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Áreas prioritárias para a restauração no Cerrado: aumentando benefícios e reduzindo conflitos

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“O conhecimento nos faz responsáveis.”

Ernesto Che Guevara

Resumo

O Cerrado, um *hotspot* de biodiversidade e importante provedor de serviços ecossistêmicos, é a maior fronteira agrícola brasileira. Cerca de 43% da sua vegetação original já foi convertida para uso antrópico, sendo que pastagens representam 29% de sua área. Essas pastagens encontram-se subutilizadas, representando uma oportunidade para a expansão da agricultura evitando novos desmatamento e também para o cumprimento de demandas de restauração. O planejamento espacial da restauração pode identificar áreas mais valiosas para a conservação e evitar maiores conflitos com as demandas da agricultura. Nosso objetivo foi gerar um mapa de áreas prioritárias para a restauração de pastagens no Cerrado considerando ganhos para a biodiversidade e serviços ecossistêmicos, potencial de regeneração natural e a aptidão agrícola. Utilizamos análises de conectividade de habitat e índice de degradação de pastagens para identificar áreas com maior potencial de regeneração natural. Também geramos sete cenários de priorização para a restauração de pastagens no Cerrado assim como para quatro ecorregiões. Esses cenários foram sobrepostos para identificarmos áreas com maior importância para a conservação. Observamos que 44% das pastagens tem potencial de regeneração baixo (< 0,25), 45% têm potencial intermediário-baixo (>0,25 e <0,50), 10% intermediário-alto (>0,50 e <0,75) e 1% alto (> 0,75) indicando que mais da metade das pastagens no Cerrado tem algum potencial para regeneração natural. Os cenários de priorização para a restauração revelam *trade-offs* entre os diversos objetivos com perdas de até 16 Mha de áreas aptas para a agricultura no cenário de maior conflito. Contudo, 9,8 Mha (49% da demanda de restauração), mostram alto valor de conservação. Os padrões são distintos por ecorregião, revelando que a regionalização pode adequar projetos de priorização às demandas locais. Nossas análises mostram que o planejamento espacial das ações de restauração pode reduzir esse conflito e trazer benefícios tanto para a conservação quanto para a agricultura.

Palavras-chave: Biodiversidade; Serviços ecossistêmicos; Regeneração natural; Agricultura

Abstract

Cerrado, a biodiversity hotspot and an important ecosystem services provider, is the Brazilian greater agricultural frontier. Roughly 43% of its original vegetation has been converted to human use, and pastures cover 29% of its territory. Those pastures are underused and have different degrees of degradation, representing an opportunity for agriculture expansion without further deforestation and to meet restoration demands. Spatial planning for restoration can identify important areas for conservation and avoid major conflicts with agriculture. Our objective was to create a priority map for restoration in Cerrado's pastures considering gains in biodiversity and ecosystem services, the potential for natural regeneration, and agriculture suitability. We used habitat connectivity analysis and pasture degradation index to identify areas with a greater potential for natural regeneration. We also generated seven scenarios for the restoration of the entire Cerrado's pastures and for four ecoregions to minimize spatial bias. We overleap these scenarios to find areas with greater conservation value. Our results show that 44% of Cerrado's pasture have a low potential for natural regeneration (< 0.25), 45% have intermediary-low potential (> 0.25 and < 0.50), 10% have an intermediary-high potential (> 0.50 and < 0.75) and only 1% have high potential (> 0.75), indicating that more than half of Cerrado's pastures have some potential for natural regeneration. The prioritization for restoration scenarios revealed trade-offs between the targets with a loss of up to 16 Mha of areas suitable for agriculture in the highest conflict scenario. On the other hand, 9.8 Mha (49% of the restoration demand) showed high conservation value. However, these patterns are different according to the ecoregion, meaning that, by regionalizing the restoration planning, we can better meet regional demands. Our analysis shows that spatial planning for restoration may reduce conflicts and benefit both conservation and agriculture.

Keywords: Biodiversity; Ecosystem Services; Natural regeneration; Agriculture

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Introdução Geral

As atividades antrópicas, principalmente a partir do último século, têm afetado profundamente os ecossistemas, tanto aquáticos quanto terrestres, assim como os diversos processos ligados a eles que são responsáveis pela manutenção da vida no planeta (Steffen et al. 2015). Os efeitos da perda e fragmentação de hábitat, sobre-exploração dos recursos naturais e mudanças climáticas já podem ser sentidos ao redor do globo. Estamos vendo eventos extremos mais intensos e frequentes, redução da disponibilidade de água e aumento de epidemias que afetam principalmente as populações humanas mais vulneráveis (IPCC 2014). Os efeitos sobre as outras formas de vida no planeta também são severos. Os tamanhos populacionais de espécies de vertebrados declinaram em 60% nos últimos 50 anos, e observamos uma taxa de extinção cinco vezes maior que a observada no pré-Antropoceno (Barnosky et al. 2011; WWF 2018).

A perda e fragmentação de hábitat é a principal causa do declínio da biodiversidade no planeta, além de ter um enorme impacto nas emissões globais de carbono (Dobson, Bradshaw, and Baker 1997; Myers et al. 2000; Poore and Nemecek 2018). Até o ano 2000, 75% dos ambientes naturais já haviam sido convertidos para o uso antrópico, sendo a expansão agropecuária a atividade mais importante nesse processo (Ellis 2011). As regiões tropicais, que concentram grande parte da biodiversidade do mundo, são especialmente ameaçadas pelo desmatamento. Cerca de 6,5 Mha de florestas tropicais foram cortadas entre 2002 e 2010 (Kim, Sexton, and Townshend 2015). Além disso, estima-se que 26% das emissões de carbono mundial venham da cadeia de produção agrícola, incluindo o desflorestamento causado para expansão da fronteira agrícola, a produção de fertilizantes e o uso de combustíveis fósseis no transporte e que 65% da água doce consumida no mundo sejam para irrigação (Poore et al. 2018).

Hábitats fragmentados estão mais suscetíveis ao efeito de borda e à redução da biodiversidade em longo prazo, além de terem suas funções, como a ciclagem de nutrientes, comprometidas (Haddad et al. 2015). O uso intensivo, prolongado e sem o manejo adequado também leva à degradação do solo das áreas convertidas. Solos degradados são incapazes de sustentar a produção agropecuária, perdem sua resiliência e têm suas funções ecológicas reduzidas (Lal 1993). Como esses sistemas degradados têm baixa resiliência, podendo levar muitos anos para retornarem a um estado similar ao original, intervenções de restauração se tornam uma alternativa para acelerar o processo e recuperar a biodiversidade, estrutura e funções desses ecossistemas (Clewell, Aronson, and Winterhalder 2004; Young 2000).

A restauração ecológica é definida justamente como o processo de auxiliar ecossistemas degradados a recuperar suas características, visando restabelecer os atributos chave para seu bom funcionamento (Clewell, Aronson, and Winterhalder 2004; Mcdonald et al. 2016). Esses atributos são específicos de cada ecossistema e consistem das condições físicas, composição de espécies, diversidade estrutural, funções ecossistêmicas e conectividade do sistema alvo com demais manchas de hábitat (Mcdonald et al. 2016). Um ecossistema é considerado restaurado quando esses atributos se assemelham aos de um ecossistema equivalente e conservado usado como referência (Clewell, Aronson, and Winterhalder 2004).

