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Territorial dynamics and productive potential of agro-extractive species in strengthening sociobioeconomy

Renan Augusto Miranda Matias (✉)
Embrapa Recursos Genéticos e Biotecnologia, Laboratório de Ecologia e Conservação, Projeto Bem Diverso, Brasília, DF, Brazil.
E-mail: renanmatias@hotmail.com

Anderson Cássio Sevilha
Embrapa Recursos Genéticos e Biotecnologia, Laboratório de Ecologia e Conservação, Brasília, DF, Brazil.
E-mail: anderson.sevilha@embrapa.br

Alba Valéria Rezende
Universidade de Brasília, Departamento de Engenharia Florestal, Campus Darcy Ribeiro, Brasília, DF, Brazil. E-mail: albavr@unb.br

Aldicir Scariot
Embrapa Recursos Genéticos e Biotecnologia, Laboratório de Ecologia e Conservação, Brasília, DF, Brazil.
E-mail: aldicir.scariot@embrapa.br

Eraldo Aparecido Trondoli Matricardi
Universidade de Brasília, Departamento de Engenharia Florestal, Campus Darcy Ribeiro, Brasília, DF, Brazil. E-mail: ematricardi@unb.br

Helga Correa Wiederhecker
WWF-Brasil, Brasília, DF, Brazil.
E-mail: helgacorrea@wwf.org.br

Levi Carina Terribile
Universidade Federal de Jataí, Ciências Biológicas, Laboratório de Macroecologia, Jataí, GO, Brazil.
E-mail: levicarina@gmail.com

Larissa de Assis Ferreira
Embrapa Recursos Genéticos e Biotecnologia, Laboratório de Ecologia e Conservação, Projeto Bem Diverso, Brasília, DF, Brazil.
E-mail: larissaferreira621@gmail.com

✉ Corresponding author

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Abstract – The objective of this work was to estimate the population density of five Brazilian Cerrado species and to evaluate their productive potential under two scenarios, one with vegetation conservation and the other with deforestation. The studied species were: *Annona crassiflora*, *Caryocar brasiliense*, *Eugenia dysenterica*, *Hancornia speciosa*, and *Tachigali subvelutina*. For this, nine species distribution models were used, each one encompassing 23 bioclimatic and geomorphological environmental variables. Population density was quantified and spatialized with exponential regression models using forest inventory data. The models indicated a moderate to strong proportional relationship between habitat suitability and population density, with a root mean square error ranging from 35.8 to 55.7%. Estimated productivity varied from 1,325 to 254,844 Mg per year, with *E. dysenterica* showing the highest productive potential. The modeling of species distribution allows for the estimation of population density and productive potential. Its accuracy depends on the used species, environment, and scale of data. Climate pressures and Cerrado degradation intensify the challenges faced by local communities, highlighting the urgency of conservation strategies, sustainable management, and climate adaptation to strengthen sociobioeconomy.

Index terms: bioeconomy, ecological niche modelling, habitat suitability, population density, productivity, species density modelling.

Dinâmicas territoriais e potencial produtivo de espécies de interesse agroextrativista no fortalecimento da sociobioeconomia

Resumo – O objetivo deste trabalho foi estimar a densidade populacional de cinco espécies do Cerrado brasileiro e avaliar seu potencial produtivo em dois cenários, um de conservação da vegetação e outro de desmatamento. As espécies estudadas foram: *Annona crassiflora*, *Caryocar brasiliense*, *Eugenia dysenterica*, *Hancornia speciosa* e *Tachigali subvelutina*. Para tanto, foram utilizados nove modelos de distribuição de espécies, cada um com 23 variáveis ambientais bioclimáticas e geomorfológicas. A densidade populacional foi quantificada e espacializada a partir de modelos exponenciais de regressão, tendo-se utilizado dados de inventário florestal. Os modelos indicaram moderada a forte relação de proporcionalidade entre adequabilidade ambiental e densidade populacional, com erro médio quadrático de 35,8 a 55,7%. A produtividade estimada variou de 1.325 a 254.844 Mg por ano, com *E. dysenterica* tendo apresentado o maior potencial produtivo. A modelagem de distribuição de espécies permite a estimação de densidade populacional e potencial produtivo. Sua precisão depende da espécie, do ambiente e da escala dos dados utilizados. As pressões climáticas e a degradação do Cerrado intensificam os desafios para comunidades locais, o que destaca a urgência de estratégias de conservação, manejo sustentável e adaptação climática para fortalecer a sociobioeconomia.

Termos para indexação: bioeconomia, modelagem de nicho ecológico, adequação de habitat, densidade populacional, produtividade, modelagem de densidade de espécies.

Introduction

The importance of non-timber forest products (NTFP) is increasingly recognized worldwide (Meinhold et al., 2022), as evidenced by the numerous contributions of these products to improve household income, generating revenue along the production chain while conserving natural resources, which leads to their high demand by a thriving market in this sector (Wahlén, 2017). Among the global population, approximately 44% uses NTFP (Shackleton & de Vos, 2022), whereas, in tropical regions, about three-quarters depend on these products for nutrition and primary healthcare (Talukdar et al., 2021).

In this scenario, the need for the conservation of NTFP is underscored, requiring a better understanding of the relationships between the abundance of these products and plant diversity, aiming to identify potential synergies between NTFP supply and ongoing biodiversity conservation efforts (Steur et al., 2021).

In the management of native species, the density of individuals per species is one of the most important parameters in planning the sustainable use of vegetation (Bruzinga et al., 2014). Since this density is generally highly variable across space and time, extensive density surveys are necessary to estimate population sizes accurately and efficiently (Jędrzejewski et al., 2018). Species distribution models (SDM) or ecological niche models (ENM) can serve as a foundation for inferring the density of individuals of target species. Specifically, SDM are built on robust statistical principles, take into account occurrence data, and use environmental variables with a high predictive power regarding species distribution.

