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Recognizing Brazilian Cerrado Enclaves by Modeling Geoenvironmental Parameters

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Abstract

This work focused on the prediction modeling of Cerrado occurrences in the Atlantic Rainforest predominance in the São Paulo Metropolitan Region (SPMR), the fourth largest urban area, in the city of Guarulhos, southeastern Brazil. The methodology was based on the selection of records of occurrence of Cerrado in georeferenced databases, thematic maps of geoenvironmental layers, and modeling of the distribution of species through the MaxEnt tool. Besides that, field research confirmed the presence or not of the species in the areas with a high probability of occurrence of Cerrado (≥0.7). As a result, the model observed a great capacity for the prediction of the occurrence of Cerrado in Ecotonal and anthropic regions (AUC = 0.82), revealing important hotspots such as relics from the past or Cerrado enclaves of high biodiversity. The work also points priority areas for the conservation and preservation of this increasingly endangered biome.

Keywords

Cerrado Enclave, Hotspots Remaining, Geoenvironmental Parameters, Prediction of Adequacy, MaxEnt

1. Introduction

The presence of Cerrado in other biomes is pointed out as a consequence of climatic changes that alternates wet and dry periods, which provided the fragmentation of extensive forest areas [1] [2] [3]. The transition zone between the Brazilian biodiversity hotspots, the Cerrado and the Atlantic Rainforest [4], is char-

acterized in the State of Sao Paulo by the presence of a small enclave of Cerrado-like vegetation sharing species between those two ecosystems [5].

According to [6], these areas lead in terms of biodiversity and endemism amongst seed plants coinciding with the hotspots highlighted by [4] [7] [8]. These micro vegetation refuges have been interpreted by [9] as remnants of a former contiguous Cerrado distribution in southern and southeastern Brazil, possibly associated with past climatic changes. Aside from this debate, these small nuclei of Cerrado plant species are of considerable importance for conservation. This is especially important in the Sao Paulo Metropolitan Region (SPMR), the fourth largest urban area in the world, containing one last Cerrado refuge at the Juquery State Park, a known Cerrado enclave within this large urban area, a total of 273 Cerrado species in opposition to 122 Atlantic Rainforest taxa have been reported by [5]. The historical dramatic habitat loss in Sao Paulo alone is exemplified by a total of 3,500,000 hectares in the 19th Century, accounting for 14% of the total state area (**Figure 1**), in opposition to only 205,000 hectares in 2001, equivalent to 0.83% of that area [5]. The Cerrado has lost 88 Mha (46%) of its native vegetation cover, and as little as 19.8% remains undisturbed [10].

Considering the urgency in protecting these endangered small vegetation islands, we carried out a methodology for the recognition of Cerrado enclaves by modeling geoenvironmental parameters. Our analysis took into account the identification and quantification of geoenvironmental parameters associated with these Cerrado islands in a suburban area of the SPMR, the second-largest metropolitan in Latin America, with ca. 20 million inhabitants. Considering the urgency in protecting these endangered small vegetation islands, we carried out a methodology for the recognition of Cerrado enclaves by modeling geoenvironmental parameters. Our analysis identified and quantified, for the first time, the relics of the past inside high-density urban areas, pointing priority areas for the conservation and preservation of this endangered biome.

2. Material and Methods

The methodology was divided into five stages (**Figure 2**): 1) selection of records of Cerrado species in the SPMR in geo-referenced databases; 2) preparation of
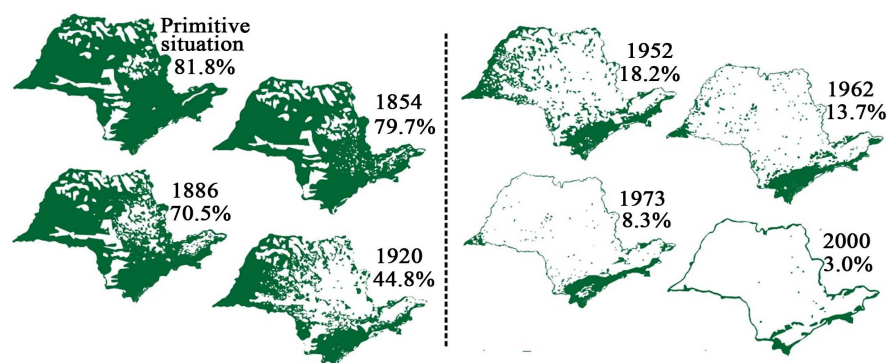

