DANIELLE RAMOS DE ALVARENGA

EVALUATION OF THE CONTRIBUTION OF ENVIRONMENTAL PROTECTION AREAS IN THE CERRADO TO THE PROTECTION OF NATURAL ENVIRONMENTS

LAVRAS – MG
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Prof. Dr. Rafael Dudeque Zenni
Orientador

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Ficha catalográfica elaborada pelo Sistema de Geração de Ficha Catalográfica da Biblioteca Universitária da UFLA, com dados informados pela própria autora.

de Alvarenga, Danielle Ramos.
Evaluation of the contribution of Environmental Protection Areas in the Cerrado to the protection of natural environments / Danielle Ramos de Alvarenga. - 2022.
44 p. : il.

Orientador(a): Rafael Dudeque Zenni.

Dissertação (mestrado acadêmico) - Universidade Federal de Lavras, 2022.
Bibliografia.

1. áreas protegidas. 2. mudanças climáticas. 3. serviços ecossitêmicos. I. Zenni, Rafael Dudeque. II. Título.

DANIELLE RAMOS DE ALVARENGA

AVALIAÇÃO DA CONTRIBUIÇÃO DAS ÁREAS DE PROTEÇÃO AMBIENTAL DO CERRADO PARA A PROTEÇÃO DE AMBIENTES NATURAIS

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APROVADA em 25 de fevereiro de 2022.
Dra. Kátia Torres Ribeiro, ICMBio
Dr. Marcelo Passamani, UFLA

Prof. Dr. Rafael Dudeque Zenni
Orientador

LAVRAS – MG
2022

AGRADECIMENTOS

Ao meu orientador Rafael Zenni, primeiro por ter aceitado me orientar e depois por ter me incentivado a desenvolver um projeto que fosse com algo que eu realmente gostasse. Muito obrigada!

Aos membros da minha banca de qualificação, Renata Françoso, Maria Auxiliadora (Dodora) e Reuber Brandão pelas sugestões e colaborações.

À todas as pessoas que colaboraram com seus conhecimentos e trocas de experiência para essa dissertação, Rafaela Guimarães, Cézar Borges, Gabriela Duarte, Arthur Soares e ao professor Lucas Faria pela ideia de utilizar o lambda em nosso modelo estatístico.

Ao meu colega de mestrado Gui Albertino, pelas disciplinas que fizemos juntos e apoio mútuo.

Aos meus colegas de laboratório, Carol, Ana Luiza, Gustavo, Jonathan, Karla, Marina, Vitor, Daniel e Wanda por terem me acolhido e apoiado ao longo desses dois anos. Em especial, gostaria de agradecer a Carol e Ana Luiza. Obrigada Carol por você ser esse doce de pessoa, me tornei sua amiga desde que entrei para o mestrado. Obrigada Ana por tudo, pela oportunidade de poder te ensinar um pouco das coisas que aprendi e por me ensinar tanto.

À minha família, que sempre esteve comigo e agora sabe muito sobre Áreas de Proteção Ambiental. Agradeço ao meu pai, que sempre foi minha maior inspiração. Você é a pessoa mais trabalhadora e bondosa que eu conheço. Pensar sobre a sua trajetória me faz querer ser sempre uma pessoa melhor a cada dia, e isso é o mínimo que eu posso fazer. À minha mãe por ser uma pessoa tão paciente comigo. Você é muito tranquila e divertida, mesmo quando a gente fica pegando no seu pé e isso é bem admirável. À minha versão masculina, meu irmão Tiago pelo apoio e pelo carinho demonstrando interesse sobre o que eu estou fazendo no meu mestrado. À minha irmã Érika, por me apoiar, pelas discussões e interpretações de dados e por ter me dado uma sobrinha no meio deste mestrado que é a coisa mais fofinha desse mundo. Aos meus enteados Pedro e Gabi por saberem tanto dessa dissertação. Obrigada por vocês terem escutado apresentações, lido meus textos, assistido minha qualificação e escutado eu falar tanto sobre o meu projeto. Gabi, obrigada pelos momentos que você esteve com a gente nesse período de pandemia, pelas conversas e apoio que recebi de você. Pedro, obrigada por ser meu parceirinho de buraco, por aprender sobre as fitofisionomias do Cerrado, estoque de carbono e tanta coisa que nem é a sua praia para ficar conversando comigo sobre o meu mestrado. Amo vocês.

Gostaria de agradecer especialmente ao Dri, meu esposo, por tudo e por tanto. Você é mais do que eu poderia sonhar. Obrigada pela parceria, pelo apoio, pelo interesse, pelo amor que a gente tem um pelo outro e por ser a pessoa que eu chamo de casa, pelo sentimento de lar. Não me faltou sorte.

Aos meus amigos Emily Stephanie, Flávio Rodrigues, Fernanda Silva, Daniele Kasper, Rafael Leitão, Flávia Coelho, Elaine Cotrim, Daniela Boanares, por deixar a minha vida mais leve e prazerosa.

Ao grupo Galhas e a minha primeira orientadora, Rosy Isaias, por terem me ensinado tanto antes de entrar para o mestrado.

À minha professora de inglês Belma, pelo apoio e incentivo ao longo de todos esses anos. Você é uma professora incrível.

Ao Luis Felipe, meu grande amigo e parceiro inseparável desde a graduação. Obrigada por a gente dar tão certo de um jeito tão peculiar. É sempre uma boa aventura trabalhar com você.

Aos meus cãopanheiros Bones e Elvis, que tiveram papel importantíssimo para a minha saúde mental ao longo deste mestrado que foi em meio a uma pandemia, 90% do tempo da execução desta dissertação eles estiveram do meu lado, literalmente.

Ao Programa de Pós-graduação em Ecologia e a Universidade Federal de Lavras pela oportunidade de estudo, muito grata pelo ensino público que nosso país oferece.

À CAPES, pela bolsa concedida.

O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Código de Financiamento 001.

À todas as pessoas que lutam para deixar um mundo melhor.

À minha sobrinha Luísa que nasceu junto a essa dissertação.

Dedico.

RESUMO

Áreas de Proteção Ambiental (APA) representam cerca de 65% de toda área protegida por unidade de conservação no Cerrado brasileiro. A conservação de áreas de vegetação nativa tem sido considerada uma grande estratégia para garantir a provisão de serviços ecossistêmicos, como a manutenção climática. O estoque de carbono contido em ambientes naturais é um dos serviços ecossistêmicos afetados diretamente pela conversão destes em ambientes antrópicos. Neste contexto, a dissertação buscou compreender o papel das APA na conservação das áreas de vegetação nativa e estimar o estoque de carbono agregado por estas. Para isso, comparamos 16 APA e 16 áreas não protegidas utilizando a classificação do MapBiomas que estabelece três tipos de formação vegetal: florestal, savânica e campestre. Avaliamos se houve mudança diferenciada na proporção de cobertura vegetal entre áreas protegidas e não protegidas desde a criação de APA até 2020. Utilizando o modelo InVEST, estimamos o estoque de carbono de cada APA no momento inicial de sua criação e em 2020. As APA apresentaram padrão temporal semelhante em relação às áreas não protegidas e, embora pequena, apresentaram perda de estoque de carbono. Isso nos diz que, como medida de mitigação das mudanças climáticas de longo prazo, as APA provavelmente não são eficazes.

Palavras-chave: Balanço zero. Biomassa vegetal. Ecossistemas naturais. Estoque de Carbono. Mudança no uso e cobertura do solo. Mudanças Climáticas. Paisagem protegida. Unidades de conservação.

ABSTRACT

Environmental Protection Areas (EPA) represent about 65% of the entire protected areas for conservation unit in the Brazilian Cerrado. The conservation of native vegetation areas has been considered a great strategy to guarantee the provision of ecosystem services, such as climate maintenance. The carbon stock contained in natural environments is one of the ecosystem services directly affected by their conversion to anthropogenic environments. In this context, we sought to understand the role of EPA in the conservation of native vegetation areas and to estimate the carbon stock added by them. For this, we compare 16 EPA and 16 unprotected areas, using the MapBiomas classification, which establishes three types of vegetation: forest, savanna, and grassland. We evaluated whether there was a differentiated change in the proportion of vegetation cover between protected and non-protected areas from the creation of the EPA to 2020. Using the InVEST model, we estimated the carbon stock of each EPA at the initial moment of its creation and in 2020. EPA showed a similar pattern in relation to unprotected areas in Cerrado and, although small, showed a loss of carbon stock. This tells us that as a long-term climate change mitigation measure, they are probably not effective.

