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ORIGINAL RESEARCH

Defining priorities areas for biodiversity conservation and trading forest certificates in the Cerrado biome in Brazil

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Abstract
Habitat loss and natural vegetation fragmentation are significant causes of global biodiversity decline, impacting plant and animal species negatively. This issue is worrisome in the private areas of Cerrado in Brazil, which is the second-largest biome, considered a hotspot for biodiversity conservation, and a provider of ecosystem services. Herein, we present a novel integrated approach to define priority areas for biodiversity conservation and environmental compensation in Cerrado, using multicriteria analysis. Our approach combines variables like deforestation projection, integral index of connectivity, threatened species occurrence, and environmental information of rural properties, ranking the importance of remaining native vegetation for biodiversity conservation and forest certificate issuance. Landscape metrics were used to observe and predict land use and land cover changes from 1988 to 2038. We found a loss of native vegetation in the Cerrado superior to 20% between 1988 and 2018, associated with increased of its fragmentation and its connectivity loss, especially after 2008. Natural cover was replaced mostly by pasture and more recently by agriculture. Moreover, we determined that is expected a loss of native vegetation of around 55% by 2038 in the study area. The proposed approach can predict the consequences of future changes in the landscape of the private areas in the Cerrado biome. It should be replicated in other ecosystems, supporting the decision-making process for biodiversity protection.

Keywords Brazilian savanna · Threatened species · Habitat loss · Land use and land cover dynamics

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Introduction

Habitat loss and natural vegetation fragmentation are major causes of global biodiversity decline (Grande et al. 2020; Villard and Metzger 2014; Wang et al. 2016). In Brazil, landscape changes caused by agriculture and infrastructure expansion are the main threat to more than the 3,286 plant and animal species, according to the surveying of the Official National List of Threatened Species (Martinelli and Moraes 2013; Mustin et al. 2017). A total of 25% of the threatened species in Brazil still lack protection and are considered “gap species” (Brasil 2016; Martins et al. 2018), even though efforts for reducing the deforestation areas and increasing the protected areas have been made in the past 20 years (Fonseca and Venticinque 2018).

The aforementioned situation is critical in Cerrado, which is the second-largest Brazilian biome. Cerrado is considered a hotspot for biodiversity conservation and a provider of ecosystem services (Colli et al. 2020; Strassburg et al. 2017). Despite its importance, almost half of Cerrado natural areas had already been converted to other land uses (Alencar et al. 2020), and only 9% of them are under legal protection (Françoso et al. 2015). In addition, about 39 million ha of natural vegetation in the Cerrado biome may be suppressed in the next future, most of them in the MATOPIBA region (Vieira et al. 2018). This region is located in the northeastern part of the Cerrado, encompassing the states of Maranhão, Tocantins, Piauí, and Bahia.

A total of 53% of the vegetation in Brazil is inside private properties (Soares-Filho et al. 2014) and, to promote environmental protection in these areas, it was created the Law n°. 12,651 of 25 May 2012 (popular name: New Forest Code), which regulates forest conservation in Brazil. The two main instruments of the New Forest Code are the Rural Environmental Registry (CAR), and the Environmental Reserve Quotas (CRA) (Soares-Filho et al. 2016; Strassburg et al. 2017). CAR is a mandatory electronic registry where farmers must upload information about their properties like borders, cultivars, and natural vegetation distribution. CRA consists of forest trading certificates, comprising 1 ha of intact or regenerating natural vegetation, that exceeds the Legal Reserve (LR) of a property and can be purchased by landowners with debts in LR. According to Law n°. 12,651, the LR is a fraction of the property that must remain covered with native vegetation. In the Cerrado biome, this fraction is 20%, increasing to 35% if the property is located in the Legal Amazon (Brasil 2012).