Figure 1. Historical changes on the natural vegetation cover of the State of Sao Paulo, adapted from [11].
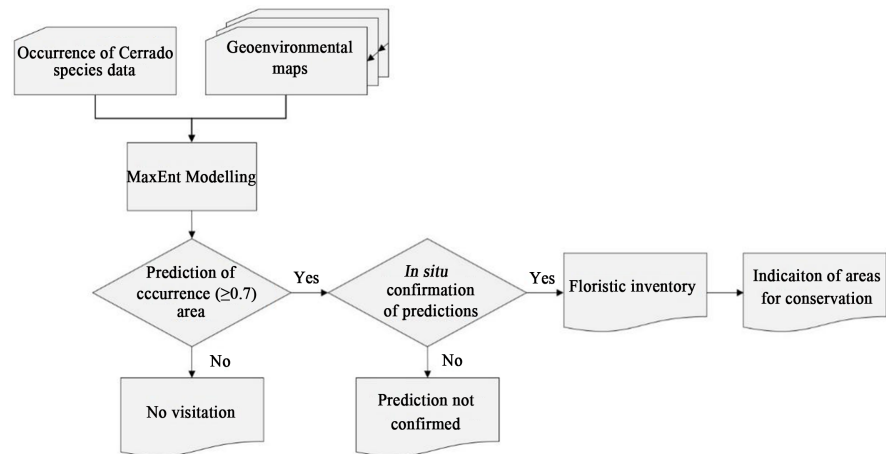
Figure 2. Flowchart of the methodology used.

thematic maps with geoenvironmental layers; 3) Prediction of the geographic distribution of Cerrado species within the SPMR by means of MaxEnt modeling; 4) Field investigation to confirm the presence or not of areas with a high probability of Cerrado species occurrence (≥0.7); 5) Indication of priority areas for Cerrado conservation.

2.1. Study Area

The SPMR is made up of 39 municipalities with approximately 20 million inhabitants [12] containing large industrial, commercial and financial complexes, which accounts for 18% of the country and more than half of the State of São Paulo GNP. The study area, selected for this analysis, is located at the Guarulhos Municipality (23°16'23''S - 23°30'33''S, 46°20'06''W - 46°34'39''W) [13].

2.2. Occurrence of Cerrado Species and Geoenvironmental Variables

The occurrence data of Cerrado species in the SPMR were obtained from: 1) georeferenced database of the Distributed Information System for Scientific Collections [14], and; 2) publications. This analysis recognized the occurrence of 381 Cerrado species that did not coincide with current urbanized areas, exposed soil and water bodies. Only those that occurred in vegetated areas according to the land cover map of the Environmental Planning Coordination [15] were selected, as shown in **Figure 3**.

The geoenvironmental parameters used for the modeling were: 1) Pedology, Soil map of the State of São Paulo, Campinas Agronomic Institute, IAC. Scale 1:500,000, in the shapefile format (one layer) [16]; 2) Normalized Difference Vegetation Index (NDVI) images derived from product MOD13Q1 (16-day image composition) of MODIS sensor aboard Terra and Aqua satellites, with a spatial resolution of 250 m, totaling 17 images for the year 2010 acquired and processed by Google Earth Engine [17]; 3) Topographic data-elevation (one layer); relief (one layer); land surface aspect (one layer) extracted from the orbital image
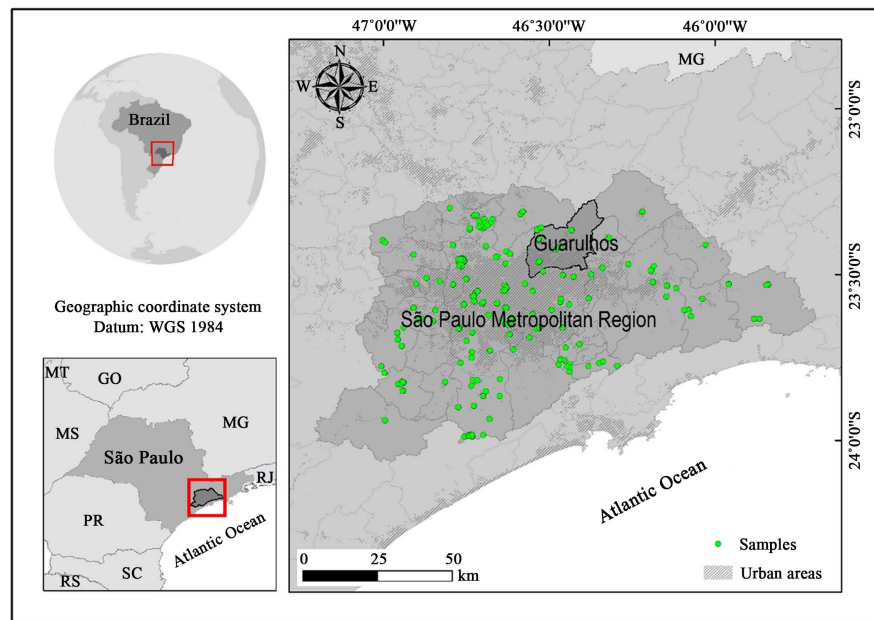
Figure 3. Geographic distribution of Cerrado species in the Sao Paulo metropolitan region obtained from the distributed information system for scientific collections database, [14], and publications.