Keywords: Carbon stick. Climate changes. Conservation units. Land use land cover change. Natural ecosystems. Plant biomass. Protected Landscape.

SUMÁRIO

PRIMEIRA PARTE

Introdução geral

O Painel Intergovernamental sobre Mudanças Climáticas (IPCC) relata o atual cenário climático global como muito preocupante e já inclui diversas mudanças irreversíveis para o planeta, o que tem aumentado a pressão às autoridades políticas por metas mais ambiciosas de redução de emissão de gases de efeito estufa (IPCC 2021). Vários trabalhos têm evidenciado o aumento de dióxido de carbono em consequência de atividades antrópicas como o principal causador das mudanças climáticas (LE QUÉRÉ et al., 2016; FRIEDLINGSTEIN et al., 2020; NOAA 2021; IPCC 2021). Os ecossistemas naturais desempenham um papel importante no ciclo global do carbono, servindo como sumidouros (MELLILO et al., 2015) e auxiliando na mitigação e adaptação às mudanças climáticas (MALHI et al., 2020).

Nas últimas décadas, a proteção de ambientes naturais tem sido incluída nas principais discussões globais sobre as mudanças climáticas. Por exemplo, o mecanismo de Redução das Emissões por Desmatamento e Degradação Florestal (REDD), iniciado em 2003 a partir das discussões durante a Conferência das Partes – 9 (COP- 9) em Milão, apresenta um meio de compensação no qual os países desenvolvidos oferecem incentivos financeiros aos países em desenvolvimento. Em 2010, 192 países adotaram um plano estratégico se comprometendo em proteger 17% de suas áreas terrestres (CBD 2010). Com o Acordo de Paris em 2015 foi indicado, como uma das medidas de enfrentamento das mudanças climáticas, conservar e melhorar áreas de vegetação nativa a fim de garantir sumidouros de gases de efeito estufa, colocando em pauta o que hoje é chamado de REDD+, que inclui o papel da conservação, do manejo sustentável e do aumento de estoques de carbono nas florestas. No último evento, a COP 26, realizada em 2021 e pautada no Acordo de Paris, um dos grandes temas discutidos foi o balanço zero (emissão líquida zero) e novamente a redução do desmatamento ganha papel de relevância nas discussões a fim de diminuir as emissões de gases de efeito estufa.

A criação de novas Unidades de Conservação (UC), bem como a manutenção das UC já existentes, atende aos compromissos internacionais assumidos pelo Brasil, como a Convenção das Nações Unidas sobre Diversidade Biológica (CBD) e Convenção-Quadro das Nações Unidas sobre a Mudança do Clima. Se gerenciadas adequadamente, as UC podem servir como instrumento para garantir a conservação da biodiversidade, o uso sustentável dos recursos naturais e de seus serviços ecossistêmicos, bem como conter os efeitos das mudanças climáticas

(MELILLO et al., 2016). Elas ainda podem gerar recursos econômicos para países como o Brasil através de políticas de REDD+ (SCHARLEMANN et al., 2010; SHI et al., 2020).

Dentre os diversos tipos de unidade de conservação existentes no Brasil, a Área de Proteção Ambiental (APA) é a categoria com a maior extensão territorial, representando 5,5% de todo o território brasileiro e quase um terço de toda a área continental protegida por UC. De acordo com o art.14 da lei Nº 9.985 (Lei do Sistema Nacional de Unidades de Conservação da Natureza – SNUC) "*Área de Proteção Ambiental é uma área em geral extensa, com um certo grau de ocupação humana, [...], e tem como objetivos básicos proteger a diversidade biológica, disciplinar o processo de ocupação e assegurar a sustentabilidade do uso dos recursos naturais*".

Os recursos naturais podem fornecer diversos serviços ecossistêmicos, como controle microclimático, controle de erosão do solo, proteção de bacias hidrográficas, reciclagem de nutrientes e armazenamento de carbono (MELILLO et al., 2016; DAILY & MATSON 2008). A conservação de áreas de vegetação nativa é considerada uma grande estratégia para garantir a sustentabilidade desses recursos, preservando o solo e a flora, protegendo a biodiversidade e promovendo armazenamento de carbono (MELILLO et al., 2016; NAIDOO et al., 2008). Por outro lado, a mudança de uso e cobertura do solo, provocada principalmente pelo desmatamento, é o fator de maior ameaça para esses recursos, para a biodiversidade e para a provisão de serviços ecossistêmicos (HOUGHTON 2012; OVERBECK et al., 2015). A mudança de uso e cobertura do solo pode ser motivada por diversas atividades antrópicas como expansão urbana, construção de infraestrutura, mineração e atividade agropecuária (ARRAES, MARIANO & SIMONASSI, 2012; SONTER et al., 2017).

No Brasil, o desmatamento ocorre de forma heterogênea entre os biomas e o Cerrado está entre os que possui as maiores taxas atuais de perda de vegetação nativa, tendo em 2020 o equivalente a 432.183 ha de área desmatada (MAPBIOMAS 2021). O Cerrado é considerado o bioma savânico mais rico em biodiversidade do mundo (MYERS et al., 2000) e é responsável pela provisão de diversos serviços ecossistêmicos (STRASSBURG et al., 2017). Entre os serviços ecossistêmicos providos, o armazenamento de carbono agregado pela vegetação nativa tem sido afetado diretamente pelas altas taxas de conversão da vegetação nativa (NOOJIPADY et al., 2017).

A perda de áreas de vegetação nativa neste bioma é motivada principalmente pela expansão das atividades agropecuárias (MAPBIOMAS 2020; GARCIA & BALLESTER 2016; RATTER, RIBEIRO & BRIDGEWATER 1997). Estudos têm demostrado que as áreas de vegetação nativa do Cerrado apresentam também taxas de conversão diferenciadas entre os tipos de formação vegetal existentes, havendo maior taxa de modificação na formação savânica do que nas formações florestais e campestres (ALENCAR et al., 2020, MAPBIOMAS 2020 & NOOJIPADY et al., 2017). Por exemplo, Noojipady et al. (2017) analisaram as áreas de expansão agrícola e demonstraram que a conversão da formação savânica apresenta a maior taxa de emissão de carbono comparada a formação florestal. Apesar dos autores apontarem este padrão para o Cerrado de maneira geral, ainda não há estudos que indiquem se este mesmo padrão ocorre dentro de áreas protegidas.

De acordo com os dados do Ministério do Meio Ambiente (MMA), as APA representam cerca de 65% de toda área protegida por UC no Cerrado. Os objetivos básicos das APA definidos pelo SNUC, como disciplinar o processo de ocupação e garantir a proteção da biodiversidade e a sustentabilidade de recursos naturais, estão relacionados diretamente com as necessidades para a preservação deste bioma. Como toda unidade de conservação, as APA devem dispor de um Plano de Manejo que deve ser elaborado em um prazo de até cinco anos após a criação da UC (BRASIL, 2000). O plano de manejo é um documento que estabelece as normas da UC e tem como uma das funções o estabelecimento de diretrizes para o manejo dos recursos naturais (BRASIL, 2000). De acordo com os dados disponíveis pelo Cadastro Nacional de Unidades de Conservação (MMA, 2020), cerca de 89% das APA do Cerrado se encontram irregulares por não dispor de plano de manejo dentro do prazo legal estabelecido. Em uma comparação entre a proporção de remanescentes de vegetação nativa de cada categoria de unidade de conservação com áreas não protegidas no ano de 2008, Françoso et al. (2015) observaram que as APA foram ineficazes na prevenção do desmatamento. Estes fatos, associados à grande extensão territorial das APA e a permissividade de ocupação humana com pouca restrição do uso da terra quando comparada às outras categorias nos permite questionar sobre a eficiência das APA em cumprir os objetivos básicos estabelecidos pelo SNUC.

Nesse contexto, essa dissertação visa entender qual a contribuição das APA para a cobertura de vegetação nativa do Cerrado, bem como investigar se houve mudança diferenciada na proporção de cobertura entre os tipos de formação vegetal e estimar o estoque de carbono agregado por estes. Este tipo de informação nos ajuda a preencher a lacuna do conhecimento relacionada a efetividade das APA em proteger ambientes naturais, além de servir como instrumento na tomada de decisão para os órgãos gestores das unidades.