The SDM used to spatialize species occurrence are widely adopted as tools for knowledge acquirement and the documentation of distributive aspects related to biodiversity (Macedo, 2019). In many cases, these models are of primary interest because they provide a strong predictive foundation for inferences about biodiversity and its spatial and temporal distribution (Peterson et al., 2011). Therefore, the use of SDM is essential for monitoring populations and supporting conservation outcomes, offering insights on where to focus research efforts through species distribution, biology, and ecology (Wauchope-Drumm et al., 2020). In these models, areas classified as suitable refer to potential zones for the occurrence of a given species.

In addition to the occurrence suitability indicated by the SDM, studies should relate the absolute suitability value at pixel level with the recorded density of individuals for the species. The environmental favorability for occurrence is associated with larger populations, as favorable local conditions increase birth and survival rates, although anthropogenic interference may alter this relationship (Morrison et al., 2006). However, studies that associate SDM (continuous suitability values) with the abundance of individuals are still lacking (Weber et al., 2017), despite the need of understanding the relationship between occurrence suitability in SDM and the density of individuals of species of economic interest to plan the latter's use and conservation.

In the context of promoting conservation through use, methods to estimate the productivity of NTFP are essential to generate forecasts of economic return from the sustainable exploitation of these resources, consequently contributing to the valuation of standing vegetation (Paludo et al., 2012). As they enable the spatial identification of species occurrence and assist in identifying areas that are more productive, density maps are fundamental in estimating the productive potential of NTFP in a given region. However, there is still a gap in information combining changes in the land cover, environmental policies, and modeling necessary to support economic decision in semiarid environments, such as the Brazilian Cerrado (Stan et al., 2015).

The Cerrado is one of the biomes in Brazil that stands out the most for its large number of species with non-timber potential, meaning that the sustainable use of its rich biodiversity is key for promoting the conservation of natural resources (Afonso & Ângelo, 2009). However, due to intense human activity, only 50% of the Cerrado's original area is covered by native vegetation as of 2019 (Vieira et al., 2022), resulting in a significant reduction in natural resources, especially in NTFP, which are critically important in the context of sociobioeconomy.

The objective of this work was to estimate the population density of five Brazilian Cerrado species and to evaluate their productive potential under two scenarios, one with vegetation conservation and the other with deforestation.

Materials and Methods

The study was conducted in the territory of Alto Rio Pardo (TARP), located in the far north of the state of Minas Gerais, Brazil. This region is characterized by the culture of the long-established inhabitants of the Cerrado, known as *geraizeiros*, and by the agro-extractivism activities practiced by traditional communities (Nogueira, 2017). Covering an area of 15,323 km^2, TARP comprises 15 municipalities, encompassing parts of the upper Pardo and Jequitinhonha river basins, covered by typical cerrado vegetation and areas of transition to the Caatinga biome (Carvalho et al., 2009; Ribeiro et al., 2025).

The climate of the region is diverse: Cwb, subtropical with dry winters and mild summers in the northern and northwestern areas, particularly on plateaus and higher elevations in the Serra Geral do Espinhaço, up to 1,700 m above sea level; As, tropical climate with dry summers in the south-center, in the Jequitinhonha valley depression and floodplains, at an average altitude of 700 m above sea level; and Cwa, humid subtropical with dry winters and hot summers in the plateau, at an average altitude of 1,000 m above sea level (Alvares et al., 2013). In the TARP, the average temperature is 24.2°C, and the annual mean precipitation is 795 mm (INMET, 2020).

The five following species were studied: *Annona crassiflora* Mart., *Caryocar brasiliense* Cambess., *Eugenia dysenterica* DC., *Hancornia speciosa* Gomes, and *Tachigali subvelutina* (Benth.) Oliveira-Filho. The majority were chosen due to their fruits and their importance for income generation, with the exception of *Tachigali subvelutina*, a timber traditionally used by local communities.

Nine SDM developed by Matias et al. (2024) were used to obtain the habitat suitability layers used in the present study. Each model took into account 23 environmental variables, including 19 bioclimatic and 4 geomorphological variables (altitude, slope, aspect, and minimum curvature of the terrain). Model fitting was performed using the following nine algorithms: artificial neural networks, classification tree analysis, flexible discriminant analysis, generalized additive models, generalized boosting model, generalized linear models, maximum entropy, multiple adaptive regression splines, and random forest, following the ensemble modeling approach proposed by Araujo & New (2007). The resulting habitat suitability layers are available on the Bem Diverso geoportal (Bem Diverso, 2017).

To obtain density data that reflect the gradient of habitat suitability, a forest inventory was carried out and suitability values were stratified into five equal class intervals, i.e., 0–19, 20–39, and so on (Supplementary Material, Table S1) (Sevilha et al., 2025). The allocation of plot numbers was weighted according to the area extent of each interval, based on the consensus model for each species (Supplementary Material, Figure S2) (Sevilha et al., 2025). The used sampling method consisted of fixed-area plots of 1,000 m² (20×50 m), randomly distributed within previously-stratified native vegetation areas. To define the boundaries for plot selection, a land use map available on the Bem Diverso geoportal was used (Bem Diverso, 2017).

A total of 64 plots were allocated in 14 municipalities, namely: Berizal, Curral de Dentro, Fruta de Leite, Indaiabira, Montezuma, Novorizonte, Rio Pardo de Minas, Rubelita, Salinas, Santa Cruz de Salinas, Santo Antônio do Retiro, São João do Paraíso, Taiobeiras, and Vargem Grande do Rio Pardo. In each plot, the number of living individuals of each target species was counted, with measurements taken for diameter, at 0.30 m above the ground when equal to or greater than 5.0 cm, and height, in meters.

Secondary data were incorporated from the forest inventory using the same methodological criteria and conducted by Mazer (2016) in Reserva de Desenvolvimento Sustentável Nascentes Geraizeira, the sustainable development reserve of Nascentes Geraizeiras. With these data, the total database for the present study consisted of 139 plots.

The central coordinate points of each plot were overlaid onto the habitat suitability layers to extract the values for each fitting algorithm and for the consensus model. The plots were grouped into 20 habitat suitability classes with a range of 5, from 0 to 100.

For each class, the mean suitability and mean density values of the included plots were calculated, also being used for density-model fitting.