Dentre as diversas iniciativas que buscam reduzir e mitigar os impactos das atividades humanas no meio ambiente, se destacam as 20 metas para a redução da perda de biodiversidade no mundo, conhecidas como as metas Aichi para a Biodiversidade, estabelecidas na 10ª Conferência das Partes da Convenção sobre Diversidade Biológica (COP-10) realizada em 2010, no Japão. Dentre essas, as metas 14 e 15 preveem o aumento dos benefícios à biodiversidade por meio da recuperação da vegetação nativa (MMA 2017). Visando atender essas e demais metas ligadas à recuperação e conservação da biodiversidade, o Governo

Brasileiro instituiu em 2017 o Plano Nacional de Recuperação da Vegetação Nativa (PLANAVEG), que prevê a recuperação de 12 Mha em todo o país até 2030 (MMA 2017).

Além de cumprir as metas internacionais, o PLANAVEG tem como objetivo subsidiar o cumprimento da nova Lei de Proteção da Vegetação Nativa (vulgarmente conhecida como o novo Código Florestal) aprovado em 2012. Com a implementação do novo Código, o déficit ambiental das propriedades privadas no Brasil foi reduzido em mais da metade (Soares-Filho et al. 2014). Somando-se o déficit de Reserva Legal (RL) e Áreas de Proteção Permanente (APP) ripárias, aproximadamente 50 Mha estavam irregulares no país (Soares-Filho et al. 2014). Com a aprovação do novo código, o déficit caiu para 21 Mha em todo o Brasil (Soares-Filho et al. 2014). Tal redução mostra diversas faces quando se analisa as mudanças na legislação ambiental em detalhe. Umas das maiores diferenças está na determinação da RL e das APPs. De acordo com o antigo Código, áreas ripárias, assim como encostas e topos de morro, deveriam ser mantidas como APPs pelos proprietários (Silva et al. 2011). Adicionalmente, 80% da propriedade deveria ser mantida como RL para a Amazônia, e 20% para os demais biomas, sendo que, tanto para as APPs quanto para a RL, as áreas degradadas deveriam ser restauradas (Silva et al. 2011). O novo marco legal mudou a legislação referente às áreas de topo de morro, permitiu que APPs ripárias entrassem no cálculo da RL, sob condições específicas, e concedeu anistia a “pequenas” propriedades desmatadas antes de julho de 2008. (Silva et al. 2011; Soares-Filho et al. 2014). Isso causou a redução de 29 Mha na área a ser restaurada no país (Soares-Filho et al. 2014).

Juntamente com a nova Lei de Proteção da Vegetação Nativa, nasceu um mecanismo voltado a regularizar o passivo ambiental dos proprietários de terras no Brasil: o Cadastro Ambiental Rural (CAR). O CAR é o registro obrigatório e auto-declatório das propriedades e deve conter os limites georeferenciados da propriedade, assim como os limites da RL, APPs, áreas de uso restrito e áreas desmatadas antes de 2008 (Roitman, Cardoso, et al. 2018). Estima-se que 53% da vegetação nativa do Brasil esteja em propriedades privadas (Soares-Filho et al. 2014). Somando-se isso aos 21 Mha de passivo ambiental, o CAR pode se tornar uma ferramenta poderosa para o cumprimento dos objetivos brasileiros referentes à restauração de ecossistemas e conservação da biodiversidade.

Ainda assim, a expansão da fronteira agrícola brasileira é uma ameaça real à biodiversidade e tem avançado nos últimos anos (Dias et al. 2016; Sano et al. 2010). Estima-se que 2,5 Mha de florestas tropicais tenham sido cortadas no Brasil entre 2002 e 2010 (Kim, Sexton, and Townshend 2015). Mas não apenas as florestas estão ameaçadas pela expansão da fronteira agrícola. O bioma Cerrado é especialmente suscetível a essa mudança de uso da terra. Cerca de 43% de sua vegetação original já foi perdida (MapBiomas 2019), e cerca de 663.400 ha de vegetação nativa foi convertida em 2018 e 2019 (INPE 2019). Somando-se a essa taxa de conversão, há a escassez de áreas protegidas no bioma, com apenas 3% das áreas em regime de proteção integral, e os 40 Mha que ainda podem ser desmatados legalmente de acordo com a nova Lei, agravando ainda mais a situação de vulnerabilidade do bioma Cerrado (Overbeck et al. 2015; Soares-Filho et al. 2014).

O Cerrado é o segundo maior bioma brasileiro, atrás apenas da Amazônia, e ocupa uma área de 204 Mha, cerca de 23% do território nacional (IBGE 2004). Esse bioma engloba um mosaico composto por três tipos principais de vegetação: florestal, savânica e campestre (Ribeiro and Walter 2008). Atualmente, as formações florestais, representadas pelas Matas Ciliares, de Galeria, Secas e o Cerradão, ocupam 21% do território do bioma (MMA 2015; Ribeiro and Walter 2008). Já as formações não-florestais compreendem 34% do Cerrado e são caracterizadas como Cerrado *sensu stricto* e os Campos Sujos, Limpos e Rupestres (MMA 2015; Ribeiro and Walter 2008). Ambientes não vegetados e corpos d’água representam 2% do bioma, enquanto o uso antrópico corresponde a 43% da cobertura da terra (MMA 2015). Além da diversidade de formações, o bioma concentra uma das maiores biodiversidades do planeta.

Estima-se que o Cerrado abrigue mais de 14 mil espécies de plantas, 90 mil espécies de insetos, 837 de aves, 199 de mamíferos, 150 de anfíbios e 120 de répteis (WWF-Brasil 2015). Isso corresponde a cerca de 30% das espécies de flora e fauna do país e 5% das espécies do mundo (WWF-Brasil 2015). Por suas características únicas, o bioma apresenta uma alta taxa de endemismo. Cerca de 1,5% das plantas e 0,4% dos vertebrados do mundo são exclusivos do Cerrado, tornando-o um *hotspot* global para a conservação da biodiversidade (Myers et al. 2000).

As mudanças de uso da terra também apresentam um risco para a provisão de serviços ecossistêmicos. O Cerrado contribui para oito das doze principais bacias do Brasil, com 94% do volume de água da bacia do Rio São Francisco, 71% da bacia Tocantins-Araguaia e 71% da bacia Paraná-Paraguai (Lima and Silva 2005). A combinação de Latossolos bem drenados com o sistema radicular profundo da vegetação nativa também provê a recarga de aquíferos e a manutenção da umidade do ar durante a estação seca através da evapotranspiração (Oliveira et al. 2005). O sequestro e estoque de carbono também vêm sendo contabilizados como importantes serviços prestados pelos ecossistemas. O estoque original de carbono no Cerrado é estimado em 21,3 Pg C, sendo que grande parte desse carbono se encontra na biomassa abaixo do solo (Leite et al. 2012; Miranda et al. 2014). Contudo, esse estoque tem sido rapidamente mobilizado pela mudança de uso da terra. Estima-se que a emissão de carbono atribuída a mudança de uso da terra no Brasil, entre 1940 e 1995, foi de 17,2 Pg C com uma média de 0,31 Pg C por ano, sendo que 72% dessa emissão é consequência do desmatamento da Mata Atlântica e Cerrado (Leite et al. 2012).