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SEGUNDA PARTE – ARTIGO

Effectiveness of Environmental Protection Areas to maintain native vegetation and store carbon in the Brazilian Cerrado

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Target Journal: Biological Conservation

Abstract

Protected areas are being considered as a component of climate change mitigation strategies, for their potential to preserve natural ecosystems. We aimed to evaluate the contribution of Environmental Protection Area (protected area, Protected Landscape IUCN category) in protection of native habitats and carbon stock in the Brazilian Cerrado. We tested the hypothesis that Environmental Protection Areas are effective to reduce the loss of native vegetation in Cerrado, with less native vegetation conversion compared to non-protected areas. For this, we compared 16 protected areas and 16 unprotected areas using the MapBiomas classification raster that establishes three types of vegetation: forest, savanna, and grassland. We evaluated whether there was a differentiated change in the proportion of vegetation cover between protected and unprotected areas from the creation of the protected area to 2020. Using the InVEST model, we estimated the carbon stock of each protected area at the initial moment of its creation and in 2020. EPA showed a similar pattern in relation to unprotected areas in Cerrado and, although small, showed a loss of carbon stock. This tells us that as a long-term climate change mitigation measure, they are probably not effective.

Keywords: Carbon stick. Climate changes. Conservation units. Ecosystem services. Habitat loss. Land use change.

1. Introduction

In the last decade, the protection of natural environments has been included in the main global discussions on climate change. During the Conference of Parties in 2021 (COP 26) one of the major topics discussed was carbon zero target (net zero emission). The carbon zero proposal is to achieve a balance between anthropogenic emissions and removals by sinks of greenhouse gases in the second half of this century (Hohne et al. 2021; Acordo de Paris 2015). Despite past progress, existing policies that drive short-term action are currently not consistent with the announced net zero targets (Emissions Gap Report 2021).

Changes in land use and land cover caused by human activities are the main cause of loss of natural habitat and, consequently, loss of biodiversity (IPBES, 2019). The change in land use and cover may have been motivated by human activities such as urban expansion, infrastructure construction, mining, and agricultural activity (Arraes, Mariano & Simonassi 2012; Sonter et al., 2017). In contrast, as greenhouse gas emissions from human activities are altering the global climate (Le Quéré et al., 2016; Friedlingstein et al., 2020; NOAA 2021), the capacity of natural habitats to sequester and store carbon is becoming increasingly important (IPCC 2021). Natural ecosystems do an important role in the global carbon cycle, serving as sinks (Melillo et al., 2016). In this sense, protected areas are being considered as a component of climate change mitigation strategies by extracting carbon dioxide (CO2) from the atmosphere through plant photosynthesis and storing it as organic matter in vegetation biomass and soil (Reilly et al. 2012). It was estimated for Melillo et al. (2016) that about 20% of the terrestrial carbon stock was in protected areas, and more recently for Harris et al. (2021) that it is about 27%.

In the context of climate change, Brazil plays an important role. It is among the six countries responsible for 60% of net carbon flux, 56% of gross global removals of atmospheric carbon, but 51% of gross global emissions from forest loss too (Harris et al. 2021). Gonçalves-Souza et al. (2021) overall assessed Brazil's protected areas and showed that it has played a role in mitigating habitat loss and climate change over the past 30 years and reinforce its potential to maintain natural vegetation in the future. Among the Brazilian biomes, the Cerrado presented the greatest loss of native vegetation in the period from 1985 to 2018 (Gonçalves-Souza et al. 2021). Brazil lost 939,050 km^2 (10.9%) in natural vegetation in of its territory and almost a third of this loss occurred within the Cerrado biome (338,774 km^2), which had a reduction of 16.6% of its native vegetation. Despite this, among the biomes, the Cerrado was not the one with the greatest loss of vegetation in protected areas, losing to the Caatinga biome (Gonçalves-Souza et al. 2021).

In the Brazilian Cerrado, environmental protection areas make up 65% of its entire protected area by conservation unit (MMA 2021). The Environmental Protection Area (EPA; *Área de Proteção Ambiental* – APA – in Portuguese) is a conservation unit category that can be classified in the IUCN V Protected Landscape/Seascape. The EPA are extensive areas, with human occupation, allowing human activities and aim to protect biodiversity, regulate the process of human occupation, and sustainability of natural resources (according to the Brazilian Law of the National System of Conservation Units – SNUC).

Despite recognizing the potential of protected areas to store carbon and mitigate climate change, as well as to protect biodiversity through its natural ecosystems, studies that evaluate these areas are necessary. Here, we aimed at evaluating the contribution of EPA in protection of native habitats and store carbon in Brazilian Cerrado. We tested the hypothesis that EPA is effective to reduce the loss of native vegetation in Cerrado, with less conversion compared to non-protected areas. Furthermore, we expected there would be no loss of carbon stock inside the protected areas since their implementation.

2. Methods

2.1 Study area and GIS procedures

The present study was carried out in the Brazilian Cerrado. In this biome, there are 87 Environmental Protection Areas covering 11,130,713 ha. We used three criteria to select EPA for the study: (i) EPA created after the publication of the SNUC Law (18 July 2000); (ii) territorial extension of the EPA equal to or greater than 10,000 hectares, avoiding selecting small areas, as few pixels evaluated could produce outliers; and (iii) EPA that were classified as belonging entirely to the Cerrado biome according to the Brazilian Conservation Units Panel (MMA, 2020). After applying the criteria, a total of 16 EPA (Table 1) distributed across the Cerrado biome were selected (Fig. 1).

To evaluate the effect of Environmental Protection Areas on the coverage of native vegetation in the Cerrado, each EPA was compared with a reference area (RA) of equivalent size and located in the same region. Reference areas were established from the westernmost boundary of the EPA, using the centroid of each EPA as reference, the criterion for the direction was a draw. In cases where there were protected areas of other categories within the polygon of the reference area, as well as in the EPA, we excluded the area corresponding to those protected areas. All RA used in the study were located entirely within the Cerrado.

Table 1: Name, management sphere, year of creation and size of the Environmental Protected Areas selected for the study.

Environmental Protection Area	Management	Year	Area (ha)
Planalto Central*	Federal	2002	503,415
Nascentes do Rio Vermelho	Federal	2001	176,321
Cochá e Gibão*	Estadual	2004	285,549
Estrada Parque de Piraputanga	Estadual	2000	10,129
Jalapão*	Estadual	2000	134,950
João Leite*	Estadual	2002	71,342
Lago de Peixe/Angical	Estadual	2002	75,451
Lago de São Salvador do Tocantins, Paranã e Palmeirópolis	Estadual	2002	14,225
Morros Garapenses	Estadual	2010	234,326
Nascentes do Rio Paraguai	Estadual	2006	70,857
Nascentes do Rio Vermelho	Federal	2001	176,321
Pireneus	Estadual	2000	19,183
Planalto Central*	Federal	2002	503,415
Pouso Alto	Estadual	2001	839,491
Rio Cênico Rotas Monçoeiras*	Estadual	2000	17,205
São Desidério	Estadual	2006	10,970
Serra da Jibóia	Estadual	2000	17,162
Serra das Galés e da Portaria	Estadual	2002	46,285

* EPA with management plan.

To identify land use and land cover patterns over time, we used spatial data from the MapBiomas Brasil Collection 6.0 (2021). These data were made up of annual maps, in raster format, with a spatial resolution of 30 m, with the WGS84 Geographical Coordinate System. MapBiomas 6.0 classifies Cerrado's land cover and land use into 17 classes, but we considered only three in our analyses, namely the classes of native vegetation in the Cerrado: forest, grassland, and savanna (MapBiomas 2020a). According to the interpretation key of MapBiomas based on Ribeiro & Walter (2008), forest refers to riparian forest (*mata ciliar),* gallery forest (*mata de galeria),* seasonally dry tropical forest (*mata seca*), dense cerrado woodland (*cerradão*), and seasonal semideciduous forests *(florestas estacionais semideciduais);* savanna encompasses areas of *parque de cerrado* and typical cerrado (*stricto sensu* cerrado), including *cerrado denso, cerrado típico, cerrado ralo,* rupestrian cerrado (*cerrado rupestre*); grassland refers to areas with a predominance of *campo sujo, campo limpo* and rupestrian grassland (*campo rupestre*).

To obtain the size of the areas corresponding to the three types of native vegetation for each of the environmental protection areas and their reference areas, we used ArcGIS PRO 2.8.2 software (ESRI Inc., USA). For this, we used rasters for the years 2000 to 2020, clipping for the Cerrado biome. We used the following tools (Fig. 2): Iterate Rasters, so that the process is done for all rasters of all years contained in a folder; Extract by Mask, cropping the Cerrado MapBiomas raster to the areas of interest (reference and environmental protection areas); Raster to Polygon, to measure the areas; and Spatial Join, for each polygon to gain identification. After these processes, we used the Dissolve tool to join the polygons corresponding to each class in each sampling unit (RA or EPA). Finally, we used the Calculate Geometry Attributes tool to obtain the total area value corresponding to each class for each sampling unit for each year. Individual adjustments using the Clip tool were made later. We cleaned the final spreadsheet manually, eliminating the collections from years before the creation of the environmental protection areas.