Five species, four regression models widely used in forest science (Soares et al., 2004; Rocha, 2011; Thiersch et al., 2013; Martins et al., 2021), and ten fit algorithms were employed to estimate habitat suitability. The respective Curtis (Curtis, 1967), exponential (Martins et al., 2021), Hush (Husch, 1963), and Prodan (Scolforo, 1993) regression models were applied:

$$D + e^{\beta_0 + \beta_1 \times \frac{1}{Adq}} = \varepsilon$$

$$D = \beta_0 \times e^{\beta_1 \times Adq} + \varepsilon$$

$$D = \beta_0 \times Adq^{\beta_1} + \varepsilon$$

$$D = \frac{Adq^2}{\beta_0} + \beta_1 \times Adq + \beta_2 \times Adq^2 + \varepsilon$$

where D is individual density (individuals per hectare); Adq is the habitat suitability value obtained through the techniques of the ENM; β_i are the regression coefficients; and ε is the error associated with the model.

The regression model with the best performance in predicting density as a function of habitat suitability for each species was selected. For this, the three used criteria were: distribution of observed and estimated density values in relation to suitability (absolute error in density estimation); lowest root mean square error in percentage (RMSE%) according to Yadav et al. (2021); and highest correlation coefficient (RYY) as in Campos & Leite (2013). Density maps were obtained using both the Raster Calculator tool available in the ArcGIS Pro software (Esri Inc., Redlands, CA, USA) and the correspondent selected density model of each species. Model fit was tested using the F-test ($\alpha = 0.05$), and normality was checked with the Anderson-Darling test ($\alpha = 0.05$).

The individual density layers of the species used for fruit production were associated with the available secondary data of fruit yield. In addition, the layers of the timber species were associated to timber yield from native populations in the states of Minas Gerais and Goiás, as well as in the Nascentes Geraizeiras sustainable development reserve. Data fruit yield of *H. speciosa* were obtained from Lima et al. (2013) and Mazer (2016), of *C. brasiliense* from unpublished data of Oliveira & Scariot found in Mazer (2016), of *E. dysenterica* from Scariot & Ribeiro (2015) and Mazer (2016), and of *A. crassiflora* from unpublished data of Scariot and Mazer (2016). For *T. subvelutina*, timber volume data were compiled from Mazer (2016).

The density values per hectare of each pixel were multiplied by fruit productivity per individual and by the total area of each density class in order to plot the productivity maps.

Productive potential was estimated for the following two scenarios: scenario 1, considering the full range of habitat suitability for species occurrence, assuming a landscape conservation context with a native vegetation coverage similar to the region's original conditions; and scenario 2, considering remnants of native vegetation as a mask layer of land cover. In the latter scenario, classes without the occurrence of the studied species included eucalyptus plantation areas, former eucalyptus plantations without regenerated native vegetation, agropastoral areas, irrigated agricultural zones, exposed soil, water bodies, floodplains, urban areas, and forest formations (gallery forests and dry forests) without the five evaluated species.

Results and Discussion

In the literature, SDM is a widely applied technique for spatializing species occurrence across various contexts (Fois et al., 2018; Hao et al., 2019; Zurell et al., 2020; Sillero et al., 2021). In the present study, the obtained results showed the potential of using SDM to estimate the productivity of five species of economic interest in the TARP. It was observed that the density in the forest inventories increased along with habitat suitability values, especially with those above 80 (Supplementary Material, Figures S3, S4, S5, S6, and S7) (Sevilha et al., 2025), and that this relationship was, in general, consistent across all SDM.

In the four studied models, there was a proportional relationship between individual density and occurrence suitability, as indicated by RYY. In the selected models, the predictive power of proportionality (RYY > 0.9) was strong for the *A. crassiflora*, *C. brasiliense*, *E. dysenterica*, and *H. speciosa* fruit species, but moderate for the *T. subvelutina* timber species (RYY > 0.7), as shown in Figure 1. The RMSE% ranged from 35.8 to 55.7%, with the lowest value found for *C. Brasiliense*, and the highest for *T. subvelutina*. All models showed statistically significant fits ($p < 0.05$) and a normal distribution ($p < 0.05$).

The obtained results are an indicative that the use of habitat suitability values is a promising alternative, as it provides good precision in density estimations. Rullens et al. (2021) reported similar results when modeling the distribution and density of marine mollusks. In another study, Weber et al. (2017) concluded that areas with a high habitat suitability tend to support larger populations, since favorable local conditions increase birth probability and individual survival.

A high variability was observed in the relationship between species and algorithms, which was expected because biotic and abiotic factors influence the occurrence and abundance of species, and physical barriers act as filters for propagule dispersal (Espínola & Júlio Junior, 2007). These effects may be intensified due to anthropogenic environmental degradation, such as deforestation and fires (Feeley & Rehm, 2012). However, if species populations undergo rapid changes, real and significant correlations are not expected (Weber et al., 2017). In the literature, the