Nesse período (1940-1995), observa-se um padrão claro de ocupação do Cerrado a partir do sul do bioma, nos estados de São Paulo e Mato Grosso do Sul, e que recentemente se intensificou na porção norte, nas regiões do chamado MATOPIBA, que incluiu os estados do Maranhão, Tocantins, Piauí e Bahia, e do Arco do Desmatamento (Dias et al. 2016; Leite et al.

2012; Parente and Ferreira 2018). A pecuária é a principal atividade desenvolvida no bioma, sendo predominantemente exercida sobre pastagens naturais até 1975, quando iniciou-se a expansão das pastagens plantadas, principalmente com gramíneas exóticas (Dias et al. 2016; Leite et al. 2012). Atualmente as pastagens plantadas ocupam 29% da área do Cerrado, enquanto a agricultura representa cerca de 12% do uso da terra (MMA 2015; Sano et al. 2010). Essas pastagens se encontram em diversos níveis de degradação, muitas vezes sendo impróprias para a produção pecuária e apresentando altas proporções de solo descoberto e taxas de erosão (Dias-Filho 2014).

A combinação da expansão agrícola com poucas áreas de proteção no Cerrado geram projeções preocupantes quanto ao futuro do bioma e sua biodiversidade. Caso os padrões atuais de mudança no uso da terra se mantenham, espera-se a perda de 34% da vegetação remanescente do Cerrado até 2050, levando aproximadamente 480 plantas endêmicas à extinção (Câmara et al. 2015; Strassburg et al. 2017). Esse cenário pode ser evitado com a mudança do sistema extensivo de produção agropecuária para um mais intensivo e uso de áreas já desmatadas disponíveis para a agricultura (Strassburg et al. 2017). Contudo, a intensificação da agricultura também gera impactos e tem sua demanda energética e hídrica. Ao se intensificar o sistema de cultivo de simples para duplo, por exemplo, se aumenta a produção geral da propriedade ao mesmo tempo que se aumenta o consumo de água para a irrigação e a emissão de carbono pelo uso e transporte de insumos (FAO 2016).

A esse cenário de uso mais inteligente da terra para a produção, e convergindo com os objetivos e obrigações legais previstos pela Lei de Proteção da Vegetação Nativa e no PLANAVEG, podemos destacar a importância do planejamento espacial da restauração, em especial no bioma Cerrado que apresenta um grande potencial agrícola associado a uma das maiores biodiversidades do mundo e grande importância para o abastecimento de água em todo o país. Esse planejamento pode maximizar os benefícios para a conservação da biodiversidade e os ganhos em serviços ecossistêmicos ao mesmo tempo que reduz os conflitos com a produção agropecuária.

A partir da classificação das áreas de pastagens menos adequadas para conversão para a agricultura, é possível identificar e priorizar aquelas com maior potencial de regeneração natural e que resultem em maiores benefícios para conservação da biodiversidade, assim como áreas importantes para a manutenção dos recursos hídricos e estabilidade climática por meio de sequestro de carbono com a restauração.

Dessa forma, o objetivo geral desse trabalho foi priorizar áreas para a restauração no Cerrado visando o máximo retorno em biodiversidade e serviços ecossistêmicos, e reduzindo o conflito com a produção agropecuária, espacializado em um mapa de áreas prioritárias para a restauração no Cerrado.

Para atingir o objetivo geral, quatro objetivos específicos foram definidos: (i) agregar as informações e mapas já existentes sobre o passivo ambiental, pastagens degradadas, distribuição da biodiversidade, distribuição de biomassa por hectare, potencial de recarga de aquíferos, malha hidrográfica e potencial expansão agrícola; (ii) gerar um mapa do potencial de regeneração natural para as pastagens do Cerrado, considerando a conectividade e o estado de degradação dessas pastagens; (iii) gerar cenários de priorização focados em cada um dos benefícios citados em *i* identificando os *trade-offs* entre os cenários; e (iv) integrar e espacializar todas as informações em um mapa de áreas prioritárias para a restauração no Cerrado.

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Capítulo I

Estimating the potential for natural regeneration of Cerrado vegetation in pasturelands

Abstract

Natural regeneration has been considered as a strategy to lower costs of restoration and help it to gain a larger scale. It has two main premises to happen: propagule source and local conditions that allow the establishment of those propagules. Overall, landscape connectivity plays a critical role in propagule dispersal, while land-use history has a direct effect on local conditions. The Brazilian Cerrado is the most biodiverse savanna in the world and provides essential ecosystem services. The biome is also very threatened by agriculture expansion and has over 4.3 Mha of land that must be restored according to the Brazilian Forest Code. Pastures cover around 29% of its territory in different levels of degradation and thus represent an excellent opportunity to meet the restoration goals. To estimate the potential of natural regeneration of these pastures, we developed a framework consisting of two steps: (a) to assess Cerrado's landscape conditions based on the amount habitat and connectivity; and (b) merge this information with a Pasture Quality Index, used as a proxy to local conditions for propagule establishment. We also conducted a pilot field assessment in an area showing sites in different regeneration stages based on remote sensing. We found that most pastures in the Cerrado are located in poorly connected areas and present a low potential for natural regeneration. Our field assessment also revealed that restoration projects based on natural regeneration must be monitored and managed to guarantee its success as periodic disturbances such as fire events hinder the development of the plant community.

Keywords: Connectivity; Ecosystem resilience; Landscape quality; Land cover; Restoration

1. Introduction

The growth of the human population and the consequent expansion of cities and agricultural lands over natural ecosystems has profoundly altered the landscape configurations and functionality (Tilman et al. 1994; Ellis 2011). What once was a continuous habitat became a set of small and isolated fragments that, in many cases, are not able to sustain biodiversity (Fahrig 2003; Haddad et al. 2015). Fragmented landscapes have three main components that directly influence the ecosystems processes and the biodiversity: patches features, such as size and form; patches spatial arrangement, distance from other patches and position on the landscape; and matrix quality, which directly influences the quality of the habitat inside the patch and the connectivity between patches (Fahrig 2003).

There are many ways to manage the matrix component to improve the overall quality of the landscape. One of the most studied is the ecological restoration of the vegetation at a landscape scale. It is well established that strategic restoration actions can improve connectivity and patch quality (Rudnick et al. 2012; Crouzeilles et al. 2016). However, the overall characteristics, especially the connectivity of a landscape, can have significant impacts on restoration success (Tambosi et al., 2014; Crouzeilles et al., 2017; Molin et al., 2018). According to Clewell, Aronson, and Winterhalder (2004), restoration success is achieved when the characteristics of a restored site, such as species composition, structure and ecosystem functions, are equivalent to those of a well-preserved reference site.

Many variables are determinant for the success of a restoration project, and the method applied to restore an ecosystem has a key role in that. Ecological restoration techniques vary on a spectrum of human intervention intensity, from actively planting seedlings to a minimal intervention natural regeneration (Clewell, Aronson, and Winterhalder 2004). Worldwide, the most used method is the active planting of available seedlings (Clewell, Aronson, and Winterhalder 2004). However, a meta-analysis conducted by Latawiec et al. (2016) showed that self-regenerated forests were more similar to old-growth references than actively restored ones.