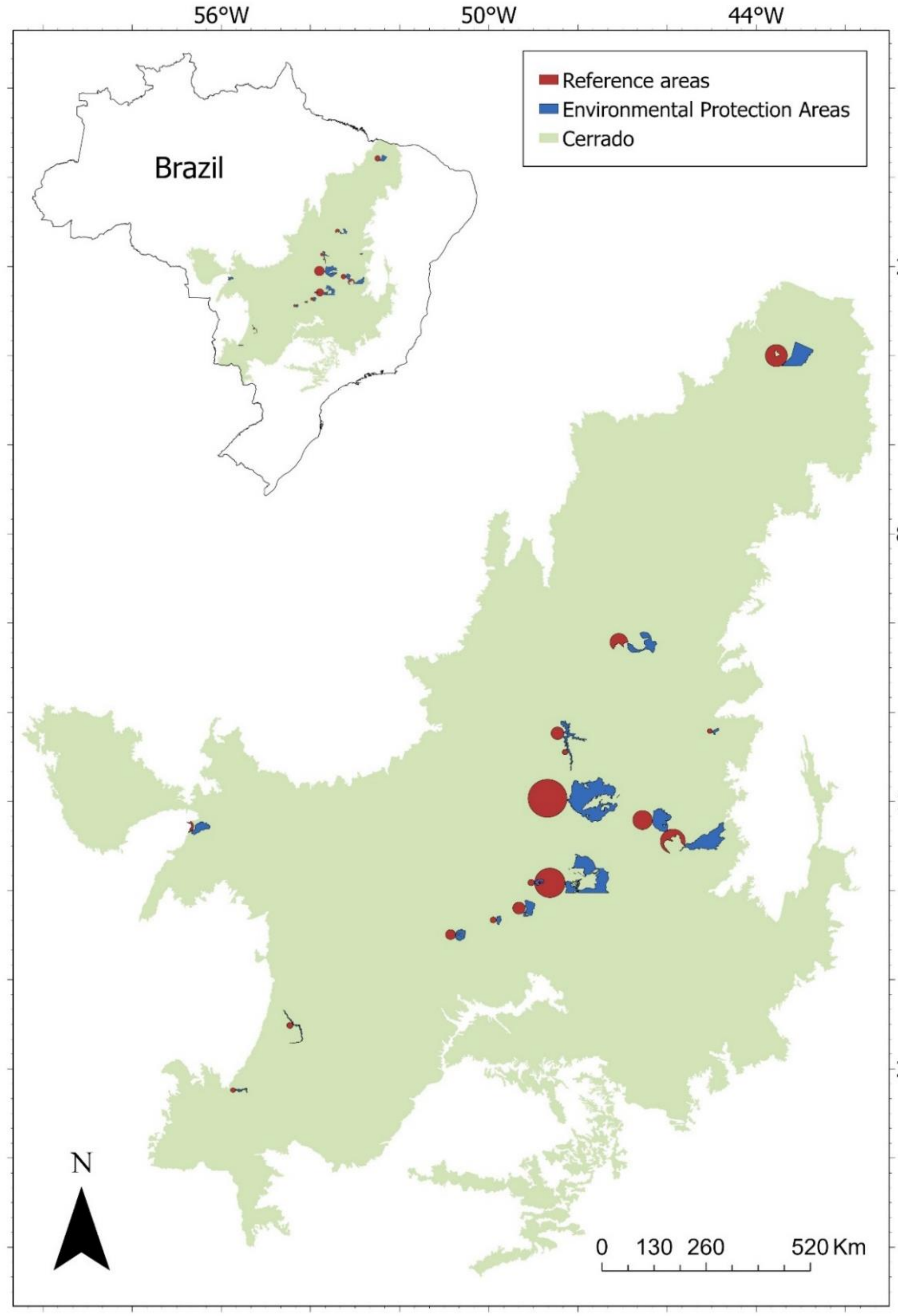

Fig. 1: Environmental Protection Areas selected for this study (blue polygons) and their corresponding reference areas (red polygons). Cerrado Biome (green polygon) according to IBGE 2019, Protected Areas to ICMBIO 2021 and Ministry of Environment 2021. Spatial reference WGS 1984.

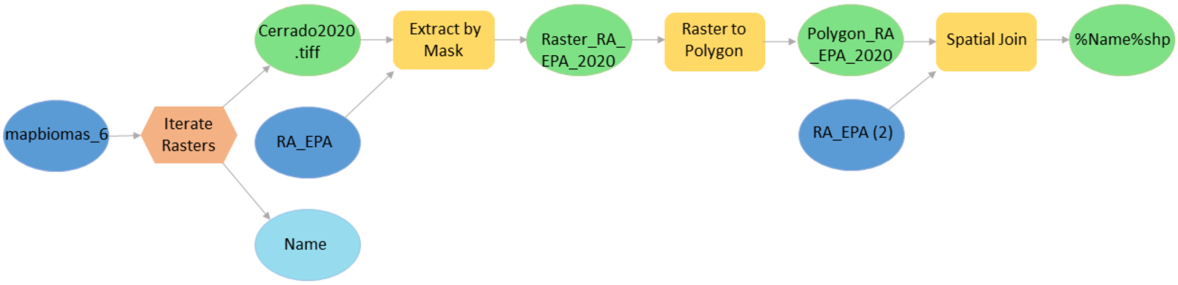

Fig. 2: Flowchart of the geoprocessing processes used to obtain the sizes of areas corresponding to the types of native vegetation over time. Input data (blue), Iterate (orange), geoprocessing tools (yellow), results of each step (green).

2.2 Carbon stock

To test whether the creation of EPA had any effect on carbon storage by native vegetation, we analyzed the carbon stock inside the EPA before and after their creation, considering the year of creation of each EPA and the most recent year available (2020). To estimate the carbon stock aggregated by the native vegetation, we used the ArcGIS PRO (ESRI Inc., USA) program together with the InVEST 3.9.0 model (Natural Capital 2021), which required data on carbon stored in aboveground biomass (trunk, leaves, branches, etc.), belowground (roots), in soil, and aboveground dead organic matter. Total carbon was estimated by InVEST using the following model:

$$CT = \sum (CA \text{ x } A) + (CR \text{ x } A) + (CS \text{ x } A) + (CM \text{ x } A)$$

Where, CT = total carbon; CA = average amount of carbon stored by aboveground biomass; A = area size; CR = average amount of carbon stored by the roots; CS = average amount of carbon stored in the soil; and CM = average amount of carbon stored in dead organic matter.

For the carbon data stored by each element mentioned, we built a database through a bibliographic survey of values estimated by collections of aboveground and underground biomass, soil organic carbon, and dead organic carbon (appendix). The bibliographic search was carried out in Google Scholar in October/2021 using the following keywords: *Estoque de carbono Cerrado, Estoque de Carbono floresta cerrado, Estoque de carbono campo rupestre Cerrado, Estoque de Carbono Cerradão, Cerrado forest carbon, Cerrado forest carbon storage, Cerrado grassland carbon, carbon Cerrado, carbon storage Cerrado Goias, Carbon* *storage Pouso Alto, review carbon Cerrado, review carbon storage Cerrado, review carbon stock Cerrado, review carbon stock Cerrado grassland, review carbon stock Cerrado forest, Carbon dead matter Cerrado, Carbon belowground biomass Cerradão, Carbon belowground biomass Cerrado forest, Carbon soil campo Cerrado, Carbon belowground biomass rupestrian grassland, litter carbon stock, 30 cm carbon grassland Cerrado, 2 m Cerrado forest carbon root, carbon storage savanna forest.*

As a geographic criterion, studies carried out in Brazilian states that did not contain any environmental protection area in our study were disregarded. We did not consider studies that presented estimation data in figure format, due to the imprecision of values. We only compiled data from estimates presented in ton per hectare (t ha^{-1}, t/ha, Mg ha^{-1}, and Mg/ha), disregarding studies in g kg-1 due to the impossibility of direct conversion. In total, we included 27 scientific studies that provided information on carbon stock estimates (appendix). Through these data, we calculated the averages for carbon stock for each type of vegetation in EPA (Table 3).