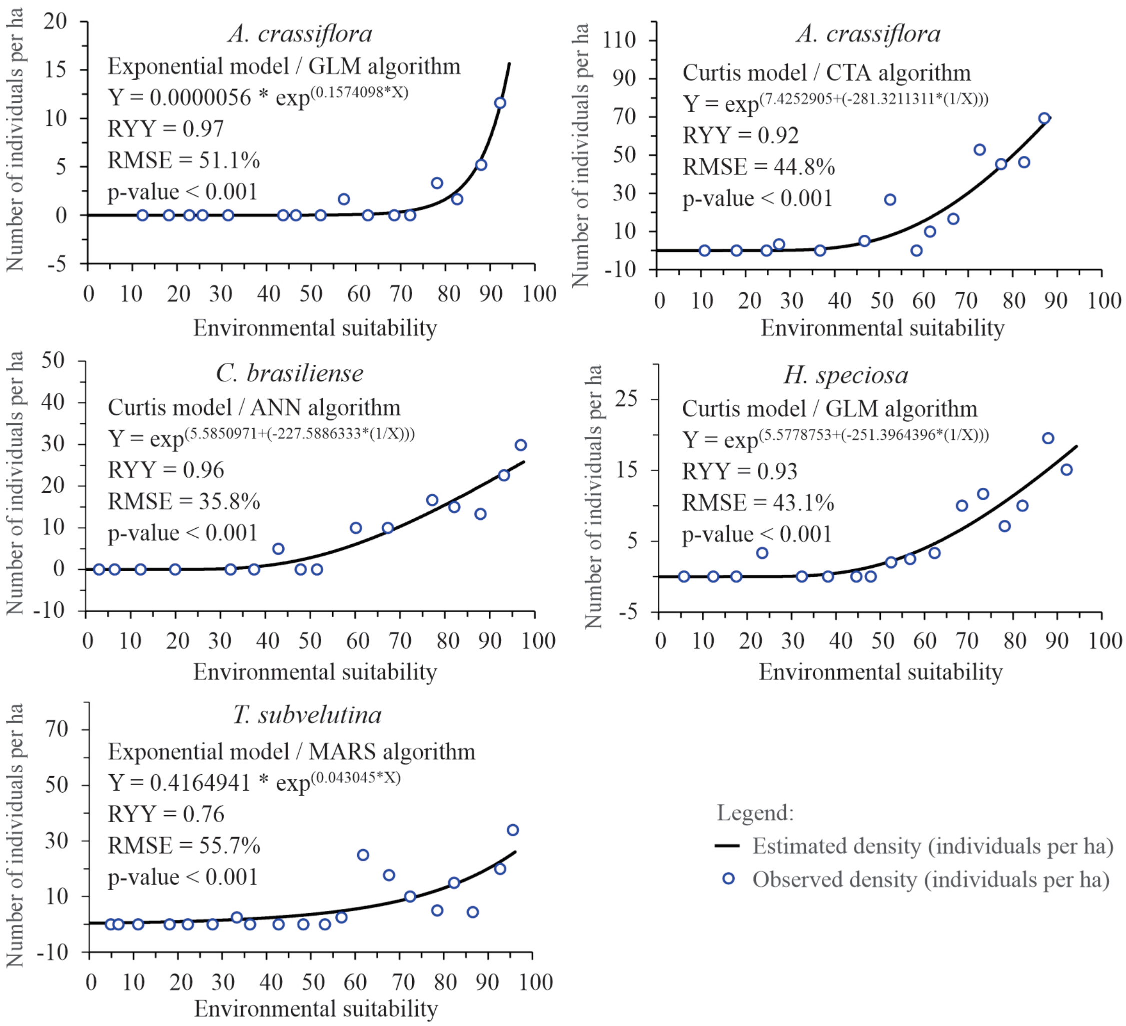

Figure 1. Observed and estimated population density as a function of habitat suitability, selected allometric models, used fit algorithm, regression equation, root mean square error, correlation coefficient, and F-test result for the model fit of five species (*Annona crassiflora*, *Caryocar brasiliense*, *Eugenia dysenterica*, *Hancornia speciosa*, and *Tachigali subvelutina*) of economic interest in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil. GLM, generalized linear models; CTA, classification tree analysis; ANN, artificial neural networks; MARS, multiple adaptive regression splines; RYY, correlation coefficient; and RMSE, root mean square error in percentage.

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proportional relationship between habitat suitability and population density has been shown to be affected by the cited factors and environment degradation, with a strong (Rullens et al., 2021) or weak (Jiménez-Valverde et al., 2009) explanatory strength. In the present study, the results allow the spatial extrapolation of the density of individual species in the landscape under consideration.

The northwestern region of the TARP presented the highest individual density values for all species in scenario 1 (Figure 2). *Eugenia dysenterica* exhibited the highest individual density values in the region, reaching up to 69 individuals per hectare in the northernmost part of the study area. *Caryocar brasiliense* covered the largest area of 361,142 ha within the highest density class, ranging from 21 to 25 individuals per hectare. *Hancornia speciosa* had the most balanced representation across density classes, with a maximum density value of 18 individuals per hectare. In contrast, *A. crassiflora* and *T. subvelutina* were spread over the smallest areas of 74,672 ha (11 to 15 individuals per hectare) and 44,926 ha (21 to 26 individuals per hectare), respectively, in the highest density classes. The area values for the individual density classes by species are presented in Table 1.

In the southern region of the territory, areas without individual occurrence were identified for all species.

In the southeast of the TARP, *A. crassiflora*, *C. brasiliense*, and *H. speciosa* were not recorded. This region is part of the upper Jequitinhonha river basin, corresponding to the geomorphological unit known as a "dissected depression" (Bem Diverso, 2017), i.e., a narrow strip of areas where density estimates were projected specifically.

The northeast of the territory is a transition area between the Cerrado and Caatinga biomes. There, the applied models predicted the absence of *A. crassiflora* and *T. subvelutina*.

The extreme western region, situated outside the TARP's boundaries, is a dissected depression influenced by the São Francisco River basin (Bem Diverso, 2017). In this location, no density estimates were projected for any species.