The CRA mechanism has the potential to evolve into the largest market of trading forest certificates in the world (Pacheco et al. 2021; Soares-Filho et al. 2016). However, its effectiveness for biodiversity maintenance depends on an integrated approach to defining priority areas for this protection (Strassburg et al. 2017). This integrated approach should involve factors related to the occurrence of threatened species and ecosystem services provision, and consider the prioritization of landscape connectivity and deforestation trends (Stan and Sanchez-Azofeifa 2017; Wang et al. 2016). Land use and land cover dynamics can be evaluated using landscape metrics, which allow analyzing landscape connectivity and deforestation trends. Nonetheless, up to the writing moment, this integrated approach for predicting the consequences of future changes in the landscape and supporting the decision-making process of biodiversity protection is unknown in the Cerrado biome. Therefore, herein, we define priority areas for biodiversity conservation and environmental compensation in the Cerrado of the Tocantins, Brazil, based on multicriterial analysis. This work presents the

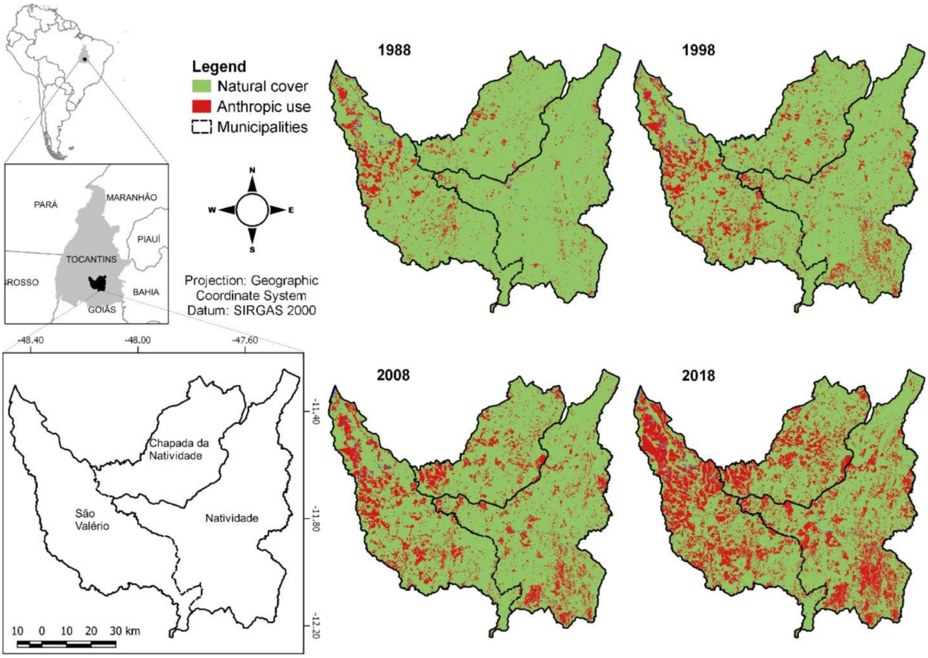

Fig. 1 Location of the study area in the Tocantins State nthropic use areas and natural vegetation cover in 1988, 1998, 2008 and 2018.

following three-fold major contributions: a description of the landscape dynamics in the Cerrado in the last 30 years (1988–2018), a presentation of the deforestation projections to 2028 and 2038 in the study area, and a determination of the priory areas for conservation in the Cerrado biome.

Materials and methods

Study area

The study area refers to a portion of the Cerrado biome located in southeastern Tocantins State (Fig. 1). Due to its ecological attributes and occurrence of threatened species, this region of Cerrado is considered a priority region for biodiversity conservation, according to the Ministry of Environment of Brazil (MMA) (Brasil 2016). The area covers 740 thousand ha, encompassing the municipalities of Natividade, Chapada da Natividade, and São Valério. Natural vegetation covers 73% of the area (Mapbiomas 2021). The dominant climate is Aw (tropical savanna with dry winter), according to the Köppen climate classification (Alvares et al. 2013), and there is potential for intensive land use for agriculture (SEPLAN 2017). Population density is low (2.17 inhabitants km^{-2}), and the Municipal Human Development Index (HDI) is equal to 0.645 on average, which is lower than the national HDI of 0.765 (UNDP 2020).