2.3 Data analysis

To measure the rate of change in land use and land cover over time for each EPA and RA we used the following finite rate of change equation:

$$\lambda = e^{\left[\frac{(\ln A_t)-(\ln A_0)}{t}\right]}$$

Where **λ** is the finite rate of change; **e** is the base of the natural logarithm (ln); $\mathbf{A_t}$ is the current amount of natural area; $\mathbf{A_0}$ is the amount of natural area in the year the EPA was created; and **t** is the number of years since EPA creation. Lambda values below 1 mean loss of native vegetation since EPA creation. Values above 1 mean gain of native vegetation and values equal 1 mean no change.

To test the effect of the existence of EPA and types of native vegetation on the rate of change (λ) we used a dependent sample factorial ANOVA since samples from EPA and its corresponding RA are spatially correlated. To test whether EPA presence affected carbon stock, we used a repeated measures ANOVA with carbon stock estimate for the time of EPA creation and for the current time, with age of the EPA as a covariate. All statistical analyses were performed using Statistica 13.0 software (Statsoft Inc. Tulsa, Oklahoma, USA).

3. Results

3.1 Land cover change

The current proportion of native vegetation in EPA ranges from 22.24% (EPA João Leite) to 96.12% (EPA Cochá e Gibão) (Table 2), with average value of 59.34%. This large variation was also present in reference areas, ranging from 10.24% (Serra da Jibóia) to 98.57% (Morros Garapenses), and average value of 50.39%.

Of the 16 EPA studied, nine presented very similar vegetation proportion at the time of creation with their respective reference areas, with a difference of less than 10% between them (Table 2). These were: Planalto Central, João Leite, Cochá e Gibão, São Desidério, Serra das Galés e da Portaria, Lago de Peixe/Angical, Jalapão, Morros Garampenses, Lago de São Salvador do Tocantins, Paranã e Palmeirópolis. There were EPA that presented more significant differences with their reference areas, having a greater proportion of vegetation. These were: Nascentes do Rio Vermelho (44.26% de diferença); Pouso Alto (23.55%); Rio Cênico Rotas Monçoeiras (27.01%); Estrada Parque de Piraputanga (19.7%); Pireneus (19.99%); Serra da Jibóia (15.7%), Nascentes do Rio Paraguai (51.53%).

In the Jalapão, Morro Garampenses e São Desidério areas the EPA had more than 70% of their area covered with native vegetation, but their respective reference areas had a slightly higher proportion of native vegetation than the protected areas themselves. In contrast, the João Leite, Serra da Jibóia e Serra das Galés e da Portaria protected areas showed a low proportion of native vegetation cover (less than 30% of their areas), with the EPA showing a slightly higher proportion of native vegetation cover than their respective reference sites.

Both EPA and RA showed little variation in the proportion of native vegetation over time (Fig. 3), but all areas showed loss of vegetation (Table 2). Two EPA showed loss of native vegetation after creation over 20%, namely: EPA Lago de Peixe/Angical, EPA Lago de São Salvador do Tocantins, Paranã e Palmeirópolis (Fig 3; Table 2). Regarding the reference areas, Lago de Peixe and Cochá e Gibão were the areas with the greatest loss of vegetation, corresponding to 13.51% and 19.63% respectively.

Environmental protection areas and non-protected areas presented similar patterns of land cover change (Fig. 4). The rate of change (λ) for environmental protection areas varied between 0.91 and 1.02, while in the reference areas it ranged from 0.91 to 1.07, with an average value of 0.99 for both. We found no significant difference in the rate of change between EPA and the reference area ($F_{1; 44}$=1.03; p = 0.31). The interaction between territorial category and vegetation type was marginally significant ($F_{2; 44}$=2.49; p = 0.094). Savanna had a significant loss, but forest and grasslands show not, with values overlapping 1 (Fig. 4). Regarding the types of vegetation, there was a difference between savanna and grassland in the reference areas, with loss of vegetation in savanna and gain in the grassland (Fig. 4).

Table 2 – Proportion of native vegetation in Environmental Protection Area (EPA) and its corresponding reference area, with difference between EPA creation and 2020. Areas with greatest difference are indicated in red

Area	**Type**	**Native vegetation (%)**		**Diff. (%)**
		Creation	2020	
Planalto Central	EPA	48.04	45.55	-2.48
	Reference	43.05	38.78	-4.26
Nascentes do Rio Vermelho	EPA	83.53	77.79	-5.74
	Reference	39.27	31.34	-7.94
João Leite	EPA	24.16	22.24	-1.91
	Reference	16.26	15.75	-0.51
Cochá e Gibão	EPA	97.96	96.12	-1.84
	Reference	92.90	73.28	**-19.63**
Pouso Alto	EPA	85.96	83.20	-2.76
	Reference	62.41	55.32	-7.08
São Desidério	EPA	73.71	69.93	-3.78
	Reference	79.97	76.14	-3.83
Lago de Peixe/Angical	EPA	81.56	54.96	**-26.60**
	Reference	85.03	71.52	**-13.51**
Jalapão	EPA	93.28	93.25	-0.02
	Reference	96.83	96.55	-0.28
Rio Cênico Rotas Monçoeiras	EPA	56.16	52.36	-3.80
	Reference	29.15	26.37	-2.78
Estrada Parque de Piraputanga	EPA	37.51	37.04	-0.47
	Reference	17.81	16.45	-1.36
Pireneus	EPA	70.88	69.84	-1.04
	Reference	50.89	50.17	-0.72
Serra da Jibóia	EPA	26.72	25.77	-0.94
	Reference	11.02	10.24	-0.78
Serra das Galés e da Portaria	EPA	27.98	27.30	-0.68
	Reference	24.19	20.87	-3.32
Nascentes do Rio Paraguai	EPA	67.33	65.49	-1.85
	Reference	15.80	14.97	-0.83
Morros Garapenses	EPA	92.66	88.18	-4.48
	Reference	99.10	98.57	-0.53
Lago de São Salvador do Tocantins, Paranã e Palmeirópolis	EPA	71.65	40.43	**-31.22**
	Reference	70.08	64.40	-5.68