Matrix quality, landscape connectivity, and disturbance regime and intensity are critical determiners of a site resilience, which is the ability of an ecosystem to recover from past disturbances (Bowen et al., 2007; Lange et al., 2012; Buisson et al., 2018). This feature also allows a less interventionist restoration method, considerably reducing the costs of the project (Chazdon, 2013; Strassburg et al., 2016). Habitat amount and landscape connectivity are majorly important for propagule dispersal. However, for a propagule to be able to colonize a site, the site must have appropriate conditions for it to establish. These conditions are directly linked to previous land use and how it was managed (Bowen et al., 2007; Crouzeilles et al., 2016).

Generally, sites where land use was very intense for an extended period, have considerably lower resilience and need a more interventionist restoration. This pattern can be observed in Brazilian pasturelands. Brazil has the greatest cattle herd in the world, being responsible for approximately 15% of the world’s cattle production, most of it on pastures (LAPIG, 2017b). There are 178 million hectares of planted pastures in Brazil, and 50% to 70% present some degree of degradation (Dias-Filho, 2014; Parente and Ferreira, 2018). Pasture degradation can be classified into two primary forms: agronomically degraded and biologically degraded. Agronomic degradation is characterized by the increase of the vegetation density, with the presence of shrubs and small trees, making it difficult for the cattle to graze. In contrast, biological degradation is characterized by soil depletion and low fertility, reducing the vegetation cover (Dias-Filho, 2014).

A significant portion of the Brazilian pastures is located in the Cerrado Biome. Covering 57 million ha of the Cerrado, planted pastures corresponds to 29% of its territory (LAPIG, 2017a; MapBiomas, 2019). The Cerrado biome is a biodiversity hotspot housing 30% of

Brazilian fauna and flora, and 5% of the world species (Myers et al., 2000; WWF-Brasil, 2015). It is also an important provider of ecosystem services, especially related to water provision and climate regulation. The biome feeds eight out of the twelve major basins in Brazil and has a crucial role in recharging aquifers (Lima & Silva, 2005, Oliveira et al., 2005; Sano et al., 2019). The Cerrado vegetation also regulates local climate through evapotranspiration and have the potential to store up to 28.8 Pg of Carbon, mainly on its below ground structures (Miranda et al. 2014).

These facts and the growing threat of agriculture expansion make it very important to find more sustainable alternatives for land use. Mapping the degradation status of the pastures may provide an important tool for spatial planning for agriculture expansion without further deforestation. However, these lands also offer an opportunity to meet ecological restoration goals without conflicts with agribusiness. The Brazilian Forest Code, the main legal framework for conservation in private properties, stipulates the preservation of 20% of rural properties as Legal Reserves (LRs) and the maintenance of the native vegetation on river margins and hilltops as Permanent Protection Areas (PPAs). Many properties, however, have illegally deforested LRs and PPAs and are in Environmental Debt, being obligated to restore these areas. The restoration demand is estimated at 4.6 million ha of LRs in Cerrado (Soares-Filho et al. 2014; Strassburg et al. 2017).

Beyond meeting legal requirements, the restoration of 12.5 Mha is one of the Brazilian Nationally Determined Contributions (NDCs) to mitigate climate change (Bustamante et al. 2019). The NDCs were established in 2015 on the 21st Conference of the Parties in Paris, and set objectives and contributions to reduce carbon emissions and keep global warming below 2ºC (Bustamante et al. 2019). The restoration of degraded areas captures CO_2 from the atmosphere and stock it on the vegetation and soil, helping to mitigate climate change (Bustamante et al. 2019). The Cerrado biome, with its potential to store carbon, may help to accomplish these restoration and mitigation goals. In this scenario, natural regeneration represents an alternative to lower the costs of restoration, making it more attractive to stakeholders and allowing large scale restoration planning (Latawiec et al., 2016; Stefanes et al., 2016; Crouzeilles et al., 2017).

To infer the potential of natural regeneration of native Cerrado vegetation in pastures, we analyzed the conservation status of Cerrado on a landscape level, assessing the amount of remaining habitat and its connectivity. This information will be merged with a spatialized pasture quality indicator to create a spatial index for Cerrado natural regeneration potential in areas occupied by pastures. We assume that both local and landscape-scale conditions play equally important roles in natural regeneration once they are critical for both dispersal and establishment of propagules.

Remote sensing techniques, however, only capture vegetation's primary production as a proxy to biomass, not showing species composition and other important characteristics of a regenerated site. Having this limitation of remote sensing in mind, and to better understand how natural regeneration occurs in Cerrado, we also made pilot field study in a natural regeneration chronosequence identified via satellite images from MapBiomas 4.0.

2. Methods

2.1. Study area

The entire extension of pasturelands in the Cerrado is our study area, which covered 57 Mha in 2018, according to MapBiomas 4.0 (MapBiomas 2019). Most of these pasturelands are located in the southern-west and center regions of the biome, especially on the states of Minas Gerais, Goiás, and Mato Grosso do Sul, which are also the regions with less native vegetation cover (Sano et al., 2010; LAPIG, 2017a; MapBiomas, 2019).

2.2. Potential of natural regeneration framework

For determining the potential for natural regeneration of Cerrado native vegetation in pasturelands, we adapted the framework proposed by Tambosi et al. (2014) for the Atlantic Forest. We focus on the first two steps, which are (a) calculating the amount of native habitat and its connectivity, and (b) inferring the resilience of native vegetation in the pasturelands based on the results of the first step and the Pasture Quality Index by Santos (in preparation)[1] (Figure 1).

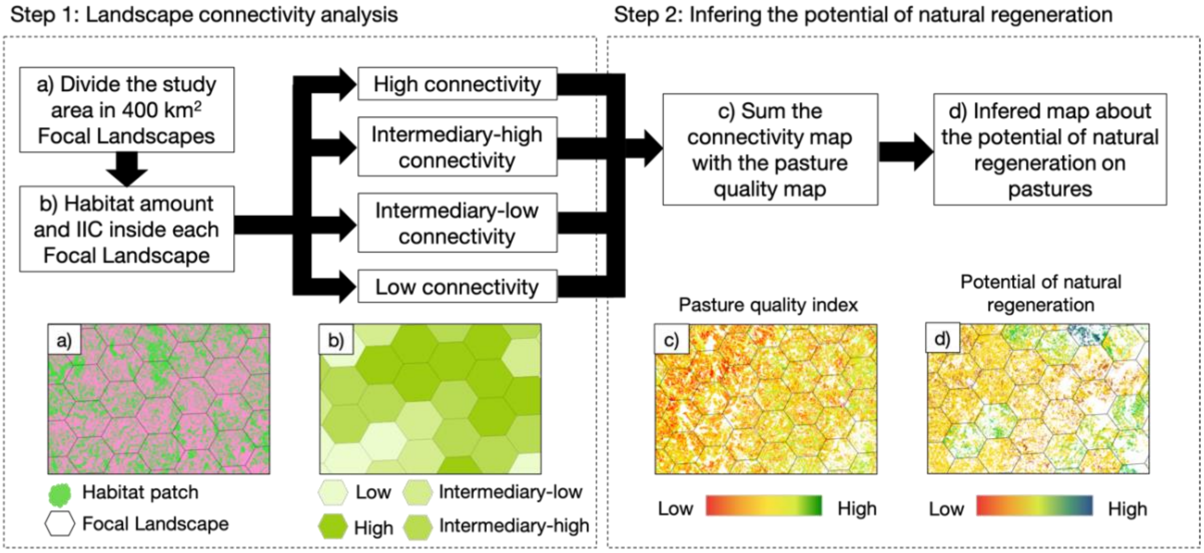

Figure 1: Conceptual framework with the two steps for estimating the Potential for Natural Regeneration. Step 1 consists of the connectivity analysis for the entire region of interest, and Step 2 consists of the merging of the landscape level information generated in step 1 with the local scale habitat quality information to infer the potential of natural regeneration.

