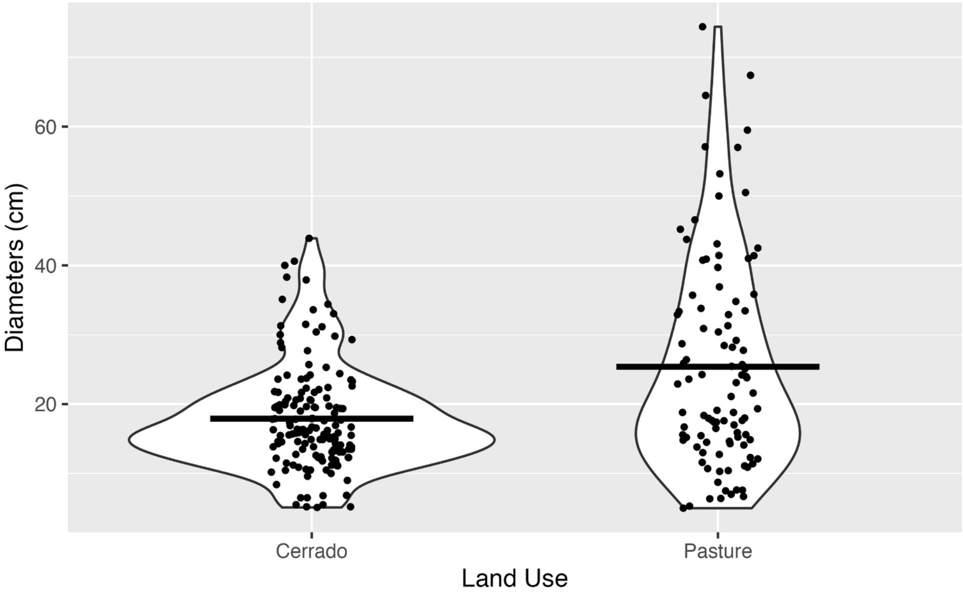

Fig. 6. Violin plot showing the diameter at breast height (DBH, in centimeters) of *Dipteryx alata* in two distinct land-use types, based on PRODES imagery. The black line represents the mean DBH for each land-use type.

Table 2
Quantile regression of Diameter at Breast Height in function of environmental suitability (indicated by niche modelling) and land use (indicated by two axis of PCoA). See graphical representation in supplementary material.

	Quantile 20 %		Quantile 50 %		Quantile 90 %	
	Slope standardized	P-Value	Slope standardized	P-Value	Slope standardized	P-Value
Environmental Suitability	−0.066	0.129	−0.061	0.39	−0.065	0.631
PC1	0.238	0.001	0.472	0.001	1.098	0.001
PC2	0.005	0.872	−0.051	0.453	−0.0008	0.994

et al., 2004). This might be due to local environmental factors or management practices. In other words, trees occurring in pasture areas have fewer competitors for light and/or water use, due to the low plant density (e.g. Ford et al., 2017; Castagneri et al., 2022). With fewer competitors, trees can grow more and exhibit a larger DBH and canopy. Another local environmental factor that could explain a larger DBH in pasture areas is soil productivity (Furley and Ratter, 1988; Haridasan, 2008; Viani et al., 2011). Furthermore, considering that the Cerrado is deficient in several nutrients (e.g. Lopes and Guilherme, 2016), some ranchers treat the soil with nutrients that can contribute to the growth of species in pastures.

On the other hand, isolated trees in pasture areas may experience low population recruitment due to limited seed dispersal efficiency (Radford et al., 2001) or the failure of seedlings growth, either due to microclimatic constraints or predation by cattle (Esquivel et al., 2008). Consequently, although the larger DBH observed in pasture areas indicates the persistence of mature individuals, these populations may exhibit a decline in diversity and population viability over time. Specifically for *D. alata*, the reduction of climatically suitable areas under future climate change scenarios, combined with the potential vulnerabilities of populations in pasture areas, could further decrease the population viability of this species in the Cerrado. Therefore, the adoption of management practices that promote population regeneration in pasture areas is essential for the conservation of forest species (Sano et al., 2004).