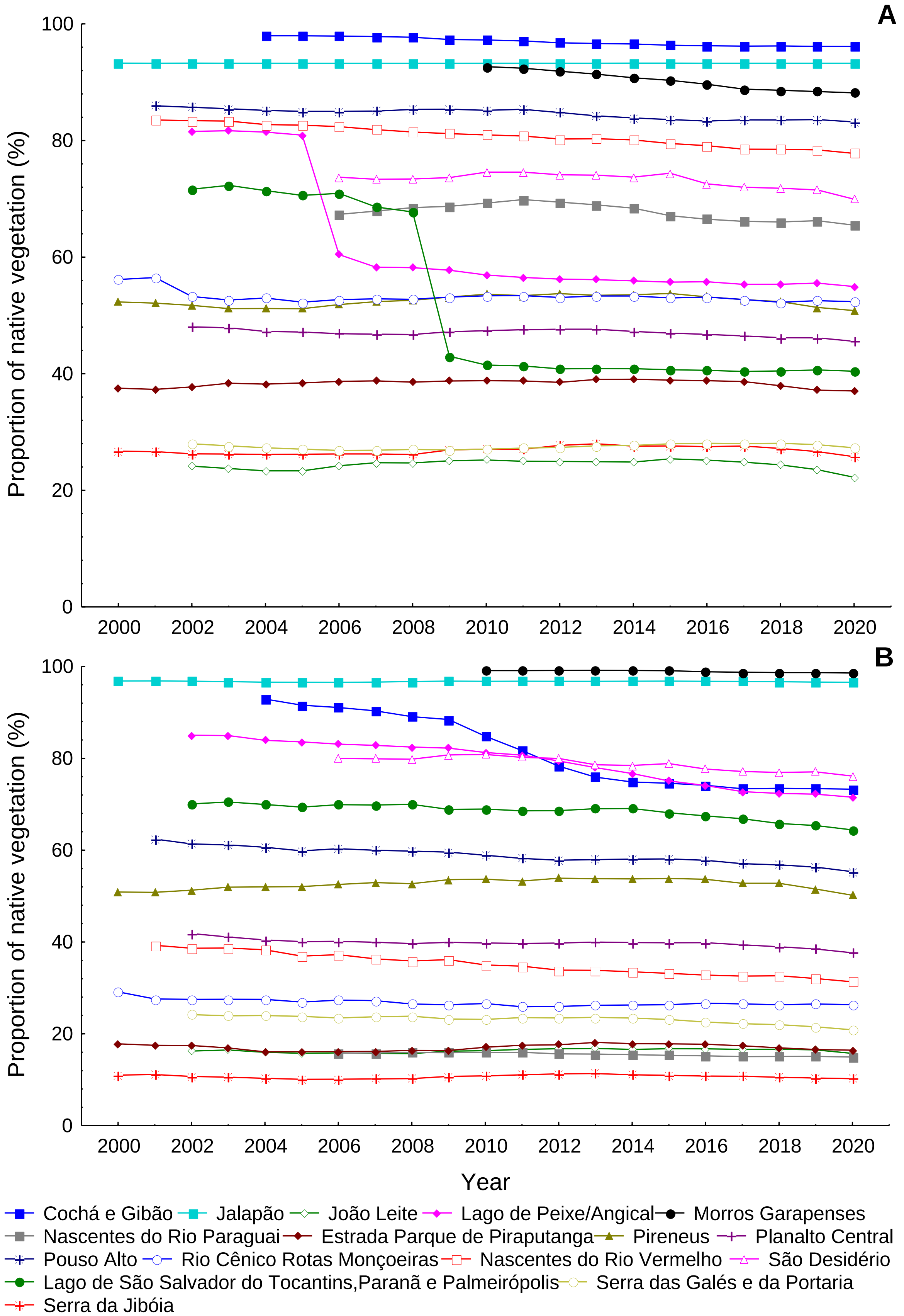

Fig. 3: Proportion of native vegetation over time in Environmental Protection Area (A) and its corresponding reference area (B), starting EPA creation year. Each line corresponds to a sample unit identified above.

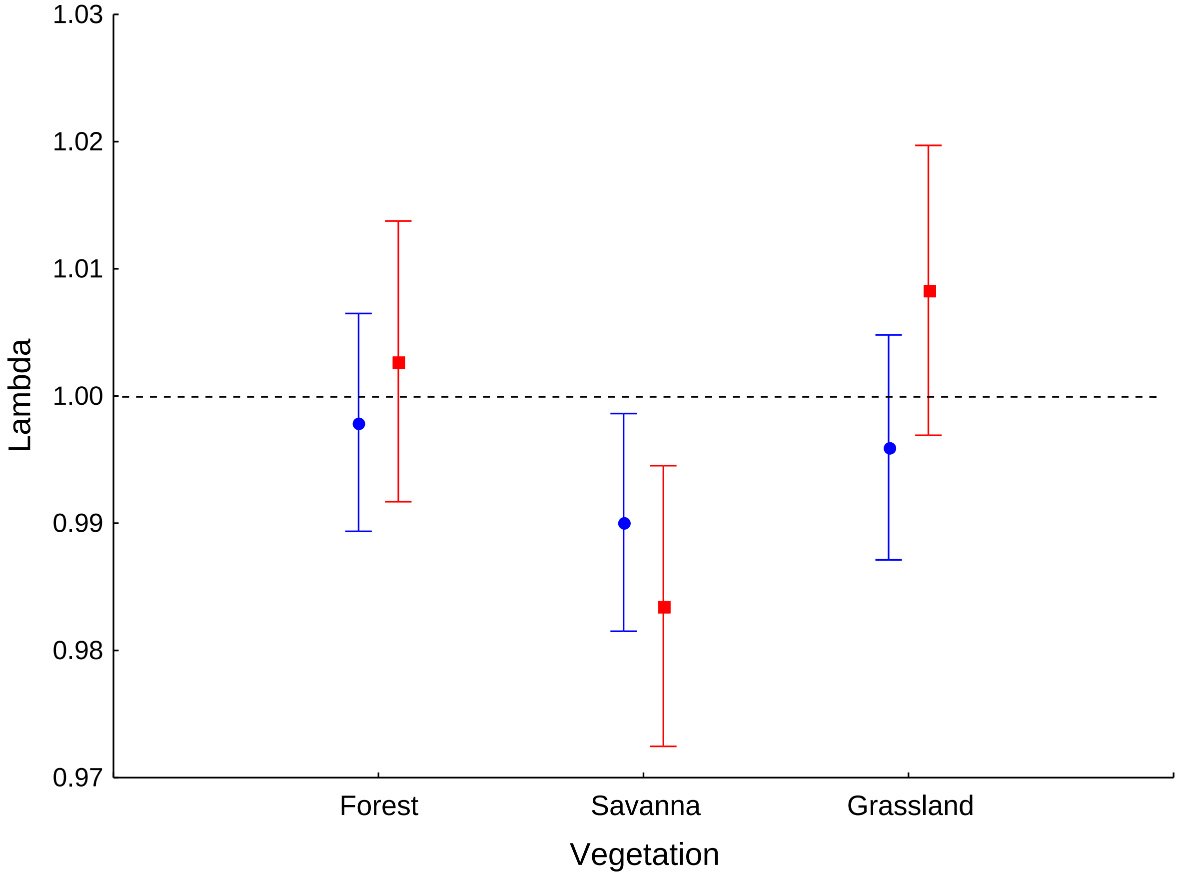

Fig. 4: Mean and 95% confidence interval of native cover rate of change (λ) by vegetation types in EPA (blue) and Reference Areas (red) in Cerrado biome. *Lambda* value equal to 1 (dotted line).

3.2 Carbon stock

Through the literature review, 27 scientific articles were used, collecting 67 estimated values of carbon stock in total (appendix). Most of the values found were for savanna (39), having 30 estimated values for soil organic carbon, 6 for aboveground biomass, 2 for belowground biomass, and 1 for dead organic carbon. We found 13 estimated values for grassland, being 4 for soil organic carbon, 6 for aboveground biomass, 2 for belowground biomass, and 1 for dead organic carbon. Finally, for forest we had 15 values, being 5 for soil organic carbon, 5 for aboveground biomass, 1 for belowground biomass, and 4 for dead organic carbon.

According to the average carbon stock values obtained from our literature review (Table 3), Forest was the vegetation type that presented the highest estimated total carbon stock (125.62 t ha^{-1}), followed by Savanna (99.89 t ha^{-1}) and Grassland (86.4 t ha^{-1}). Our results were consistent with the known characteristics of the vegetations. Forest vegetation showed high aboveground biomass (54 t ha^{-1}) compared to other vegetation types (14.23 t ha^{-1} in Savanna and 3.98 t ha^{-1} in Grassland). Therefore, the greater volume of leaves and branches of the trees reflects in greater value in Dead Organic Carbon (Morais et al., 2017), which was also found in our study. Savanna showed a higher value of belowground biomass, which is expected due to its characteristics of large volume and depth of its roots. Campo presented the highest average Soil Organic Carbon compared to woody vegetation types, consistent with what has already been reported by Chapuis Lardy et al. (2002).

Table 3: Average values used in the carbon stock model obtained from literature (appendix). Values for forest root and grassland soil were estimated through linear interpolation of data for 100 cm depth for forest root and for 20 and 40 cm depth for grassland soil. t ha^{-1}: ton per hectare.

Vegetation	Aboveground biomass	Belowground biomass (2 m)	Soil Organic Carbon (30 cm)	Dead Organic Carbon
	t ha^{-1}			
Forest	54	14.6	51.66	5.36
Savanna	14.23	21.92	60	3.74
Grassland	3.98	11.6	68.35	2.47

The average carbon stored by EPA at the initial moment was 11.2 megatons, and by 2020 (current) was 10.7. It was estimated that the EPA initially stocked together 179.1 megatons of carbon and by current they had a stock of 170.9, a reduction in the carbon stock of 8.16 megatons. On average, the set of these areas has emitted 463,723.15 tons of carbon per year (considering the average age of the areas of 17.6 years). We found no difference between the carbon stock in the initial period of the EPA to the current period ($F_{1;14}$=0.9602; p = 0.3437).