Methods

The land use and land cover dynamics of the study area were analyzed based on the MapBiomas 4.1 maps (Souza et al. 2020) for the years 1988, 1998, 2008, and 2018, using landscape metrics and indexes. In the Fragtstats 4.2 software (McGarigal et al. 2012), the following landscape metrics were calculated: total class area (CA), percentage of landscape (PLAND), number of patches (NP), patch density (PD), mean patch area (AREA_MN), mean euclidean nearest neighbor distance (ENN_MN), aggregation index (AI), largest patch index (LPI), and division index (DIVISION). Both PLAND and DIVISION were also calculated at the municipal level. In Conefor 2.6 software (Saura and Torné 2009), the overall values for the Integral Index of Connectivity (IIC) and the Equivalent of Connectivity (EC) were calculated considering only fragments larger than 1 hectare. We used a maximum dispersion distance of 1,300 m, as suggested by Grande et al. (2020), based on the literature information about the biology of non-flying mammals significantly affected by fragmentation in the Cerrado.

From the results obtained in the analysis aforesaid, we made projections of deforestation for the years 2028 and 2038, using the Dinamica EGO 5.0.0 software (Soares-Filho et al. 2002). This software operates with input parameters in raster format, and the model´s generation depends on cellular automata, where the future condition of a cell depends on its current status, its neighboring cells, and the transition rules determined by the Bayesian statistical method of Weights of Evidence (Osis et al. 2019; Stan and Sanchez-Azofeifa 2017). Our model assumes continuity of transition rates of the natural and anthropic land use and land cover classes between 2013 and 2018 on the MapBiomas 4.1 maps.

Transition rules were calculated using categorical, continuous, and dynamic variables (Supplementary Material, Table S1) selected from the literature (Molin et al. 2017; Osis et al. 2019; Wang et al. 2016). For the projections' validation, we calculated the minimum similarity between the actual map of 2018 and the simulated one. For that, a constant decay function was used in multiple windows (sizes from 1×1 to 13×13), seeking similarities above 50% in any of the windows and similar distribution patterns (Soares-Filho et al. 2009). The same metrics and indexes applied to the 1988–2018 maps were used to evaluate the simulated maps for 2028 and 2038.

Finally, we defined the priority areas for biodiversity conservation and CRA issuing in the study area, applying a multicriteria analysis with the Weighted Linear Combination method. Exceeding vegetation was classified from very low (1) to very high (5) using a qualitative scale of importance. A total of five variables were used in the multicriteria analysis: distance to Permanent Preservation Areas (PPA); distance to Legal Reserves (LR); distance to point-occurrence records of gap species; fragment importance for landscape connectivity; and the possibility of deforestation until 2038. Exceeding vegetation refers to vegetation outside Permanently Protected Areas (PPA) and Legal Reserves (LR) (Supplementary Material, Table S2).

The multicriteria analysis was built based on the literature (Castro et al. 2020; May et al. 2015; Metzger et al. 2019; Soares-Filho et al. 2014, 2016; Tubelis et al. 2004), and on the opinions of eight experts, gathered through interviews and forms following the Delphi technique (Mukherjee et al. 2015). Data on PPA, LR, and gap-species occurrence were provided by MMA.

LR limits were estimated considering the CAR data available for the study area on 30 October 2019. Topological correction was applied to remove overlaps and the information was validated with the aid of Rapideye and Sentinel-2 images according to the registration date in the CAR database. PPA limits consist of a reference layer generated according to the categories established by law (Brasil 2012; Cicerelli et al. 2021; Oliveira Filho 2016). Fragment importance refers to the IIC deltas of fragments larger than 1 ha in the 2018 map. The values were grouped into five classes using Jenks' optimization (Castro et al. 2020). The deforestation layer refers to a temporal possibility map of deforestation, generated from the Dinamica EGO software and indicates the deforested areas every five years (2023, 2028, 2033, and 2038) and those that will remain unchanged until 2038 (Supplementary material, Figure S1). The five variables were integrated using map algebra considering their respective weights, resulting in a map with exceeding vegetation classified according to its importance for biodiversity conservation and CRA issuing.