2.3. Step 1: Habitat amount and connectivity

For this step, we calculated the amount of habitat and its connectivity for the entire Cerrado extent. We used the 2018 land cover map from MapBiomas 4.0 downloaded from the

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Google Earth Engine platform (https://earthengine.google.com). This map was reclassified using ArcMap 10.6.1 (ESRI, 2018), so it would have two classes of land cover: native remnants and others. Native remnants are all classes of native vegetation except for natural non-vegetated areas, and others are all anthropic areas and natural non-vegetated areas.

The native remnants map was then divided into equally sized hexagons, called focal landscapes (FL). According to Tambosi et al. (2014), the FL area should be determined based on its influence on biodiversity persistence. We set our FL area as 400 km$_2$ based on a study made by WWF-Brazil and the Brazilian Ministry of Environment (MMA) to determine Priority Areas for Conservation in Cerrado and Pantanal (WWF-Brasil, 2015).

Our native remnant map was divided into 5,676 FLs. For each FL, we evaluated the habitat amount and connectivity based on the graph theory, which consists of a set of nodes (native remnants patches) connected by links (Urban and Keitt, 2001). We chose the Integral Index of Connectivity (IIC) as our functional connectivity index because of its robustness and simplicity to evaluate a large dataset (Saura and Pascual-Hortal, 2007). The IIC gives the overall landscape connectivity based on a dispersal threshold, which we set as 1000 m considering an average dispersal distance for mammals sensitive to fragmentation in Cerrado and our FL area (Grande, Aguiar, and Machado, 2020). For habitat amount, we examined the proportion of the FL area covered by native remnants.

All the spatial data used as input for the analysis, including patch area and distance between patches, were prepared in the software R 3.5.0 using the packages raster (Hijmans, 2020), rgdal (Bivand et al., 2019) and sf (Pebesma, 2018), and ArcMap 10.6.1. The analysis did not include fragments with an area lower than 1 ha. The IIC was calculated in the software package Conefor 2.6 (Saura and Torné, 2012).

Both the IIC and habitat amount range from 0 to 1, being 0 no connectivity or remaining habitat, and 1 a fully connected landscape or with its area entirely covered by native vegetation.

We classified the FLs in four categories according to their habitat amount and connectivity; Low - ranging from 0 to 0.25; Intermediary-low - from 0.25 to 0.50; Intermediary-high - from 0.50 to 0.75; and High - from 0.75 to 1. Finally, each category received a grade from 1 to 4, so we could create a connectivity raster map containing the four categories.

2.4. Statistical analysis

As demonstrated by Grande, Aguiar, and Machado (2020), there is a clear relationship between the amount of remnant habitat and the IIC. To test this relationship in our connectivity analyses, we fitted these parameters in linear and nonlinear regression models and selected the best four fitted models. We tested linear, logarithm, quadratic, cubic, exponential, logistic, power, and piecewise models. The best four models ware selected based on Akaike Information Criteria (AIC), in which the lower the value, the best the fit of the model. All the models' analysis was performed using the software R3.5.0. The piecewise model was also made in the software R 3.5.0 using the package segmented (Muggeo, 2008). Because some FLs presented one or none remnant fragments, it was not possible to calculate their IIC. These FLs ware excluded from this analysis, so 4103 FLs were used for the models.

To test if the four connectivity classes presented significant differences in terms of Area and IIC, we applied the non-parametric test of Kruskal-Wallis followed by a pairwise Kruskal – Nemenyi test. These analyses were run in R 3.5.0 using the packages pgirmess (Giraudoux, 2018) and PMCMR (Pohlert, 2014).

2.5. Step 2: Inferring the potential of natural regeneration

To infer the potential of natural regeneration of the native Cerrado vegetation in pasturelands, we combined the connectivity map generated in step 1 with the Pasture Quality Index created by Santos (in preparation). This index evaluates the evolution of the Normalized

Difference Vegetation Index (NDVI) in a time series from 2005 to 2017 and combines it with the 2018 NDVI to assess the actual pasture vigor. Here, pasture vigor represents the amount of biomass in a given area. The result is an index ranging from 0 to 1 in which 0 represents exposed soil, and 1 represents encroached vegetation with high biomass content. According to Santos (in preparation), pastures with an index below 0.4 were considered biologically degraded, and pastures with an index above 0.6 were regarded as agronomically degraded.

Agronomically degraded pastures located in well-connected areas are supposed to have greater resilience and, therefore, a higher Potential of Natural Regeneration (Vieira and Scariot, 2006; Buisson et al., 2018). On the other hand, biologically degraded pastures in poorly connected areas might have very low Potential of Natural Regeneration.

To determine this potential for natural regeneration of the native Cerrado vegetation in pasturelands, we sum the pasture quality map with the connectivity map generated in step 1, using ArcMap 10.6.1. Because the connectivity map ranged from 1 to 4 and the pasture quality index ranged from 0 to 1, we rescale the second one, so it would also vary from 1 to 4. We did it to equalize the weights of both maps and avoid bias towards connectivity. After the sum of the raster maps, we rescale the resultant map back to a range from 0 to 1.

2.6. Pilot field study

To further understand the dynamics of natural regeneration in Cerrado and to have a idea of the accuracy of remote sensing techniques to identify natural regeneration, we performed a quick field assessment in areas that presented signs of natural regeneration based on satellite data from Mapbiomas 4.0. The evaluation was conducted at the Floresta Nacional de Brasília (FLONA), a protected area, where we identified, using satellite images, three areas with signs of natural regeneration. Through the 33-year time series of MapBiomas 4.0, we identified areas with indications of the return of the native vegetation after a period as pasture.

We established four criteria to select the areas: (1) permanence for at least three years as pasture; (2) present a transition directly to native class; (3) stability in the native class until the present; and (4) have an area larger than 1 ha.

Based on these criteria, we selected three regeneration areas and one control area, which stayed as native vegetation throughout the time series. The selected areas have 21, 25, and 29 years since the land-use transition, and the control area has over 33 years. We set 10 plots in each of these areas to survey the woody layer. Each plot has 15 m x 15 m and is 20 m apart from each other. On one side of each plot, we installed a subplot with 30 m$_2$ to survey seedlings. We characterized as adults all woody plants with the diameter at ground level ≥ 3 cm, and seedlings with the diameter at ground level < 3 cm and height ≥ 30 cm. We recorded species identity, height and circumference for all adults, and species identity and height for all seedlings.