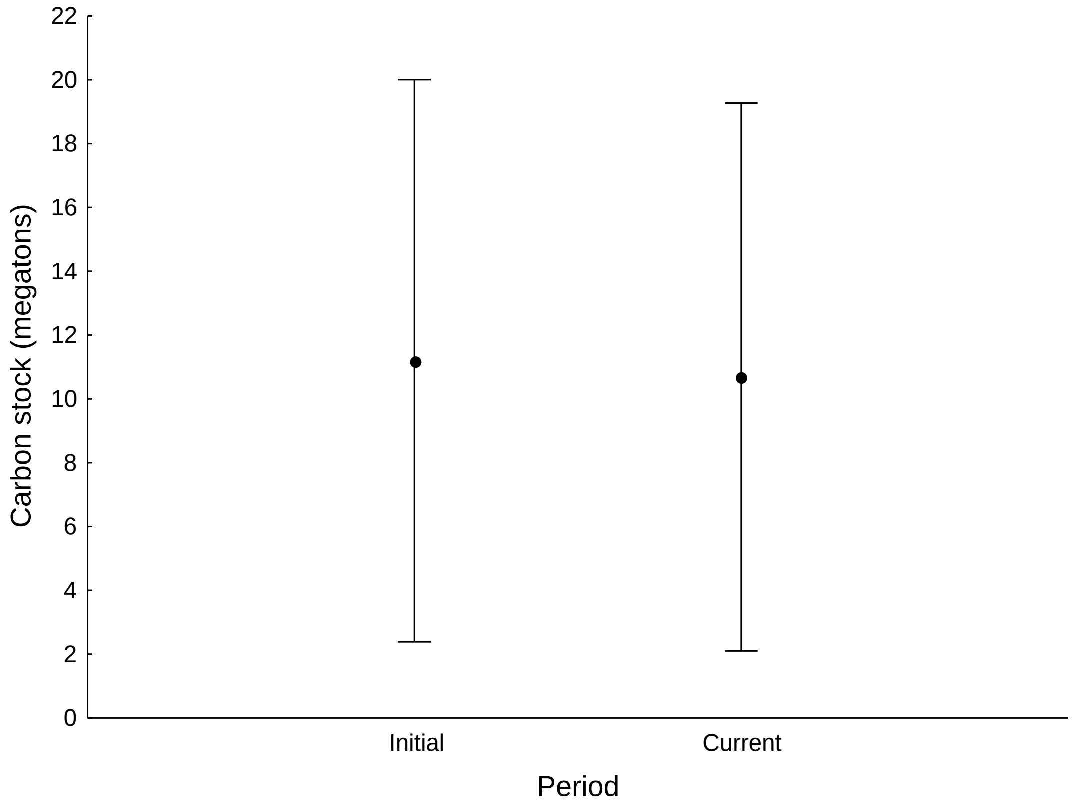

Fig. 5: Mean (95% confidence interval) of carbon stock in megatons in two periods: Initial (when EPA was created) and current (2020 data). Megaton equivalent to 1.0 x 10^6 ton.

4. Discussion

Our results indicate that the existence of protected territorial spaces in the form of EPA was not able of influencing the temporal dynamics of the change in the native vegetation cover of the Cerrado in the interval of 20 years, and its creation did not affect the carbon stock. To our knowledge, this was the first study to assess the capacity of EPA to store carbon in Brazil. In our study, we demonstrated that EPA showed the same pattern as non-protected areas and despite not having significant carbon loss, the trend in these areas was a slow loss and not an increase in carbon stock over time. Sites that were not under pressure from land use and land cover change probably tend to maintain carbon stocks, as will unprotected areas. The EPA with a low proportion of native vegetation were already inserted in the context of a degraded landscape when they were created.

According to MapBiomas, the Cerrado in 2020 presented 51.75% of its territory covered by native vegetation (forest, savanna and grassland), our reference areas data were 50.39% covered with vegetation, and the EPA presented slightly higher values of vegetation proportion

(59.34 %). The area of savanna vegetation, the dominant vegetation in Cerrado, was the one that had the greatest reduction, and its loss may be associated mainly with agricultural activities (MapBiomas 2021a; Garcia and Ballester 2016). Agriculture was the human activity that causes the greatest pressure to change land use and cover in this biome (MapBiomas 2021a).

EPA can allow agriculture activities within their areas and only 11.5% of them currently have a management plan (MMA 2021). The lack of planning in these areas is not unique to Brazil. By the end of 2018, only 5.9% of the world's protected areas had been planned (Shi et al. 2020). Despite the management plan being an indication of territorial management, in our study, we did not notice any distinction between the EPA that had a management plan and those that did. For these areas to be counted as long-term carbon sinks, efficient ways of containing deforestation are essential. To increase the capacity of EPA to store and retain carbon efficiently it is necessary to rethink environmental management policies, such as improving mechanisms for compensating environmental impacts, carrying out planning in these areas more efficiently, probably associated with means of inspection.

The loss of vegetation in the EPA Lago de Peixe/Angical and EPA Lago de São Salvador do Tocantins can been explained by land use and land cover changes were due to the flooding of areas caused by the installations of the Peixe Angical Hydroelectric Power Plant in 2006 and the São Salvador Hydroelectric Power Plant in 2009. These EPA were created before the installation of the hydroelectric plants. In both, the dams were installed on the outer boundary of the EPA, generating an intense impact on the protected area. In contrast, the EPA Lago de Peixe was created to compensate for the degradation of the environment that would be generated with the construction of the Peixe Angical Hydroelectric Power Plant (Government of the State of Tocantins 2021). In this case, the protected area, created for the purpose of environmental compensation, emitted more carbon than an unprotected area through the significant loss of vegetation.

Based on our results and other studies, the suggestion that protected areas improve carbon sequestration can be controversial. For instance, Carranza et al. (2013) evaluated the vegetation cover in Protected Areas of strict protection and sustainable use in the Cerrado and noted that although sustainable use PAs had a higher conversion rate compared to strictly protected ones, they hinder conversion compared to unprotected areas. Other authors have also shown less carbon loss within protected areas compared to unprotected areas, but carbon stocks still declined over time inside protected areas (Scharlemann et al. 2010; Nogueira et al. 2018).

However, not all studies suggest that carbon stocks decrease or remain unchanged overtime in Protected areas and some other studies showed evidence that protected areas maintained or contributed to an increase in carbon sequestration (Gizachew et al. 2018; Lu et al. 2018). In a global analysis, Shi et al. (2020) reported that carbon sequestration capacities of protected areas differ regionally and the main reason for this lies in the management capacity for these areas. Therefore, improving the management of protected areas could increase their effectiveness in retaining forest cover, and consequently, in retaining carbon stock. This can be an overall strategy to achieve the net-zero emissions.

5. Conclusion

Considering the relevance of protected areas in debates related to climate change mitigation and their plurality, this work contributes to the understanding of the role of Environmental Protection Areas, but also the Protected Landscape as all, in storing carbon as a means of providing ecosystem service. EPA showed a similar pattern in relation to unprotected areas in Cerrado and, although small, showed a loss of carbon stock. This tells us that as a long-term climate change mitigation measure, they are probably not effective. Specifically, for the Cerrado biome, this data becomes indicates something worrying pattern due to the increasing loss of native vegetation in this biome and the territorial relevance that the EPA represents.

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Appendix - Supporting Information

Table 1

Data compiled for carbon stock through a literature search. Primary source refers to the original article of the data, secondary source to the article that cites the data, sampling location to the study collection site, vegetation type was classified according to the vegetation description, Carbon site refers to AGBC, above-ground biomass carbon; BGBC, below-ground biomass carbon; DOM, dead organic matter; and soil to soil organic carbon. Depth only refers to Soil and BGCB. Carbon to the carbon stock value estimated.

Primary source	Secondary source	Sampling location	Vegetation description	Vegetation type	Carbon site	Depth	Carbon (t ha^{-1})
Marchão et al. (2009)	Batlle-Bayer et al. (2010)	Planaltina, DF	Cerrado sensu stricto	Savanna	Soil	20 cm	39.5
Marchão et al. (2009)	Batlle-Bayer et al. (2010)	Planaltina, DF	Cerrado sensu stricto	Savanna	Soil	30 cm	60.8
Freitas et al. (2000)	Batlle-Bayer et al (2010)	Goiânia, GO	Campo cerrado	Grassland	Soil	20 cm	51.2
Freitas et al. (2000)	Batlle-Bayer et al (2010)	Goiânia, GO	Campo cerrado	Grassland	Soil	40 cm	81.9
D'Andrea et al. (2004)	Batlle-Bayer et al. (2010)	Morrinhos, GO	Cerrado sensu stricto	Savanna	Soil	20 cm	37.9
Salton (2005)	Batlle-Bayer et al. (2010)	Morrinhos, GO	Cerrado sensu stricto	Savanna	Soil	40 cm	61.1
Salton (2005)	Batlle-Bayer et al (2010)	Dourados, MS	Campo cerrado	Grassland	Soil	20 cm	44.5
Salton (2005)	Batlle-Bayer et al (2010)	Maracaju, MS	Campo cerrado	Grassland	Soil	20 cm	68.7
Salton (2005)	Batlle-Bayer et al. (2010)	Campo Grande, MS	Cerrado sensu stricto	Savanna	Soil	20 cm	54
Corbeels et al. (2006)	-	Goiás	Cerrado sensu stricto	Savanna	Soil	20 cm	68.1
Dieckow et al. (2009)	Batlle-Bayer et al. (2010)	Campo Grande, MS	Cerrado sensu stricto	Savanna	Soil	20 cm	48.77