Results

Landscape dynamics and structure in the Cerrado biome

Natural vegetation remained predominant in the study area between 1988 and 2018, regardless of more than 20% loss (Table 1). The mean patch area and the AI decreased, but NP, PD, and DIVISION increased in this period. We noted that pastures replaced natural vegetation. Agricultural and urban areas expanded more between 2008 and 2018, occupying around 2.3% and 0.5% of the landscape, respectively. All anthropic classes increased in terms of NP, AI, and mean patch area values (Table 1).

Natural vegetation would still be predominant in a future scenario (Fig. 2), but with an increase in PD, reaching 4.58 in 2038. The DIVISION, which increased in 1988–1998 and 2008–2018, would reach 0.75 in 2038. We observed a downward trend for the LPI, IIC, and EC, including a significant decrease between 2008 and 2018. The ENN mean distance varied little among the years, remaining close to 100 m until 2038 (Table 1).

The municipality of São Valério showed the lowest vegetation cover (45%) and highest division (0.85) in 2038 based on the historical series analysis. Chapada da Natividade municipality presented larger natural coverage (1988: 96.7%; 2018: 75.1%) and smaller fragmentation (1988: 0.07; 2018: 0.46). However, São Valério presented less vegetation cover (2028: 64.2%; 2038: 58.1%) and greater division in the simulated scenario (2028: 0.66; 2038: 0.75) compared with the Chapada da Natividade municipality, with greater coverage (2028: 67.1%; 2038: 63.5%) and smaller division in the simulated scenario (2028: 0.59; 2038: 0.68).

Priority areas for conservation and CRA issuing

The potential exceeding vegetation was estimated at around 399 thousand ha, classified mostly as high (55%) and medium importance (39%), and located in Natividade municipality mainly. Very high important surpluses (2.5%) are concentrated in Natividade and Chapada da Natividade. Low or very low important surpluses sum 3.5% (Fig. 3).

Table 1 Values of landscape metrics and indexes calculated from MapBiomas maps (1988–2018) and simulated maps (2028–2038): Class area (CA), Percentage of landscape (PLAND), Number of patches (NP), Patch density (PD), Mean patch size (AREA_MN), Mean euclidean nearest neighbour distance (ENN_MN), Aggregation index (AI), Largest patch index (LPI), Division index (DIVISION), Integral index of connectivity (IIC), Equivalent of connectivity (EC). IIC and EC values are multiplied by10^{19} and 10^{9}, respectively.

CLASS	YEAR	CA	PLAND	NP	PD	AREA_MN	ENN_MN	AI	LPI	DIVISION	IIC	EC
Natural	1988	689,769.2	92.97	682	0.09	1,011.4	102.18	98.92	92.85	0.14	4.76	6.9
	1998	651,106.8	87.76	1,398	0.19	465.7	100.07	98.17	87.47	0.24	4.23	6.51
	2008	613,812.4	82.73	1,990	0.27	308.4	107.66	97.8	82.27	0.32	3.75	6.13
	2018	522,908.6	70.48	4,687	0.63	111.6	106.91	96.27	69.26	0.52	2.67	5.17
	2028	449,616.6	60.62	28,804	3.88	15.6	86.98	93.91	54.85	0.7	1.92	4.38
	2038	407,679.9	54.97	33,935	4.58	12.0	92.08	93.32	49.51	0.75	1.54	3.92
Pasture	1988	48,664.4	6.56	8,066	1.09	6.03	218.27	86.53	Not calculated			
	1998	87,537.4	11.8	13,510	1.82	6.4	171.29	87.34				
	2008	123,071.6	16.59	12,912	1.74	9.5	160.41	89.62				
	2018	195,959.9	26.41	16,188	2.18	12.1	137.11	89.95				
Agriculture	1988	104.5	0.01	44	0.01	2.3	4,368.37	81.24	Not calculated			
	1998	327.7	0.04	182	0.02	1.8	1,533.64	70.84				
	2008	1,566.6	0.21	197	0.05	7.9	814.35	87.8				
	2018	16,701.2	2.25	845	0.19	19.7	329.42	91.57				
Urban area	1988	931.8	0.13	547	0.07	1.7	893.14	69.29	Not calculated			
	1998	729.7	0.1	356	0.05	2.0	1,172.57	73.61				
	2008	1,124.5	0.15	402	0.05	2.8	920.48	76.15				
	2018	3,728.4	0.5	1,235	0.17	3.0	573.45	76.66				