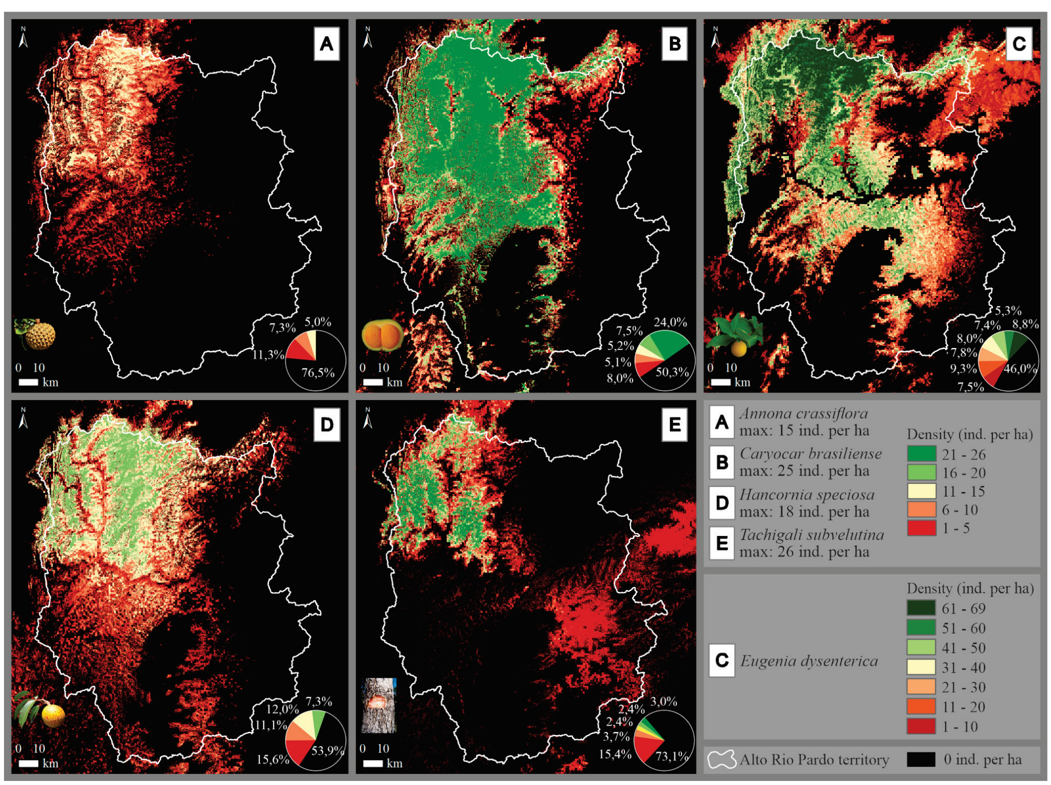

Figure 2. Individual density maps of five species (A to E) of economic interest, showing the distribution of each density class (%) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

In areas with rupestrian cerrado (*cerrado rupestre*), Mazer (2016) found 108.4 individuals of *T. subvelutina* per hectare. However, in the present study, the model underestimated densities in these areas, showing a greater accuracy in plateau (*chapada*) zones, where the species occurs at a lower density than in colluvial slope environments. On these slopes, the model for *T. subvelutina* exhibited a low predictive power and underestimated true density, a result similar to those found in studies involving other organisms (Rullens et al., 2021).

Projecting species occurrence and population density is essential for conservation science, nature management, and territorial planning (Rullens et al., 2021; Schwager & Berg, 2021). When habitat suitability values are integrated with geographic information, population density becomes even more useful, as it enables the identification of spatial variability within the same territory. This contributes to quantifying the productive potential of species in a given region. However, while species abundance is widely needed in ecological studies, such data are still scarce due to their absence in most ENM or SDM applications (Yu et al., 2020).

The productivity estimate based on extrapolated density indicated that the highest fruit-productivity values occurred in the northwestern region of the TARP. Considering the highest productive potential, the fruit species were ranked as follows: *E. dysenterica* (254,884.4 Mg), *C. brasiliense* (62,688.3 Mg), *A. crassiflora* (2,574.1 Mg), and *H. speciosa* (1,325.5 Mg). *Tachigali subvelutina* showed a timber productivity potential of 13,697.5 m^3.

When comparing scenarios 1 and 2, there was a reduction in the territory's productive potential, specifically of 58% for *E. dysenterica* (Figure 3), 58.3% for *A. crassiflora* (Figure 4), 58% for *C. brasiliense* (Figure 5), 55% for *H. speciosa* (Figure 6), and 55.9% for *T. subvelutina* (Figure 7).

Due to land cover change between scenarios 1 and 2, there was also an area reduction of 22% (179,123.1 ha) for *E. dysenterica*, 23.9% (84,872.4 ha) for *A. crassiflora*, 21.9% (163,673.9 ha) for *C. brasiliense*, 18.8% (130,254.4 ha) for *H. speciosa*, and 17.9% (72,439.0 ha) for *T. subvelutina*. These estimates correspond to plateau areas with a history of land cover conversion from native cerrado vegetation to eucalyptus plantations, whose cultivation was stopped in 32.3% (77,520 ha) of the total area by 2017 (Bem Diverso, 2017).

The findings of the present study showed that, particularly in the northwestern portion the TARP, the studied species presented a high productive potential even with the reduction in vegetation cover caused by deforestation since the 1970s. During this period, extensive plateau areas were cleared for eucalyptus silviculture (Souza & Sauer, 2020), which occupied approximately 240,000 ha (Bem Diverso, 2017). Therefore, the territory experienced a significant reduction in native vegetation cover, especially in former cerrado formations in the plateau, considered the primary habitat of the five studied species, which underwent resource extraction (Lima et al., 2012).

Table 1. Area of occurrence and two scales of individual density classes of five species (*Annona crassiflora*, *Caryocar brasiliense*, *Eugenia dysenterica*, *Hancornia speciosa*, and *Tachigali subvelutina*) of economic interest in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

Density class (individuals per ha)	Area		Density class (individuals per ha)	Area							
	E. dysenterica			*A. crassiflora*		*C. brasiliense*		*H. speciosa*		*T. subvelutina*	
	(ha)	%		ha	%	ha	%	ha	%	ha	%
0	692,310.8	46.0	0	1,150,585.7	76.4	756,934.6	50.3	811,491.9	53.9	1,100,611.8	73.1
1–10	112,097.1	7.4	1–5	169,304.9	11.2	120,518.5	8.0	235,240.4	15.6	231,491.6	15.4
11–20	140,055.8	9.3	6–10	110,527.4	7.3	76,687.5	5.1	167,204.9	11.1	56,295.7	3.7
21–30	117,185.1	7.8	11–15	74,671.8	5.0	77,557.9	5.2	180,919.4	12.0	35,711.0	2.4
31–40	120,827.8	8.0	16–20	-	-	112,249.4	7.5	110,233.3	7.3	36,035.7	2.4
41–50	111,555.3	7.4	21–25	-	-	361,142.1	24.0	-	-	44,943.9	3.0
51–60	79,361.5	5.3									
61–69	131,696.6	8.8									