of the Shuttle Radar Topography Mission (SRTM) provided by the Brazilian Agricultural Research Company—EMBRAPA (Miranda, 2005); 4) Geomorphological and geological data for the state of São Paulo, scale 1: 750,000, were derived from the GeoSGB vector files of the Geological Survey of Brazil (GeoSGB, 2019); 5) Climate data—Worldclim version 2.0 Global Climate Surface (Hijmans et al., 2005) with approximately 1 km of spatial resolution (12 layers), monthly average temperatures (12 layers), monthly minimum temperatures (12 layers), average monthly thermal amplitude (12 layers). A summary of all variables analyzed is presented in Table 1.

The modeling method using the Maximum Entropy algorithm (MaxEnt) version 3.3 k. MaxEnt, widely used for the prediction of areas of occurrence of animal and plant species [21] [22] [23] [24], generates habitat suitability models based on known geographical distributions and their geoenvironmental layers. These data files were loaded into the model with "*.asc," with a 100 m × 100 m grid using ArcGIS software (10.2). The projection system used was the UTM, Datum WGS1984, and 23 South Zone.

The importance of each variable was determined using the jack-knife procedure and the percentage of the contribution in the final model [25]. The resulting map of the modeling presents the prediction as logistic values between 0 and 1, representing habitat suitability in the pixel in a way that values closer to 1 indicate greater suitability or higher probability of the presence of the species in that particular pixel [26].

The model evaluation was performed according to the Receiver Operational Characteristic (ROC) curve that ranged from 0 to 1. The closer to 1 means, the

Table 1. Summary of geoenvironmental parameters used in vegetation modeling.

Group	Variable	Reference	Unit
Pedology	Soil type	[16]	Class name
Spectral	NDVI	[17]	Non-dimensional
	Elevation		m
Topography	Slope	[18]	Degree (˚)
	Aspect		Degree (˚)
Geomorfology	Geom		Class name
	Dist. of geological structures		km
	Lithology	[19]	Class name
Geology	Max. Age of rocks		
	Average age of rocks		Millions of years (Ma)
	Min. age of rocks		
	precipitation		mm
	Max.temp.		˚C
Climate	Avg. temp.	[20]	˚C
	Min. temp.		˚C
	Range temp.		˚C

better the model. ROC of 0.5 indicates that the discrimination of the model is no better than a random model [27]. These results were compared using the respective Area Under the Curve (AUC) of the ROC. Models with ROC values > 0.9 are considered highly accurate, values between 0.7 and 0.9 are useful, and those smaller than 0.7 are less accurate [22] [23] [28]. The modeling result was visualized and analyzed through a Geographic Information System (GIS), ArcGIS 10.2 software from ESRI.

2.3. Occurrence of Cerrado Species—*in Situ* Validation

Field expeditions were carried out to confirm or not Cerrado species occurrences predicted by the model (≥0.7) by collecting specimens of flowers and/or fruits were dehydrated, according to [29] and preserved according to usual botanical procedures [30]. The dried sampled specimens were incorporated into the Federal University of Rio Grande do Norte Herbarium (UFRN, continuously updated). The identification was made through the consultation of the specialized literature [31] [32], of specialists, and physical and virtual herbariums [14] [33].

3. Results

3.1. Historical Aspects of the SPMR Occupation

Before the extensive occupation, the SPMR was covered by dense Atlantic Rainforest composed of medium and towering trees, some up to 40 meters in height, forming a continuous canopy occupying about 92% of its entire territorial extension. The Atlantic Rainforest is mainly distributed on the eastern edge of the Brazilian shield, an area with complex topography over short geographical dis-