Discussion

The annual deforestation rate of 0.8% observed in the study area for the period 1988–2018 is slightly higher than the annual average of 0.5% observed for the Cerrado between 1985 and 2017 (Alencar et al. 2020). If the period 2008–2018 is considered, the average annual deforestation rate in the area is 1.5%. Considering the changes observed for the other land use classes, this increase may be related mainly to the expansion of pasture areas. Charcoal production may also have contributed to the increase in deforestation rates. The three municipalities are among the eight that concentrated 32% of the total charcoal production from native vegetation in the Tocantins State between 2009 and 2016, whose main consumer was the steel industry in the Minas Gerais State (Cachoeira et al. 2019).

Agricultural expansion may be another cause for the increase in deforestation rates observed in the study area, following a trend observed in MATOPIBA region (Alencar et al. 2020). However, further analysis are necessary to confirm if agricultural expansion resulted from new deforestations or from the replacement of degraded areas.

The Weights of Evidence analysis identified a significant correlation between deforestation with shrublands and grasslands, which is possibly linked to a greater concentration of these phytophysiognomies in the region (Alencar et al. 2020). New deforestation is related to the proximity to converted areas, access roads, and rivers, as well as to low slopes and clayey soils and Latosols (greater agricultural suitability) and also Planosols in Natividade municipality. The use of Planosols – poorly drained and hydromorphic soils – may be related to planted pastures or rice production (Manzatto et al. 2002). LR showed a repelling effect on deforestation, indicating their potential for protecting vegetation and biodiversity. However, these data should not be extrapolated, as there has been some degree of deforestation in these areas and the compliance with the law varies across the country (Pacheco et al. 2021; Vieira et al. 2018).

Despite the possible predominance of natural vegetation until 2038, a gradual process of vegetation loss and fragmentation is in course. The continuous decrease of the IIC and EC values suggests a decrease in connectivity, especially from 2008. However, the observed and projected values can still be considered high, and, beyond the great natural cover, may be linked to a low density of patches and proximity between fragments, characteristics of landscapes with a strong presence of livestock (Carvalho et al. 2009; Grande et al. 2020). Considering the LPI and IIC delta values and the close values of the relative variation in EC ($dEC = ECt_1 - ECt_0/ECt_0$) and the relative variation in the amount of native area in the landscape ($dA = At_1 - At_0/At_0$), the fragmentation may be related to the clearing of adjacent vegetation from a single large fragment (Grande et al. 2020).

If deforestation rates and trends are maintained until 2038, the fragmentation threshold identified by Grande et al. (2020) for the Cerrado as 40% of the original vegetation would not be reached. This is a breakpoint in which functional connectivity is drastically reduced and the survival of some species can be compromised. Below this threshold, additional vegetation losses have little impact on the quite low functional connectivity and the configuration of the remaining habitat becomes more important than its total amount (Grande et al. 2020; Saura and Pascual-Hortal 2007; Villard and Metzger 2014). However, economic and social factors and changes in the national environmental policy can result in higher rates of deforestation and fragmentation and more critical effects on biodiversity (Carvalho et al. 2019; Metzger et al. 2019).