Primary source	Secondary source	Sampling location	Vegetation description	Vegetation type	Carbon site	Depth	Carbon (t ha^{-1})
Dieckow et al. (2009)	Batlle-Bayer et al. (2010)	Dourados, MS	Cerrado sensu stricto	Savanna	Soil	20 cm	44.5
Jantalia et al. (2007)	Batlle-Bayer et al. (2010); Maia et al. (2013)	Planaltina, DF	Cerrado sensu stricto	Savanna	Soil	30 cm	96.6
De Castro and Kauffman (1998)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo limpo	Grassland	AGB	-	2.75
De Castro and Kauffman (1998)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo limpo	Grassland	BGB	2 m	8.15
Kauffman et al. (1994)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo limpo	Grassland	AGB	-	3.55
De Castro and Kauffman (1998)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo sujo	Grassland	AGB	-	4.65
De Castro and Kauffman (1998)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo sujo	Grassland	BGB	2 m	15.05
Kauffman et al. (1994)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo sujo	Grassland	AGB	-	3.65
Kauffman et al. (1994)	Batlle-Bayer et al (2010)	Brasilia, DF	Campo cerrado	Grassland	AGB	-	4.3
De Castro and Kauffman (1998)	Batlle-Bayer et al. (2010)	Brasilia, DF	Cerrado aberto/ Cerrado sensu stricto	Savanna	AGB	-	12.4
De Castro and Kauffman (1998)	Batlle-Bayer et al. (2010)	Brasilia, DF	Cerrado aberto/ Cerrado sensu stricto	Savanna	BGB	2 m	23.3
Abdala et al. (1998)	Batlle-Bayer et al. (2010)	Brasilia, DF	Cerrado sensu stricto	Savanna	AGB	-	18.4
Abdala et al. (1998)	Batlle-Bayer et al. (2010)	Brasilia, DF	Cerrado sensu stricto	Savanna	BGB	2 m	20.55
Zimbres et al. (2020)	-	Itapirapuã, GO	Cerradão	Forest	AGB	-	38.3

Primary source	Secondary source	Sampling location	Vegetation description	Vegetation type	Carbon site	Depth	Carbon (t ha^{-1})
Zimbres et al. (2020)	-	Brasilia, DF	floresta de galeria	Forest	AGB	-	149.6
Zimbres et al. (2020)	-	Brasilia, DF	Cerrado sensu stricto	Savanna	AGB	-	21.7
Maia et al. (2010)	Maia et al (2013)	Novo São Joaquim, MT	Cerradão	Forest	Soil	30 cm	53
D'Andrea et al. (2004)	Maia et al. (2013)	Morrinhos, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	45.8
D'Andrea et al. (2004)	-	Morrinhos, GO	Cerrado sensu stricto	Savanna	Soil	40 cm	61.1
Maia et al. (2010)	Maia et al (2013)	Itauba, MT	Cerradão	Forest	Soil	30 cm	54.4
Maia et al. (2010)	Maia et al (2013)	Ribeirão Cascalheira, MT	Cerradão	Forest	Soil	30 cm	38.5
Maia et al. (2010)	Maia et al (2013)	Sorriso, MT	Cerradão	Forest	Soil	30 cm	61.4
Bayer et al. (2006)	Maia et al. (2013)	Luziânia, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	47.2
Maia et al. (2010)	Maia et al. (2013)	Sapezal, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	27.9
Frazão (2007)	Maia et al. (2013)	Comodoro, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	16.5
Pavinato (2009)	Maia et al. (2013)	Sapezal, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	85.9
Maia et al. (2010)	Maia et al. (2013)	Itiquira, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	67.1
Freitas et al. (2000)	Maia et al. (2013)	Senador Canedo, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	61.4
Corazza et al. (1999)	Maia et al. (2013)	Planaltina, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	52.4
Salton et al. (2011)	Maia et al. (2013)	Dourados, MS	Cerrado sensu stricto	Savanna	Soil	30 cm	59.2

Primary source	Secondary source	Sampling location	Vegetation description	Vegetation type	Carbon site	Depth	Carbon (t ha^{-1})
Roscoe et al. (2003)	Maia et al. (2013)	Sete Lagoas, MG	Cerrado sensu stricto	Savanna	Soil	30 cm	76
Pavinato (2009)	Maia et al. (2013)	Luziania, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	72.2
Pavinato (2009)	Maia et al. (2013)	Costa Rica, MS	Cerrado sensu stricto	Savanna	Soil	30 cm	85.9
Lilienfein and Wilcke (2003)	Maia et al. (2013)	Uberlandia, MG	Cerrado sensu stricto	Savanna	Soil	30 cm	55
Dieckow et al. (2009)	Maia et al. (2013)	Dourados, MS	Cerrado sensu stricto	Savanna	Soil	30 cm	59.4
Carvalho et al. (2010)	Maia et al. (2013)	Santa Carmen, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	74.1
Carvalho et al. (2010)	Maia et al. (2013)	Montividiu, GO	Cerrado sensu stricto	Savanna	Soil	30 cm	75.4
Salton et al. (2011)	Maia et al. (2013)	Maracaju, MS	Cerrado sensu stricto	Savanna	Soil	30 cm	91.4
Maia et al. (2010)	Maia et al. (2013)	Água Boa, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	35.2
Maia et al. (2010)	Maia et al. (2013)	Sapezal, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	49
Maia et al. (2010)	Maia et al. (2013)	Sapezal, MT	Cerrado sensu stricto	Savanna	Soil	30 cm	25.7
Morais et al. (2013)	-	Limeira do Oeste, MG	Cerradão	Forest	DOM	-	5.36
Morais et al. (2013)	-	Limeira do Oeste, MG	Cerradão	Forest	AGB	-	36.78
Morais et al. (2013)	-	Limeira do Oeste, MG	Cerradão	Forest	BGB	100 cm	7.3
Scolforo et al. (2008)	Morais et al. (2017)	Minas Gerais	Campo	Grassland	AGB	-	5
Scolforo et al. (2008)	Morais et al. (2017)	Minas Gerais	Cerrado sensu stricto	Savanna	AGB	-	14.3

Primary source	Secondary source	Sampling location	Vegetation description	Vegetation type	Carbon site	Depth	Carbon ($t\ ha^{-1}$)
Scolforo et al. (2008)	Morais et al. (2017)	Minas Gerais	Floresta	Forest	AGB	-	35.1
Morais et al. (2017)	-	Minas Gerais	Campo	Grassland	DOM	-	2.47
Morais et al. (2017)	-	Minas Gerais	Cerrado sensu stricto	Savanna	DOM	-	3.74
Morais et al. (2017)	-	Minas Gerais	Floresta	Forest	DOM	-	4.68
Torres et al. (2013)	Morais et al. (2017)	Minas Gerais	Florestas estacionais semideciduais	Forest	DOM	-	5.82
Morais et al. (2013)	Morais et al. (2017)	Minas Gerais	Floresta	Forest	DOM	-	5.58
Pereira et al. (2020)	-	Montes Claros, MG	Cerrado sensu stricto	Savanna	AGB	-	11.82
Dionizio et al (2020)	-	West of Bahia	Cerradão	Forest	Soil	30 cm	51
Dionizio et al (2020)	-	West of Bahia	Cerradão	Forest	AGB	-	12.06
Dionizio et al. (2020)	-	West of Bahia	-	Savanna	AGB	-	6.771

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CONCLUSÃO GERAL

Considerando a relevância das áreas protegidas nos debates relacionados à mitigação das mudanças climáticas e sua pluralidade, este trabalho traz contribuições para a compreensão do papel das Áreas de Proteção Ambiental no armazenamento de carbono como meio de prestação de serviço ecossistêmico. As APA apresentaram padrão semelhante em relação às áreas não protegidas do Cerrado e, embora pequena, apresentaram perda de estoque de carbono. Isso nos diz que, como medida de mitigação das mudanças climáticas de longo prazo, elas provavelmente não são eficazes. Especificamente, para o bioma Cerrado, esses dados tornam-se indicativos de um padrão preocupante devido à crescente perda de vegetação nativa neste bioma e a relevância territorial que a APA representa. Considerando que o Plano Estratégico Nacional de Áreas Protegidas tem como uma das estratégias a potencialização das APA como instrumento relevante de ordenamento territorial, o nosso trabalho contribui neste sentido fornecendo uma análise robusta que pode ser utilizada na tomada de decisão pelos órgãos gestores das unidades.