tances shaped by tectonic activity during the Tertiary and by sea-level changes during the Quaternary [34] [35]. This domain encompasses part of Argentina, and fifteen Brazilian states, such as Alagoas, Bahia, Ceará, Espírito Santo, Goiás, Minas Gerais, Paraíba, Paraná, Pernambuco, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, Santa Catarina, São Paulo and Sergipe [36]. It is characterized by strong seasonality, sharp environmental gradients (stemming from the topography), and orographic driven rainfall, as a result of easterly winds from the tropical Atlantic Ocean [36]. Due to these complex factors, the Atlantic Rainforest constitutes a diverse landscape that includes open, mixed, and closed evergreen, semi-deciduous, and deciduous forests [36]. The remaining areas were covered with savanna vegetation (Cerrado), known to possess various physiognomic types such as Forest-like Cerrado ("Cerradão"), Open and Closed Cerrado fields ("Campo Limpo" "Campo Sujo," respectively) containing fewer dispersed trees and shrubs on a herbaceous open landscape. The total area of Cerrado prior to deforestation was equivalent to 8% of SPMR [5] [37] [38] (Figure 4(a)). These savanna physiognomies with *Eringium paniculatum* (Fam. Apiaceae), an indicator species, were historically recognized for the first time in the Greater São Paulo region by [39] between the 19th and 20th centuries (Figure 4(b)). The historical inventory carried out by this author also revealed the presence of floating aquatic macrophytes, typical of the Pantanal and Cerrado, found in hot regions of standing water and marshes, as well as in running waters, in the Lapa region of the SPMR [40] such as *Pontederia cordata* (Figure 4(c)) in the region of Nossa Senhora do Ó, also found in Caatinga (*stricto sensu*), Campo de Várzea, Campo Limpo, Cerrado (*sensu lato*), Ciliary Forest or Gallery, Restinga and Aquatic Vegetation (Figure 4(d)), *Utricularia globulariaefolia* in the Butantã region, typical of the Cerrado wetlands, usually found in lowland areas of valley bottoms, associated with springs or closed depressions accumulating water during the rainy season [41] (Figure 4(e)).

With the expansion of the urban occupation, two fronts of deforestation were revealed: one referring to the urban area and the other to the agricultural areas and principal road axes developed from the 1920s, and more recently, the São Paulo-Campinas axis, connected by the Anhanguera (SP-330) and Bandeirantes (SP-348) highways. From 1952 to the present day, the urban growth of the SPMR was characterized by a disordered expansion and by the radical elimination of original vegetation cover [42].

Based on the land cover map of the State of São Paulo [15], we estimate that as a result of the urbanization process and vegetation suppression in the SPMR during the last decades, out of its original area of 793,383 hectares (Figure 5(a)) of the SPMR, 70.3% (557,830 ha) of this territory was lost to urbanization. Of the remaining 235,553 hectares, 53.1% (421,593 ha) refers to arboreal and 17.2% to shrub/herbaceous vegetation (136,237 ha) (Figure 5(b)). According to [5], only 0.1% of the total vegetation of the SPMR holds Cerrado, located mainly in the Juquery State Park in the municipality of Franco da Rocha, and in a few hotspots remaining in the municipality of Guarulhos, at its northeastern section.
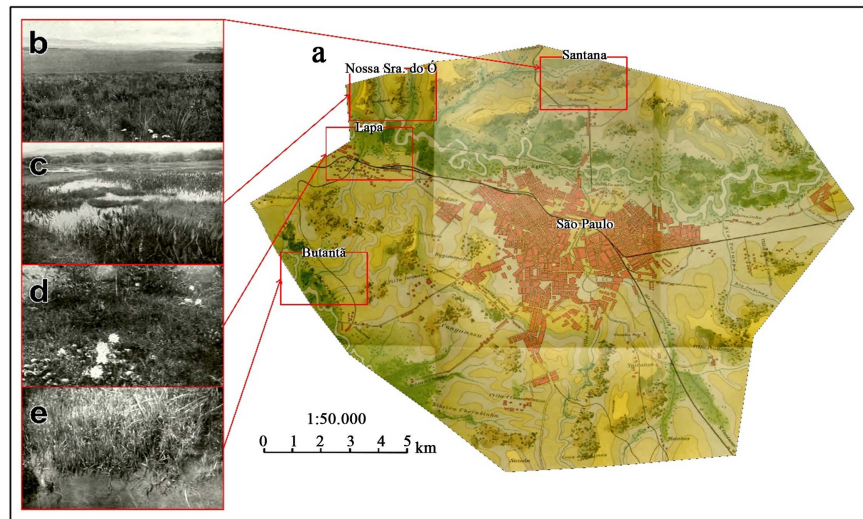
Figure 4. (a) Map of the great São Paulo of the late 19th century and early 20th century (Adapted from [39]); (b) Open and closed grasslands ("campo limpo" and "campo sujo"), with shrub-herbaceous species including *Erigium paniculatum* in the Santana region; (c) Floating aquatic macrophytes typical of the Pantanal and Cerrado found in the Lapa region; (d) *Pontederia cordata* in the region of Nossa Senhora do Ó, also found in Caatinga (*stricto sensu*), Fluvial valley savannas, open and closed grasslands, gallery forest, and aquatic vegetation; (e) *Utricularia globulariaefolia* in the Butantã region, typical of the Cerrado wetlands, found in valley bottoms at the SPMR.
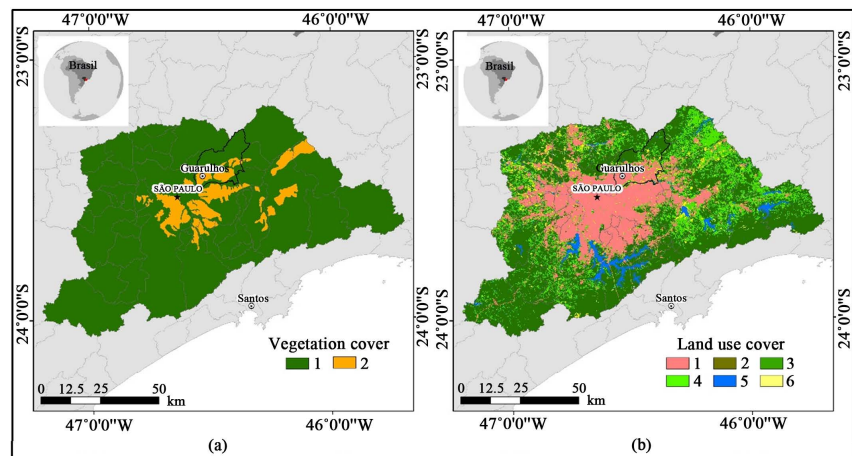