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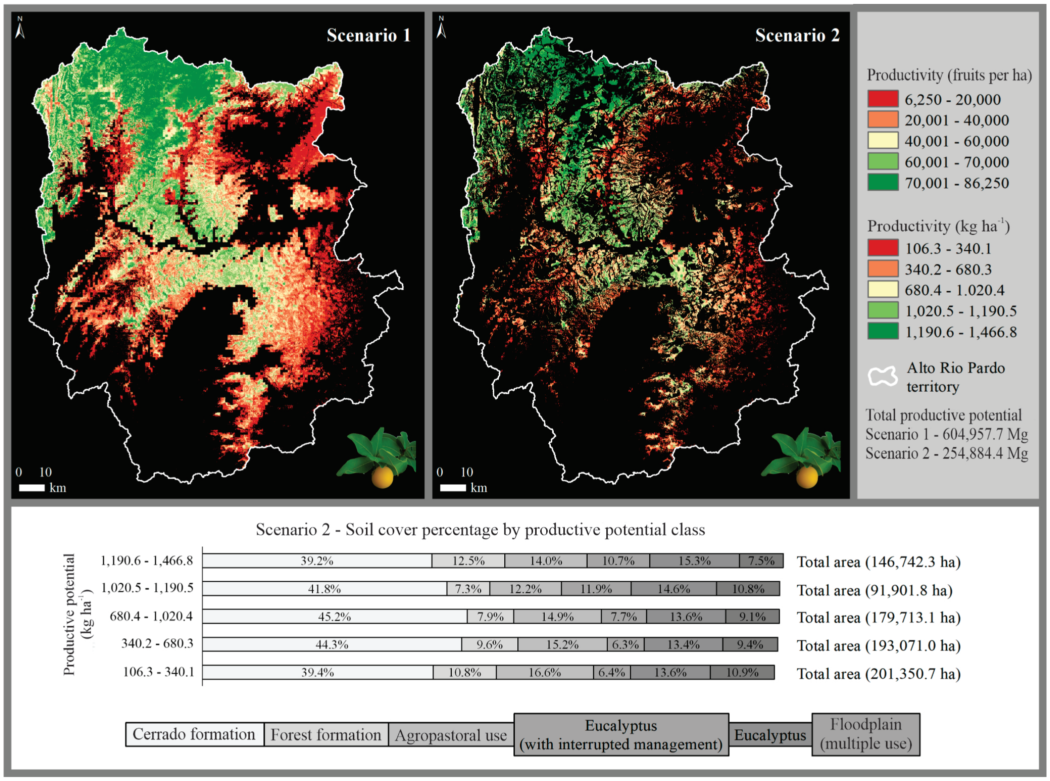

Figure 3. Productive potential of *Eugenia dysenterica* when considering original suitability (scenario 1) and areas under deforestation pressure (scenario 2) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

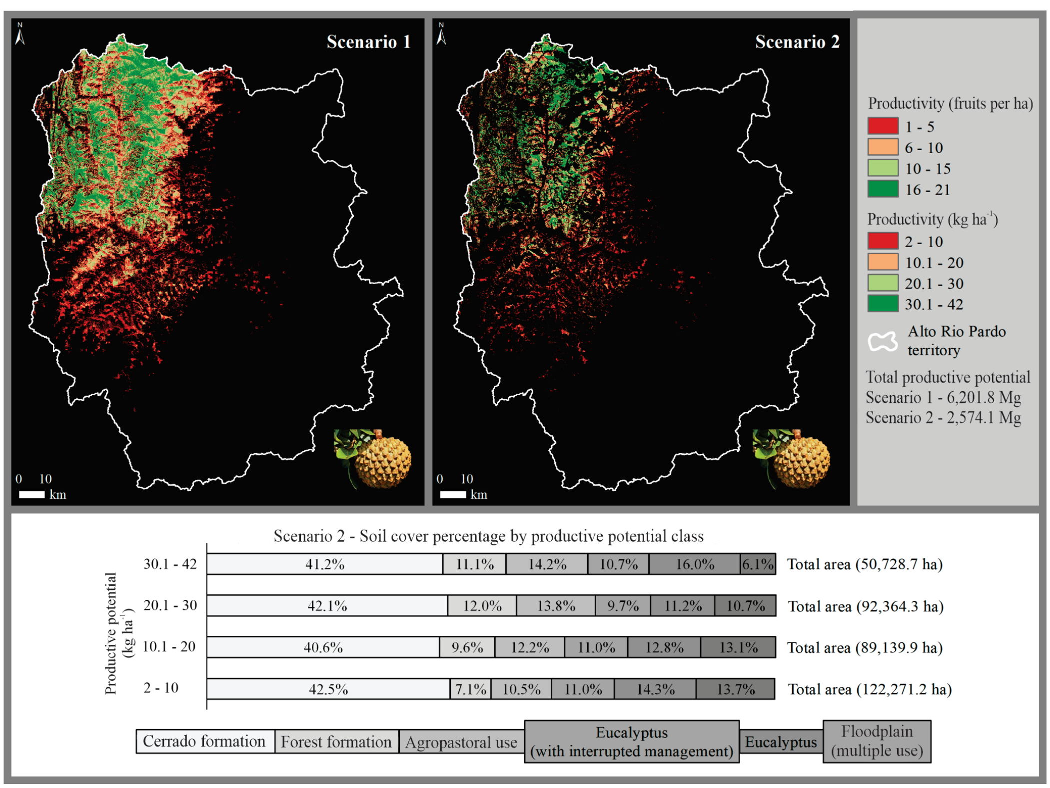

Figure 4. Productive potential of *Annona crassiflora* when considering original suitability (scenario 1) and areas under deforestation pressure (scenario 2) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