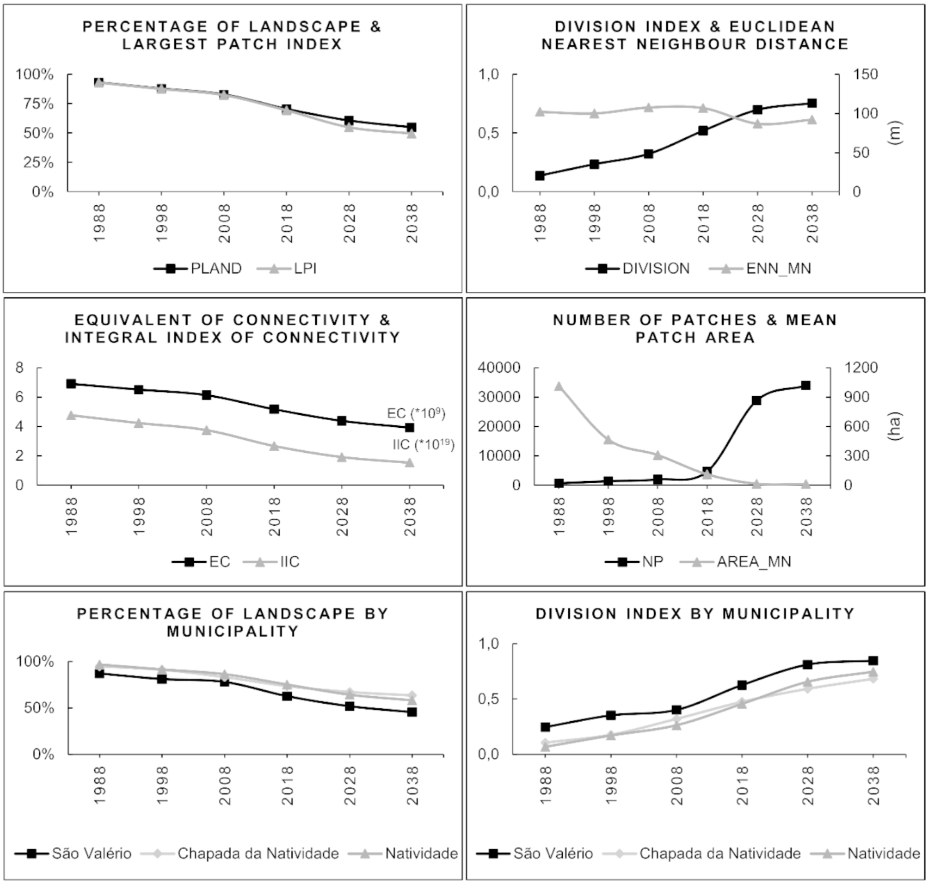

Fig. 2 Metrics for the natural vegetation class in the periods of 1988–2018 and 2028–2038

There are, therefore, opportunities to plan the use and occupation of the landscape to ensure minimum vegetation cover and connectivity. Besides the encouragement of sustainable productive activities, CRA issuance and trade could be stimulated and supported in medium to very high importance areas in Natividade and Chapada da Natividade, enhancing environmental protection and also generating income for owners with vegetation surpluses (May et al. 2015; Soares-Filho et al. 2016). Conservation units could be established in the center-south and northeast of the study area, where there is high vegetation cover and a low probability of deforestation. Areas unsuitable for production, PPAs, and LR totally or partially preserved would play a significant role in maintaining connectivity (Grande et al. 2020; Metzger et al. 2019).