Figure 5. (a) Map of the original vegetation cover of the SPRM: 1) Dense Ombrophilous Forest; 2) Savannah (Modified from [37]); (b) Map of land cover: 1) Urban area; 2) Wet area; 3) Tree Veg; 4) Shrub/herbaceous Veg; 5) Water; 6) Exposed soil, derived from the Thematic Mapping of the Earth of the State of São Paulo of the Environmental Planning Coordination [15], based on the images of the Landsat TM 5 satellite of the year 2010, in the 1:100,000 scale.

3.2. Performance of the Model and Distribution of the Predicted Areas of Cerrado

In general, the MaxEnt model for the Cerrado vegetation of the SPMR revealed an AUC equal to 0.82, thus indicating significant results close to the highest accuracy [23] [24] [27] [28]. The highest percentage contribution to the model,

with around 76%, was attained, especially by the elevation, thermal amplitude, and average temperature layers, with approximately 14% each. The other last nine variables contributed only to a total of 24% (Table 2).

According to this modeling, it is estimated that for all the SPMR, there is approximately 41,183 ha of suitable areas for the occurrence of Cerrado divided among 39 municipalities: São Paulo (23,706 ha), Santana do Parnaíba (3718 ha) and Guarulhos (3400 ha) with a total of 30,824 ha and the remaining 10,358 ha, divided among the other 36 municipalities (Figure 6(b)). It is important to note that currently, 42% of the predicted areas occupied by Cerrado are in urban coverage. According to [43], high ROC values for a given parameter or variable indicate greater relevance in the participation of this variable for the prediction of the model. Thus, in the prediction of Cerrado occurrence within the SPMR, the areas with the greatest suitability were marked ranging from orange to red (≥0.7) primarily in the center-north portion of the SPMR and associated mainly to geomorphological domains of dissected terraces, fluvial or fluvial-lacustrine
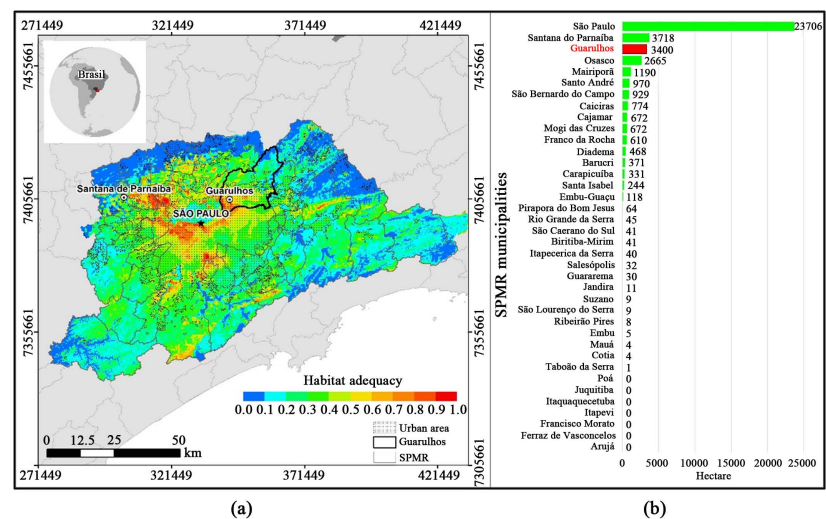

Figure 6. Geographical distribution of the habitat adequacy of Cerrado (a) and respective areas in the SPMR (b).