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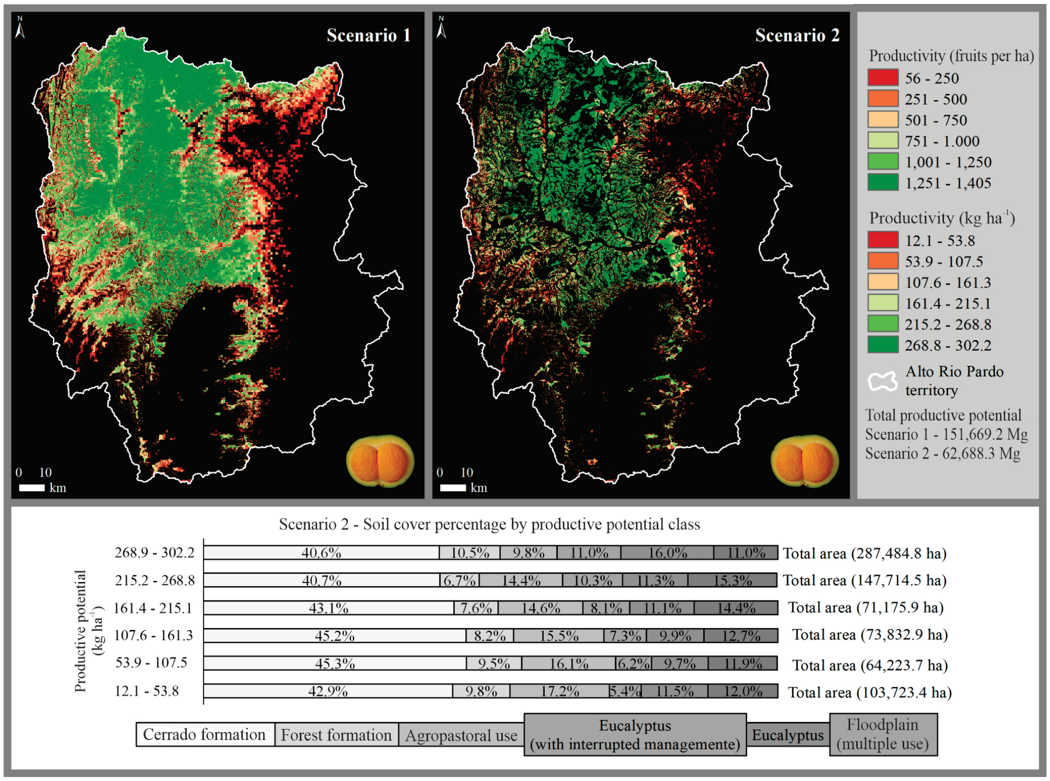

Figure 5. Productive potential of *Caryocar brasiliense* when considering original suitability (scenario 1) and areas under deforestation pressure (scenario 2) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

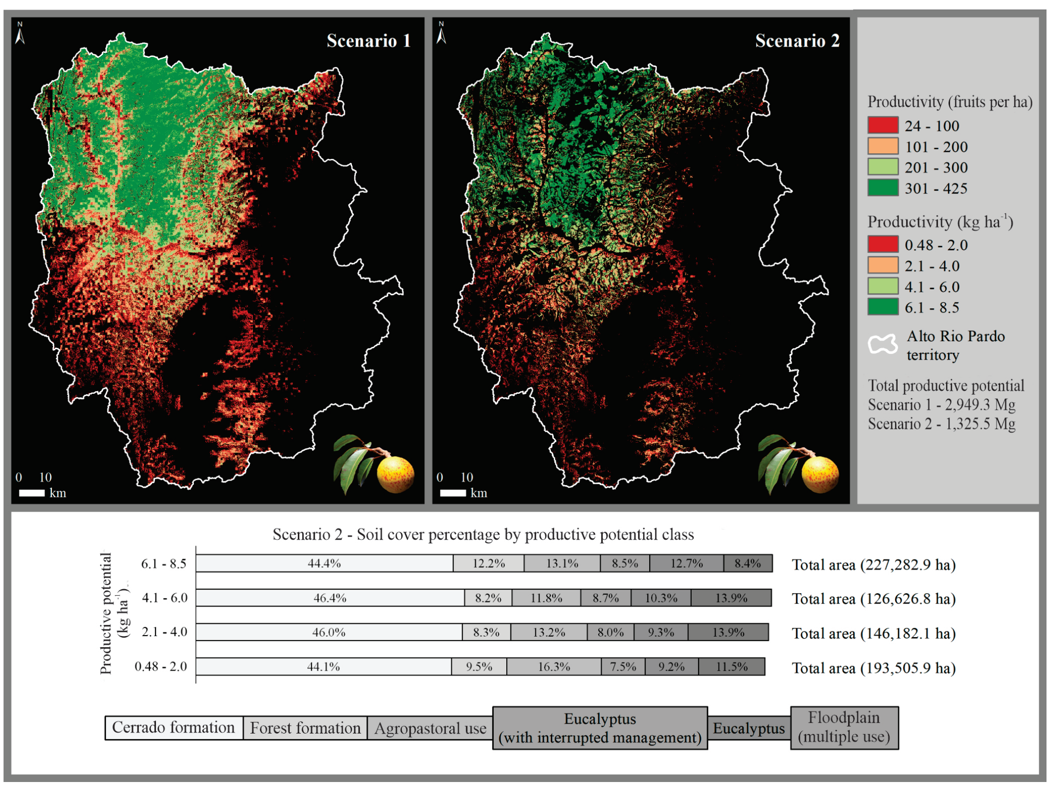

Figure 6. Productive potential of *Hancornia speciosa* when considering original suitability (scenario 1) and areas under deforestation pressure (scenario 2) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil

The reduction of natural cerrado formations is a concerning factor, considering the substantial loss of natural resources that are essential for extractivism activities and the associated decline in environmental goods and services. Carrara (2007) highlighted that the abandoned eucalyptus plantations became degraded areas, causing the springs located near floodplains to dry, which resulted in a severe hydrological imbalance. In this scenario, ecological restoration projects for Cerrado and sociobiodiversity management are essential to enable the full productive potential of native species.

These results show the need for strategies to strengthen sociobioeconomy in the studied territory. The focus should be on the development and consolidation of community-based enterprises, including cooperatives, community associations, and reference centers for the management, conservation, and restoration of agroecosystems. This will allow to operate in an integrated manner regarding sustainable extraction and the promotion of productive restoration, aligned with the cultural and organizational characteristics of local communities. These initiatives represent an important source of local income, biodiversity conservation, and community organization. The support of these enterprises involves technical advisory services, organizational planning, capacity-building initiatives, access to markets and credit, and implementation of sustainable production practices, consolidating an inclusive and resilient model of territorial development.