To compare the community parameters (diversity, richness, density, and species composition) of the different ages of regeneration, we performed MDS ordinations with the Bray-Curtis dissimilarity index to test species composition and pairwise t-tests to examine the other community parameters. The diversity was estimated using the Shannon diversity index. We also calculated the aboveground biomass of the woody layer of each area with the allometric equation by Roitman et al. (2018), and compared the structural components of the vegetation with pairwise t-tests. All the analyses were performed using the software R 3.5.0 with the packages vegan (Oksanen et al., 2019) and lme4 (Bates at al. 2015).

3. Results

3.1. Connectivity analysis

Our connectivity analysis revealed that most of the biome has a low connectivity index. Roughly 52% of the FLs presented a connectivity index between 0 and 0.25; 19% a connectivity index between 0.25 and 0.5, ranked as intermediary-low; 9% between 0.50 and 0.75, intermediary-high, and 19% had the connectivity index above 0.75 classified as high. In terms of area, it means that 147.3 million ha in the Cerrado are in poorly connected areas (below 0.50), and 65,3 million ha are relatively well-connected areas.

Most of the poorly connected areas are located on the southern portion of the biome, while the northern part still presents a higher IIC (Figure 2). This patter happens because the IIC is strongly related to the proportion of the native remnant area, as shown by all our regression models (Table 1). This relationship, however, is not linear, as shown by the four models selected by AIC (Figure 3). The models presented a relatively low R-squared because of the high dispersion of the data (Table 1, Figure 3). Despite that, we can still observe a strong positive relationship between the variables.

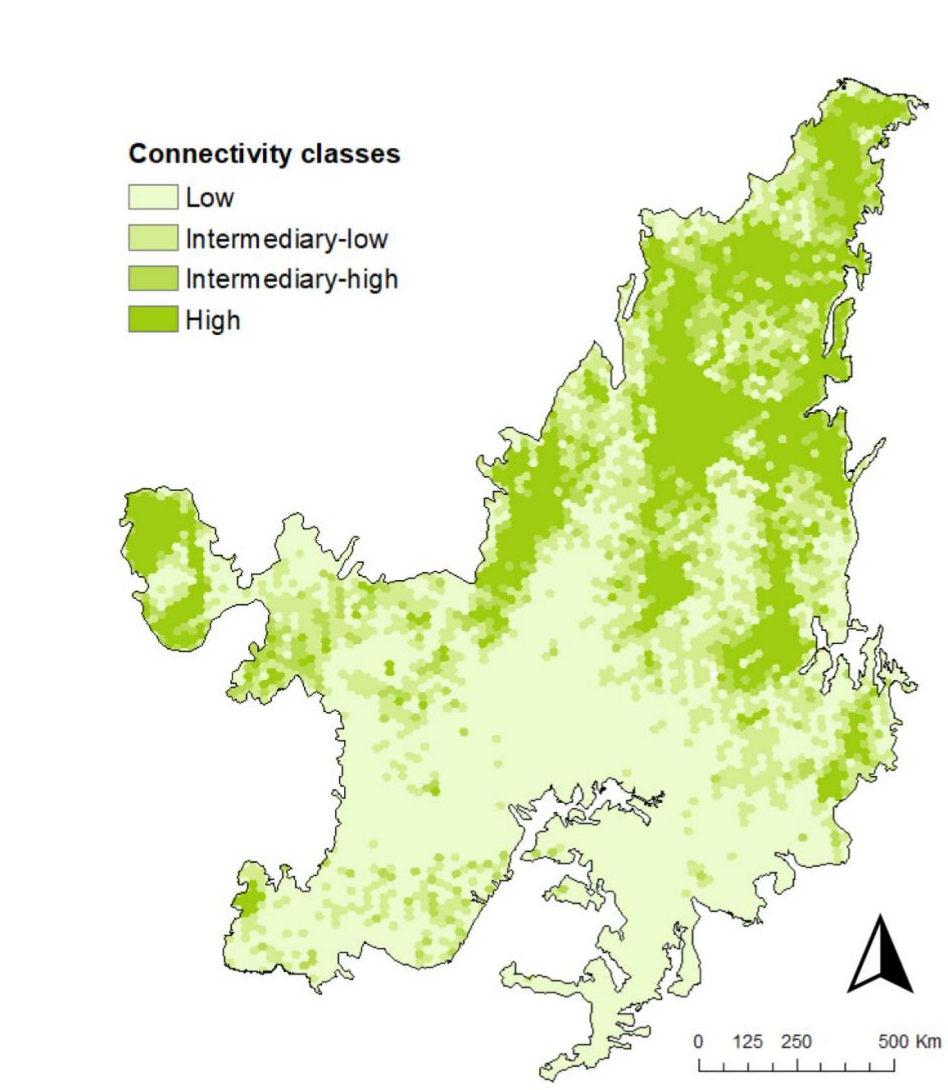

Figure 2: Spatial distribution of connectivity classes across the Cerrado biome, based on the habitat amount and the Integral Index of Connectivity for each 400 km2 Focal Landscape (FL). Habitat amount was calculated using the amount of native remnant area in each FL. Both habitat amount and IIC were calculated using the MapBiomas 4.1 land use map for the year of 2018.

The piecewise regression presented the best fit for the relationship between Area and IIC. It also revealed a breakpoint in the Area x IIC relationship. This breakpoint means that there is a minimum amount of native area above which the IIC increases with a higher slope. Our model revealed that, for Cerrado, this breakpoint is set at 31% of the native remnant area (Figure 3).

Table 1: Sum of squares, adjusted R-squared, Akaike Information Criteria (AIC), and significance for each model testing the relation between the Proportions of Native Remnant Area and the Integral Index of Connectivity (IIC) for all Focal Landscapes . AIC values in bold are the lowest and represent the best-fitted models. Exponential, power, and logistic models do not have R-squared values because they do not present a linear coefficient.

Model	Sum of squares	Adjusted R-squared	AIC	P-value
Linear	112.61	0.2722	**-3102.715**	< 0.001
Logarithmic	127.91	0.1733	-2580.015	< 0.001
Quadratic	116.895	0.2757	**-3121.504**	< 0.001
Cubic	111.723	0.2445	-2949.467	< 0.001
Exponential	113.4	-	-3074.438	< 0.001
Power	134.7	-	-2369.836	< 0.001
Logistic	111.6	-	**-3136.118**	< 0.001
Piecewise	94.771	0.3874	**-3808.354**	< 0.001

The Kruskal-Wallis test revealed a significant difference between the connectivity classes in term of Area (χ_2 = 2402.9; P < 0.001) and IIC (χ_2 = 1530.1; P < 0.001). However, this difference is not true for all classes. The pairwise analyses showed that the difference between Intermediary-low vs. High, and Intermediary-high vs. High ware not significant neither for Area (P = 0.34 and P = 0.96 respectively), nor for IIC (P = 0.19 and P = 0.51 respectively).