Table 2. Variables selected for modeling of Cerrado vegetation in the SPMR and their respective percentage contributions.

N°	Variable	Contribution %	N°	Variable	Contribution %
1	Elevation	14.2	9	Dist. of geological structures	3.8
2	Thermal range	13.8	10	NDVI	3.7
3	Thermal average	13.6	11	Min. age of rocks	1.9
4	Lithology	12.6	12	Slope	1.8
5	Precipitation	11.3	13	Geomorphology	1.4
6	Soil characteristics	10.3	14	Max. age of rocks	0.3
7	Max. temperature	7.3			
8	Min. temperature	3.9	15	Median age of rocks	0.1

plains and mountainous areas (**Figure 6(a)**) varying from 700 m to 1400 m in elevation. In these latter areas, argisols predominate over igneous and metamorphic rocks of pre-Cambrian ages with approximately 600 million years. Cerrado adequability occurs to a lesser extent, in broad and smooth hills, near river plains such as the Tietê River, on the border between the municipalities of São Paulo and Guarulhos.

In terms of climatic aspects, the most favorable bands for the occurrence of Cerrado appeared in the intervals of 16˚C - 17˚C for thermal amplitude; 17˚C - 18.5˚C for average temperatures, and 21.5˚C - 23.5˚C for maximum temperatures, with precipitation close to 1400 mm per year. These results are supported by [44], who pointed out that the climate of the phytogeographic domain of the Cerrado has an average annual temperature ranging from 18˚C to 28˚C, with rainfall from 800 to 2000 mm, with a well-defined dry season in the winter (June-September).

Most of the areas indicated with high Cerrado habitat adequability have land cover already lost to urban growth. Also, it is an important region located among two extent areas of forest preservation, notably the world's largest urban rainforest preserve, the Cantareira State Park, and the Tietê Ecological Park, the world's largest linear park.

These two conservation units have the highest suitability for the Cerrado occurrence ($\geq$0.7) is marked in green, and appear distributed in the northern, central-western, and southwest regions of this municipality (**Figure 7**). In its northern sector, areas with 2 to 29 hectares occur in the neighborhoods of Cabuçu (nº 9) and Cabuçu de Cima (n˚ 10, Cantareira State Park), described by [13] as areas of difficult access under the domain of steep hills and hills (>30%). With altitudes ranging from 900 to 1200 m, it's supported by a geological substrate highlighted by pre-Cambrian terrain represented by cambisols and neosols (**Figure 7(b)** and **Figure 7(c)**). In **Figure 7(d)**, the predicted area within the Sao Paulo International Airport neighborhood appears on a flat relief overlying sedimentary deposits of the Baquirivu-Guaçu River plain [45]. These, being in a military area, are relatively protected.
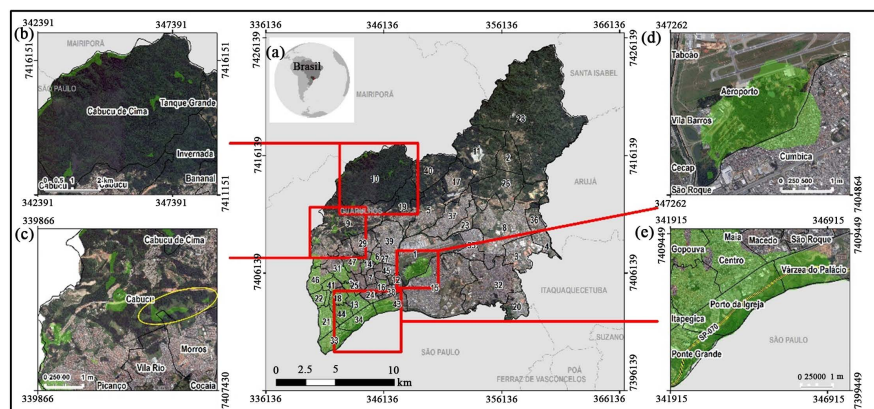

Figure 7. Prediction of the geographical distribution of habitat suitability for Cerrado species in Guarulhos.