The methodology for prioritizing areas for conservation is satisfactory for territorial planning at the regional and local levels and can be adopted as a later stage of prioritization analysis carried out on a national scale (Fonseca and Venticinque 2018). By using free and user-friendly data and software and a simple decision-making process, it is affordable for any state environmental agency (Oakleaf et al. 2017) and can be easily replicated and adapted to any region or biome. The combination of medium resolution data (30 m) and the

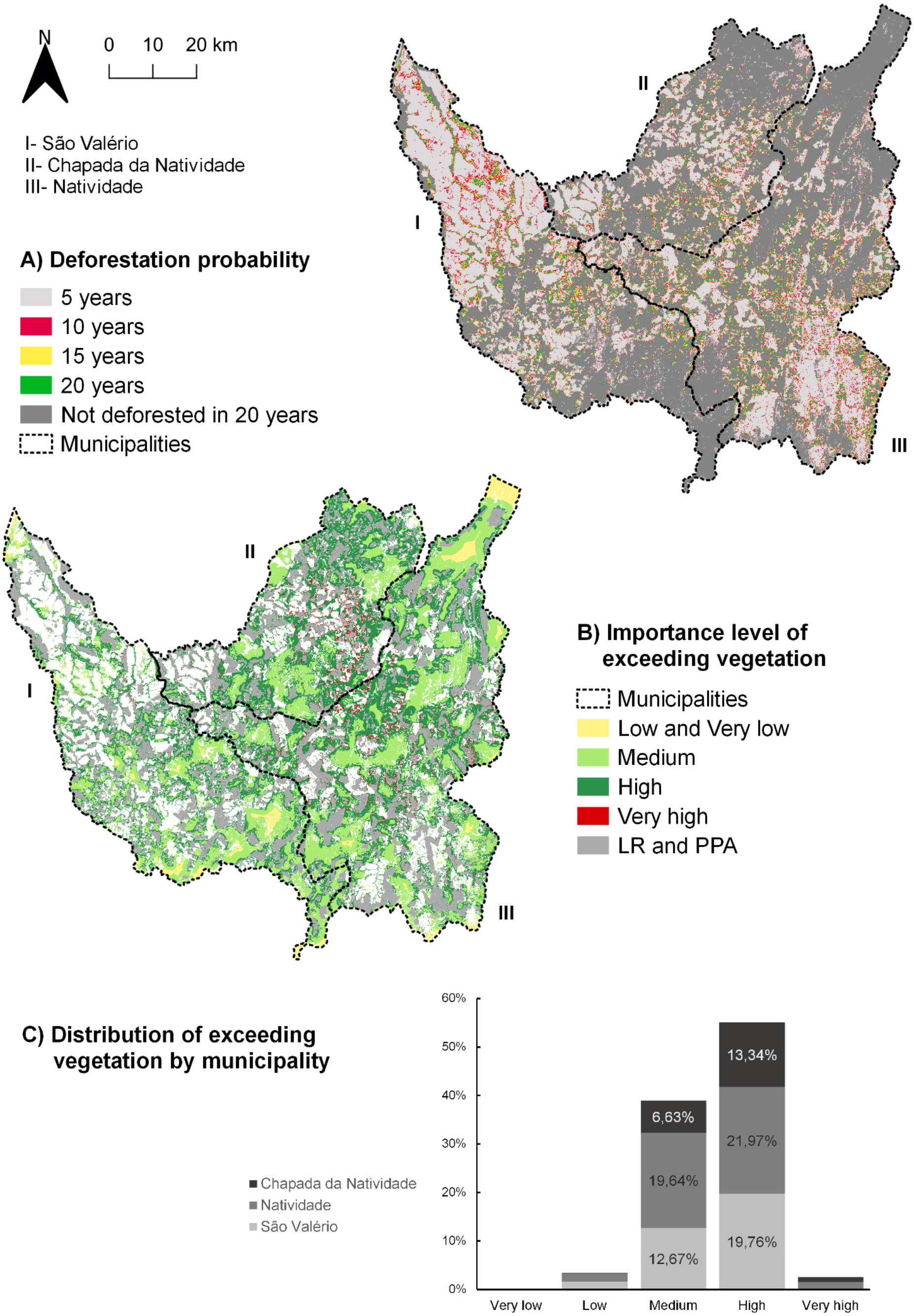

Fig. 3 A) Probability of deforestation in the next 20 years, based on the modeling carried out in the Dinamica EGO software in a "Business as Usual" scenario. B) Result of multicriteria analysis with importance classes of remnants outside LR or PPA. Blank areas refer to anthropized areas and water. C) Distribution of exceeding vegetation outside LR and PPA by importance class and municipality