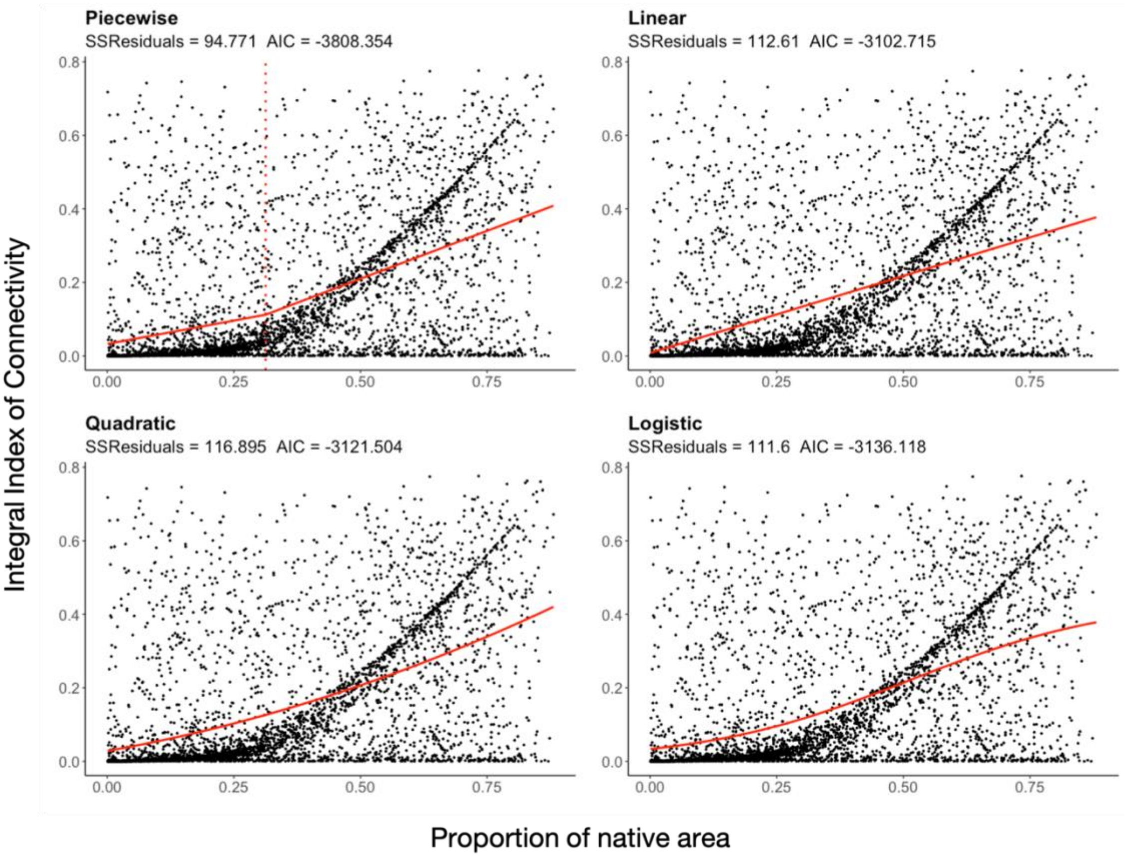

Figure 3: The four best-fitted models (red lines) for the relation between the Integral Index of Connectivity (IIC) and the Proportion of Native Area according to the Akaike Information Criteria (AIC). The four models selected presented the lowest AIC values. On the Piecewise model, the dotted red line represents the breaking point at 31% of native remnant area in which the curve slope changes to higher increase rate.

3.2. Potential of Natural Regeneration

The overlap of the connectivity map generated in Step 1 with the Pasture Quality Index (Santos, in preparation) resulted in a map of the Potential of Natural Regeneration for native Cerrado vegetation in pasturelands (Figure 4). The index ranges from 0, low potential, to 1, high potential.

Most of the pastures have a low Potential of Natural Regeneration with an index below 0.5 (Figure 4). Around 44% of the area has an index between 0 and 0.25; 45% has an index between 0.25 and 0.5, 10% from 0.5 to 0.75, and only 1% of the biome's area has a very high potential index between 0.75 and 1. In terms of area, it means that, from the 57.4 million ha of pastures in Cerrado, 51.1 million ha have a Potential of Natural Regeneration below 0.5, and only 6.3 million ha have a potential above 0.5. Overall, the pastures with higher potential for regeneration of the native Cerrado vegetation are located in well-connected areas with still a high proportion of the native area. In contrast, the lower potential pastures are located in highly anthropized areas. When we consider the two intermediary categories, however, we found that 55%, around 51.1 Mha, of the pastures have a potential for natural regeneration between 0.25 and 0.75. These areas are specially located on the southern and center portions of the biome (figure 4).

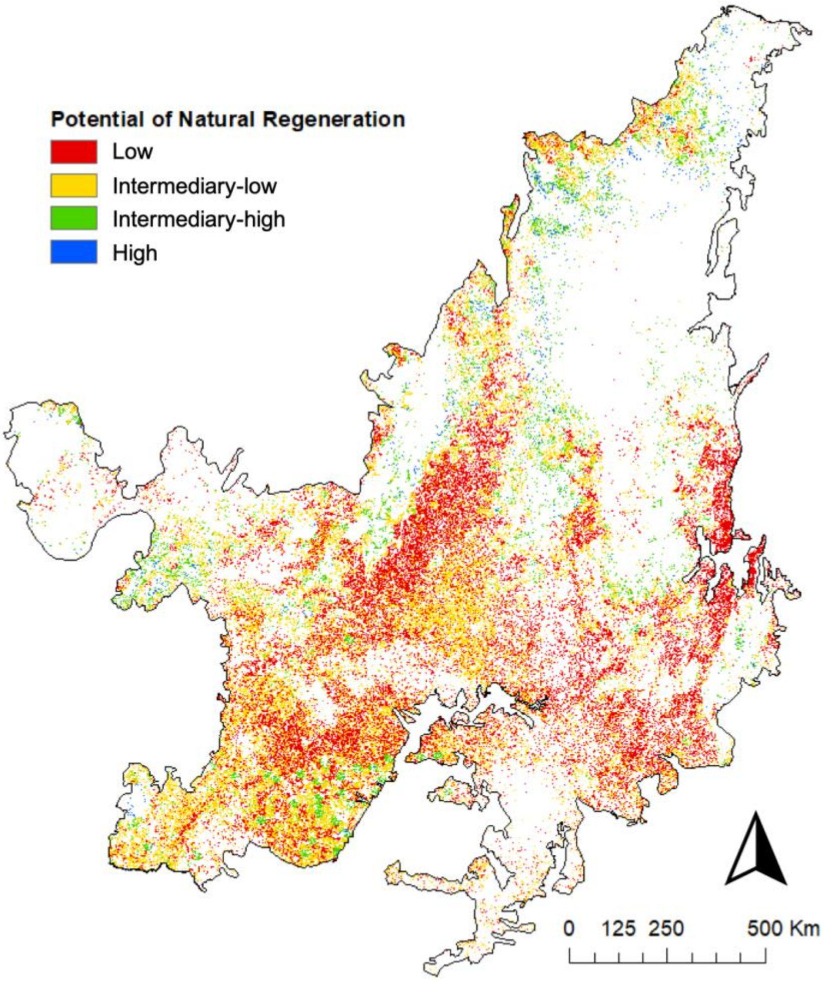

Figure 4: Map showing the spatial distribution of the Potential of Natural Regeneration categories of pastures in the Cerrado biome. Low rages from 0 – 0.25, Intermediary-low from 0.25 – 0.5, Intermediary-high from 0.5 to 0.75 and High from 0.75 – 1.