In **Figure 7(e)**, the areas predicted in the neighborhoods of Ponte Grande, Porto da Igreja, and Várzea do Palácio, which are associated with alluvial floodplain soils in the Tietê river basin, predominantly glei soils [13] [45]. It is important to emphasize that in this region, the predicted areas are located south of the Ayrton Senna Highway (SP-070, the yellow line in **Figure 7(e)**), inside the Conservation Unit of the Tietê Ecological Park. Except for the areas north of this highway, which, because they are outside the protected area, are at risk of deforestation and occupation.

The areas marked in green predicted for the other neighborhoods of Guarulhos (n˚6, 13, 14, 15, 16, 18, 21, 22, 25, 31, 41, 44, 46, 47, in **Figure 7(a)**), are currently covered by residential, commercial and industrial buildings.

3.3. Floristic Composition of Cerrado Species in Guarulhos-SP

In situ collections carried out in the areas predicted by the MaxEnt model, pointed to an area of 22.5 ha in the Pelado Peak (Pico Pelado) region (yellow circle in **Figure 7(c)**), the presence of some indicator species of Cerrado areas. These include: 1) *Dalbergia miscolobium* Benth. (F. Fabaceae), which is a typical tree of various Cerrado categories (**Figure 8(a)**) [31] [33] [46]; 2) *Byrsonima intermedia* A. Juss. and *Heteropterys umbellata* A. Juss. (F. Malpighiaceae, **Figure 8(b)**, **Figure 8(c)**, respectively), that although they also occur in the Atlantic Forest, are most commonly found in Cerrado areas and rocky outcrops; iii) *Psidium cattleianum* Sabine (F. Myrtaceae; **Figure 8(d)**).

Species of open grassland (Campo Limpo), such as *Calea triantha* (Vell.) Pruski (**Figure 8(e)**), *Moquinastrum polymorphum* (Less.) G. Sancho (**Figure 8(f)**) and *Raulinoreitzia crenulata* (Spreng.) R. M. King and H.Rob. (**Figure 8(g)**)

Figure 8. Cerrado species found in the Pelado Peak, São Paulo Air Base, and Tietê Ecological Park, Guarulhos-SP. (a) *D. miscolobium*; (b) *B. intermedia* A. Juss; (c) *H. umbellata* A. Juss; (d) *P. cattleianum* Sabine; (e) *C. triantha* (Vell.) Pruski; (f) *M. polymorphum* (Less.) G. Sancho; (g) *R. crenulata* (Spreng.) R. M. King and H. Rob; (h) *L. pacaria* A. St.-Hil; (i) *H. ochraceus* (Cham.) Mattos; (j) *H. ochraceus* (Cham.) (l) *G. ulmifolia* Lam; (m) *G. ulmifolia* Lam; (n) *L. grandiflora* Mart (o) *L. grandiflora* Mart (p) *C. crenatifolius* Ruiz & Pav; (q) *I. sessilis* (Vell.) Mart; (r) *C. armani* (Balb.) Sch. Bip; (s) *S. chilensis* Meyen.

of the Asteraceae family were also found in the Pelado Peak area. Like *Lafoensia pacari* A. St.-Hil. (F. Lythraceae) and *Handroanthus ochraceus* (Cham.) Mattos (F. Bignoniaceae, **Figures 8(h)** and **Figures 8(i)**, both in Cerrado phytophysiognomies [33].

At the São Paulo Air Base (**Figure 7(d)**), as well as in Pelado Peak, it was possible to identify *H. ochraceus* (Cham.) Mattos in the Baquirivú-Guaçu River basin, common in the Cerrado and Atlantic Rainforest (**Figure 8(j)**). Also found in the Tietê Ecological Park (**Figure 7(e)**), the species *Guazuma ulmifolia* Lam. (**Figure 7(1)** and **Figure 7(m)**) and *Luehea grandiflora* Mart. (**Figure 8(n)** and **Figure 8(o)**), both from the family Malvaceae family are usually found in Cerrado vegetation.

4. Discussion

Modern Cerrado Enclaves

[9] called the occurrence of the Cerrado in other phytogeographic domains, initially called "islands" of vegetation, due to the contrast with the dominant landscape. The author proposed that when a particular plant species was found in a specific location, surrounded by another ecosystem, it was called relics. However, when fragments of a typical ecosystem were found in provinces of another phytogeographic domain, they were called phytogeographic enclaves. The same author cited examples of Cerrado enclaves in regions such as the Amazon rainforest, the interior plateaus of São Paulo, of the Atlantic Forest, and from Caatinga.