Niche models have been widely used in environmental research, with numerous studies employing them as a tool to understand species' biogeographic boundaries, thus being useful for mapping species richness, optimizing priority conservation areas, and other applications (Peterson et al., 2011). However, there are studies demonstrating that the environmental suitability of niche models can predict population attributes (density, fruit numbers – see for example Nabout et al., 2016; Weber et al., 2017), despite the effect size being low.

Although niche models were not good predictors for DBH of *D. alata*, it is important to consider alternative explanations. The lack of correlation may be related to local factors of the species, which could allow for differential growth depending on the specific conditions of each area, regardless of environmental suitability. Additionally, microhabitat differences, such as variations in factors like nutrient availability, moisture, or temperature, could have influenced plant growth on a smaller scale (e.g. Denney et al., 2020; Seaborn et al., 2021). The microenvironmental heterogeneity, which is not adequately captured by the suitability models, could explain the observed variation in DBH, even in areas with similar environmental characteristics. These local factors and differences in microhabitats may have played a more significant role than environmental suitability in determining tree size. Moreover, in the present study, the lack of a spatial structure DBH (dispersal-limited distribution) may help explain why environmental suitability was unable to predict DBH. Local landscape changes, such as the conversion of Cerrado into pasture, locally interfere with DBH, potentially disrupting the relationship with environmental suitability. Similarly, the expected central-peripheral pattern for Cerrado plants (e.g., higher genetic diversity in the center compared to the biome's edges) has been diminished due to landscape changes (Diniz-Filho et al., 2009; Soares et al., 2015).

Other potential applications of niche modeling include understanding the biogeographical limits of the species. Therefore, with climate changes, future scenarios indicate a reduction in the suitability of *D. alata*. Consequently, climate changes may not locally affect the DBH of existing plants; however, they are likely to reduce the occurrence of new individuals, affecting the population size (see more in Soares et al., 2015; Ribeiro et al., 2019). Indeed, research has shown that, in addition to affecting species' biogeographic boundaries, climate changes can reduce plant germination rates (Ferreira et al., 2022) and even initial germination attributes of *D. alata* (Ribeiro et al., 2019).

4. Conclusion

Therefore, land use was crucial in explaining the variation of DBH of *D. alata*. Moreover, despite the pasture areas showing higher DBH values, this may also indicate lower recruitment of new individuals in these areas. Furthermore, the niche model suggests a reduction in the potential distribution of *D. alata*. Therefore, the conservation of *D. alata* populations in the Cerrado should involve the reduction of greenhouse gas emissions, deforestation, as well as reforestation in climatically suitable areas. Furthermore, future restoration programs can use the findings of this study by not only considering the current and future climatic suitable areas for the occurrence of *D. alata*, but also by identifying pasture areas that present favorable climatic conditions for restoration. These programs should focus on restoring degraded pastures in areas where *D. alata* populations are likely to thrive, ensuring the long-term viability of these populations. In addition to habitat restoration, such efforts should also prioritize maintaining genetic diversity within these populations, as this is crucial for their resilience to climate change and other environmental pressures. By integrating both climate and land use factors, restoration strategies can contribute to the successful re-establishment of *D. alata* in the Cerrado, thereby promoting biodiversity conservation and enhancing ecosystem function.

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Ethical Statement

This study did not involve human participants, animals, or any activities requiring ethical approval. All data were collected following applicable legal and institutional guidelines.

CRediT authorship contribution statement

PINHEIRO, G.H.B.P: Conceptualization, Data curation, Methodology, Formal Analysis, Funding, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. PARREIRA, M.R.: acquisition, Investigation, Methodology, Writing – review & editing. FERREIRA, R.B.: acquisition, Investigation, Methodology, Writing – review & editing. SOARES, T.N.: Methodology, Writing – review & editing. NABOUT, J.C.: Conceptualization, Investigation, Data curation, Methodology, Writing –

original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03509.

Data Availability

Data will be made available on request.

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