Although important, the results obtained in the present study are subject to some uncertainties. Those inherent to the density models are particularly due to the assumption of 23 environmental variables as representative of the species' niches. This means that not all ecological conditions or anthropogenic interferences were captured, which may have resulted either in areas with a high suitability, where the species was not observed, or in areas with a low suitability, where the species was present (Elith & Franklin, 2017). Both situations directly influence density estimates (Rullens et al., 2021).

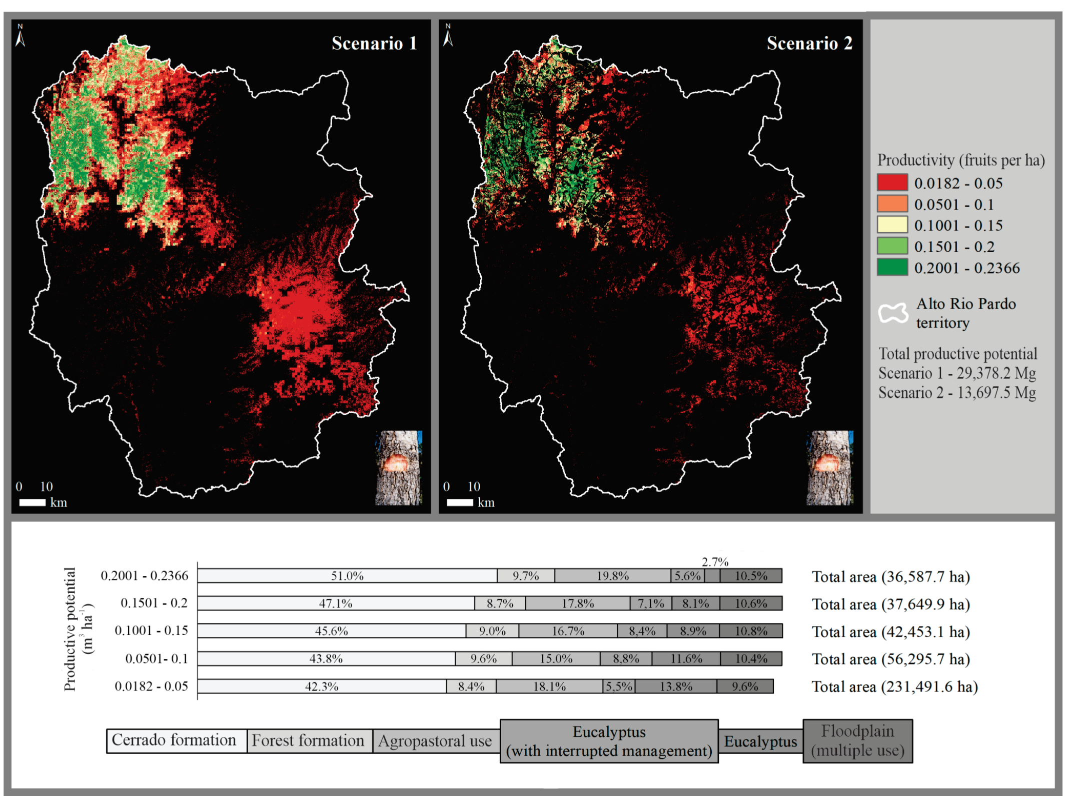

Figure 7. Productive potential of *Tachigali subvelutina* when considering original suitability (scenario 1) and areas under deforestation pressure (scenario 2) in the territory of Alto Rio Pardo, in the state of Minas Gerais, Brazil.

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Regarding the estimation of productive potential, the observed uncertainties are mainly related to the annual variability in fruit production (Ferreira et al., 2015; Lima, 2016; Bruzinga, 2017; Braga et al., 2021). Another reason is that anthropized areas with isolated productive individuals, such as wooded pastures, were not included in the study regardless of their density, which may have underestimated their actual potential.

Conclusions

1. The relationship between individual density and habitat suitability is strong for the four species used for fruit production (*Annona crassiflora*, *Caryocar brasiliense*, *Eugenia dysenterica*, and *Hancornia speciosa*) and moderate for the timber species (*Tachigali subvelutina*).
2. The selected regression models provide consistent estimates of individual density, allowing strategic planning at a regional scale.
3. The areas with the highest productive potential overlap mostly regions that have experienced the loss of cerrado vegetation.

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Author contributions

Renan Augusto Miranda Matias: conceptualization (equal), data curation (equal), formal analysis (equal), investigation (equal), methodology (equal), resources (equal), software (equal), supervision (equal), validation (equal), writing - original draft (equal), writing - review & editing (equal); **Anderson Cássio Sevilha**: conceptualization (equal), data curation (supporting), formal analysis (supporting), funding acquisition (equal), investigation (equal), methodology (equal), resources (equal), software (supporting), supervision (equal), validation (supporting), writing - original draft (equal), writing - review & editing (equal); **Alba Valéria Rezende**: conceptualization (equal), formal analysis (supporting), investigation (equal), methodology (supporting), supervision (equal), writing - original draft (supporting), writing - review & editing (equal); **Aldicir Scariot**: conceptualization (supporting), resources (supporting), writing - review & editing (equal); **Eraldo Aparecido Trondoli Matricardi**: conceptualization (supporting), data curation (supporting), formal analysis (supporting), methodology (supporting), software (supporting), writing - review & editing (equal); **Helga Correa Wiederhecker**: conceptualization (supporting), data curation (supporting), investigation (supporting), methodology (supporting), writing - original draft (equal), writing - review & editing (equal); **Levi Carina Terribile**: conceptualization (supporting), formal analysis (supporting), investigation (equal), methodology (supporting), writing - review & editing (equal); **Larissa de Assis Ferreira**: conceptualization (supporting), data curation (supporting), visualization (supporting), writing - original draft (supporting), writing - review & editing (equal) .

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No generative artificial intelligence (AI) was used in this study.

Conflict of interest statement

The authors declare no conflicts of interest.

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