[33] observed that areas of Cerrado enclaves under intense anthropic pressure presented similar species in the Pelado Peak region (**Figure 6(c)**), such as 1) *Convolvulus crenatifolius* Ruiz & Pav.—Convolvulaceae family (**Figure 7(p)**); 2) *Andropogon bicornis* L.—Poaceae family; 3) *Croton lundianus* (Didr.) Müll. Arg.—Euphorbiaceae family; 4) *Inga sessilis* (Vell.) Mart.—Leguminosae family (**Figure 7(q)**), and; 5) *Clibadium armani* (Balb.) Sch.Bip. (**Figure 7(r)**) and *Solidago chilensis* Meyen., from the Asteraceae family (**Figure 7(s)**) [33].

According to [9], this current phytogeographic framework is a reflection of the climatic fluctuations that occurred at the end of the Quaternary, which caused the expansion and retraction of the forests, allowing the creation of the "Reduction and Refuge Theory." The author concluded that non-native vegetation islands found in core areas within the different morphoclimatic and geobotanical domains are justified by exception factors, which can be: lithological; hydrological; topographic, and paleobotanical. As well, due to the retraction of ecosystems that was in the past, more territorially developed.

In this sense, according to [1] [2] [3], in the state of São Paulo, the Caatinga was first expanded in the Upper Pleistocene. Second, the change from dry to a tropical climate with two seasons was responsible for the arrival of the Cerrado to São Paulo (beginning of the Holocene, ~13,000 years BP). And finally, due to the tropical climates of the plateau, it gave origin to the re-expansion of the

tropical forests until the present day. Thus, the same author stated that the Cerrado patches currently found in the state of São Paulo are due to retractions of this biome that predominated between 18,000 and 13,000 years BP, which in general terms was designated "Theory of Forest Refuges".

For [47], the occurrences of Cerrado in the State of São Paulo are due to climatic fluctuations in the Quaternary, which had their peak around 10,000 years BP, in a period in which the climate was cooler and drier with a predominance of open Cerrado. The authors also described that in the year of 7560 years BP, there was a higher humidity, noted by the advance of the Forests of Galleries in the valleys. With the return of the dry period between 7560 and 6000 years BP, the expansion of the Cerrado is favoring.

However, the authors mentioned above proposed that from 6000 to 2180 years BP, the valleys were once again covered by Semideciduous Forests, leaving the higher regions as "relic areas" of open Cerrado. The authors also pointed out that this picture changed between 2180 and 600 years BP. With the increase of humidity, the open Cerrado in the higher areas became more closed. After 600 years BP the Semideciduous Forest gradually overlapped in the region.

Despite that, carbon isotope analyzes, pollen records, and oxygen isotope studies in cave speleothems indicated that during the last glacial maximum Brazil was under monsoon influence and that the southeastern Brazilian region has had wet periods since ~22,000 AP, and humid and hot from ~15,600 to the present [48]-[53].

It is speculated that during the glacial phases in southeastern Brazil, humid forests prevailed and that the Cerrado islands found today are representative species of a very old Cerrado that existed before the glacial periods, highly resilient and tolerant to the climatic changes. This condition is supported by [46], who pointed out, through phylogeography by amplification and sequencing of two molecular markers: the chloroplast intron and the nuclear ribosomal DNA, which the endemic species of Cerrado found today, such as the *D. miscolobium*, are remnants of the Pliocene and Pleistocene.

5. Conclusions and Recommendations

The present study is the first to present the prediction of the adequacy distribution of Cerrado, in particular in the Metropolitan Region of São Paulo and Guarulhos. In the latter, the prediction of adequacy in the regions of Pelado Peak, São Paulo Air Base and Tietê Ecological Park was corroborated *in situ* with the occurrence of typical Cerrado species such as *D. miscolobium* Benth; *B. intermedia* A. Juss., *H. umbellata* A. Juss, *Alchornea glandulosa* Poepp. & Endl. and *L. grandiflora* Mart, thus suggesting that these areas are testimonies of the remaining Pliocene and Pleistocene species.

The *in situ* verification of typical Cerrado species revealed that the Maximum Entropy algorithm has a high predictive capacity of this type of biome in transition zones. However, for the formulation of even more assertive models and more accurate floristic surveys, geoenvironmental data with a higher spatial res-

olution (*i.e.*, pedological, geological, among others with accurate scales) are necessary.

The authors also point out the need to preserve an area of about 22.5 ha in the Pelado Peak region, because, among the areas cited in this study, this is the only one that is not protected by environmental legislation, with the risk of urbanization and urban sprawl imminently. In this sense, the work suggests the transformation of the Pelado Peak private area within a Private Natural Heritage Reserve, as an alternative for the conservation. Finally, the methodology presented here has great potential in supporting strategic information for the implementation of conservation units and/or preservation areas of this threatened biome.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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