IIC, a robust connectivity index suitable for conservation planning, allows the identification of remnants that may guarantee the maintenance of critical habitats and landscape connectivity (Castro et al. 2020; Saura and Pascual-Hortal 2007).

The use of Jenks break to define classes for IIC delta values seems to be more adequate than breaks with arbitrary values since they can vary according to the characteristics of the analyzed landscape. The inclusion of gap-species occurrence data can avoid the elimination of areas important for these species. However, considering the limitations in knowledge and data on the occurrence of species in Brazil (Veiga et al. 2017), the use of the IIC considering the patch area may be effective to balance the prioritization process, valuing intrapatch connectivity and benefiting small-sized species or those with low dispersal capacity (Castro et al. 2020; Grande et al. 2020; Saura and Pascual-Hortal 2007).

The CAR data, despite not covering the entire landholding network and, as self-declaratory information, require validation and topological corrections before their use (Santos et al. 2021), have been proved to be strategic for territorial planning. As they allow locating PPA, LR, and vegetation surpluses, vegetation recovery or compensation may be better oriented to reach greater environmental gains. The issuance of CRA close to PPA and LR may ensure greater protection of ecosystem services, connectivity, and a greater amount of available protected habitat, benefiting groups of native species (Metzger et al. 2019; Tubelis et al. 2004).

The inclusion of deforestation modeling allows for identifying where and how strong the deforestation pressure is. This can favor a more appropriate use of resources available for conservation, as it is possible to avoid the selection of areas that may be deforested in the short term - more suitable for production and more difficult to preserve - and of areas with “zero environmental additionality” – which are those passively protected by their productive ineptitude, environmental sensitivity or distance from consumer markets (May et al. 2015; Soares-Filho et al. 2014, 2016). Due to its absence in the study area, protected areas were not included in the deforestation model and multicriteria analysis. However, it is recommended to add conservation units, indigenous lands, and military areas in these analyzes when present, due to their role in protecting native vegetation and biodiversity (Osis et al. 2019; Paiva et al. 2015; Silva Arimoro et al. 2017).

Conclusion

The study area, although still conserved and little fragmented, faces a gradual process of deforestation and fragmentation, especially in areas with greater productive aptitude. There was a significant loss of vegetation cover and an increase in agriculture between 2008 and 2018, but if current trends are maintained, the region will not approach the breakpoint of connectivity in the next 20 years. At the municipality level, São Valério has higher deforestation rates and greater current and future fragmentation, approaching the breakpoint in 2038.

The proposed deforestation model and the prioritization methodology using Weighted Linear Combination and Delphi Technique can be considered satisfactory, integrative, and easily replicable. The prioritization results can support regional environmental planning to preserve key areas for gap species and maintain landscape connectivity.

The results demonstrate the potential and importance of investment in the generation, organization, and availability of land use and land cover data, including time series, species occurrence data, and validated CAR information for environmental planning and biodiversity conservation.

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Author Contributions Samuel Fernando Schwaida conceptualized the work (methodology, data acquisition, analysis, and validation) and wrote the original draft manuscript. Rejane Ennes Cicerelli conceptualized the work (methodology, analysis, and validation) and helped to write the original draft manuscript. Tati de Almeida conceptualized the work (methodology, analysis, and validation) and helped to write the original draft manuscript. Edson Eyji Sano participated in the data analysis and writing-review and editing. Carlos Henrique Pires participated in the data analysis. Ana Paula Marques Ramos helped to write the original draft manuscript.

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Declarations

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

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