3.3. Pilot field study

To access the actual situation of areas under natural regeneration, we performed a field survey at sites that showed signs of native vegetation return after a period as pasture. Our MDS ordination analysis showed that the sites of different ages under regeneration and the control site did not differ markedly in terms of species composition neither for adult individuals nor for seedlings. We could not identify any coherent group, as shown in Figure 5.

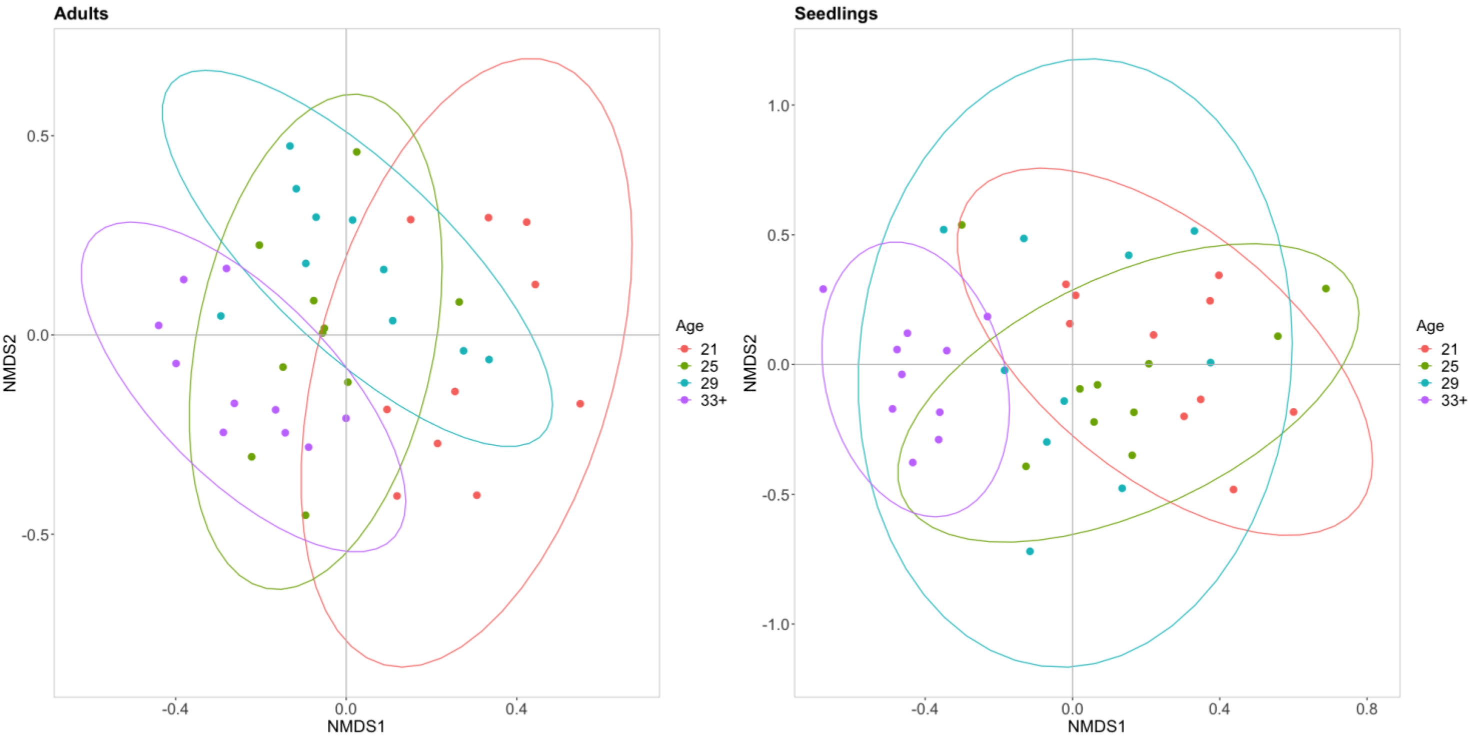

Figure 5: MDS ordination using Brey-Curtis dissimilarity index for adults and seedlings species composition considering species abundancy .

The pairwise analysis showed that some community and structural parameters were significantly different between some of the sites for both adults and seedlings (Table 2). For adults, there were no differences in terms of species richness, basal area, and biomass (Figure 6). Still, the site with 21 years of regeneration showed a higher density of individuals compared to the 25-year-old area and the control area (33+). Still, the diversity was significantly lower in the 21-year site compared to all the others (Figure 6). As expected, height presented a crescent pattern from the youngest to the oldest area. The 21-year-old area had shorter individuals compared to the 29 and 33+, and the 25-year-old areas had shorter individuals compared to the 33+ area (Figure 6).

Table 2: Significance of the pairwise t-test for the difference between each treatment in both adults and seedlings. For adults we tested species richness, density of individuals, Shannon diversity, height in meters, basal area in squared-centimeters and biomass in grams. For seedling we tested species richness, density of individual, Shannon diversity and height in centimeters. The bold P-values represent significant differences between compared pair in the specific parameter tested.

Adults			**Seedlings**		
Parameter	Pairs	P-value	Parameter	Pairs	P-value
Richness	21 - 25	0.32	Richness	21 - 25	0.86
	21 - 29	0.88		21 - 29	0.509
	21 - 33+	0.66		21 - 33+	0.509
	25 - 29	1		25 - 29	0.467
	25 - 33+	1		25 - 33+	0.509
	29 - 33+	1		29 - 33+	**0.022**
Density	21 - 25	**0.049**	Density	21 - 25	0.657
	21 - 29	0.184		21 - 29	0.83
	21 - 33+	**0.049**		21 - 33+	**<0.001**

	25 - 29	1
	25 - 33+	1
	29 - 33+	1
Diversity	21 - 25	**<0.001**
	21 - 29	**0.02**
	21 - 33+	**0.008**
	25 - 29	0.661
	25 - 33+	0.801
	29 - 33+	0.801
Height	21 - 25	0.219
	21 - 29	**0.004**
	21 - 33+	**<0.001**
	25 - 29	0.219
	25 - 33+	**0.015**
	29 - 33+	0.219
Basal area	21 - 25	1
	21 - 29	1
	21 - 33+	1
	25 - 29	1
	25 - 33+	1
	29 - 33+	1
Biomass	21 - 25	1
	21 - 29	1
	21 - 33+	1
	25 - 29	1

	25 - 29	0.657
	25 - 33+	**0.014**
	29 - 33+	**<0.001**
Diversity	21 - 25	0.718
	21 - 29	1
	21 - 33+	**0.008**
	25 - 29	1
	25 - 33+	0.116
	29 - 33+	**0.032**
Height	21 - 25	0.723
	21 - 29	**0.001**
	21 - 33+	0.379
	25 - 29	**0.004**
	25 - 33+	0.297
	29 - 33+	**<0.001**

25 - 33+	1
29 - 33+	1

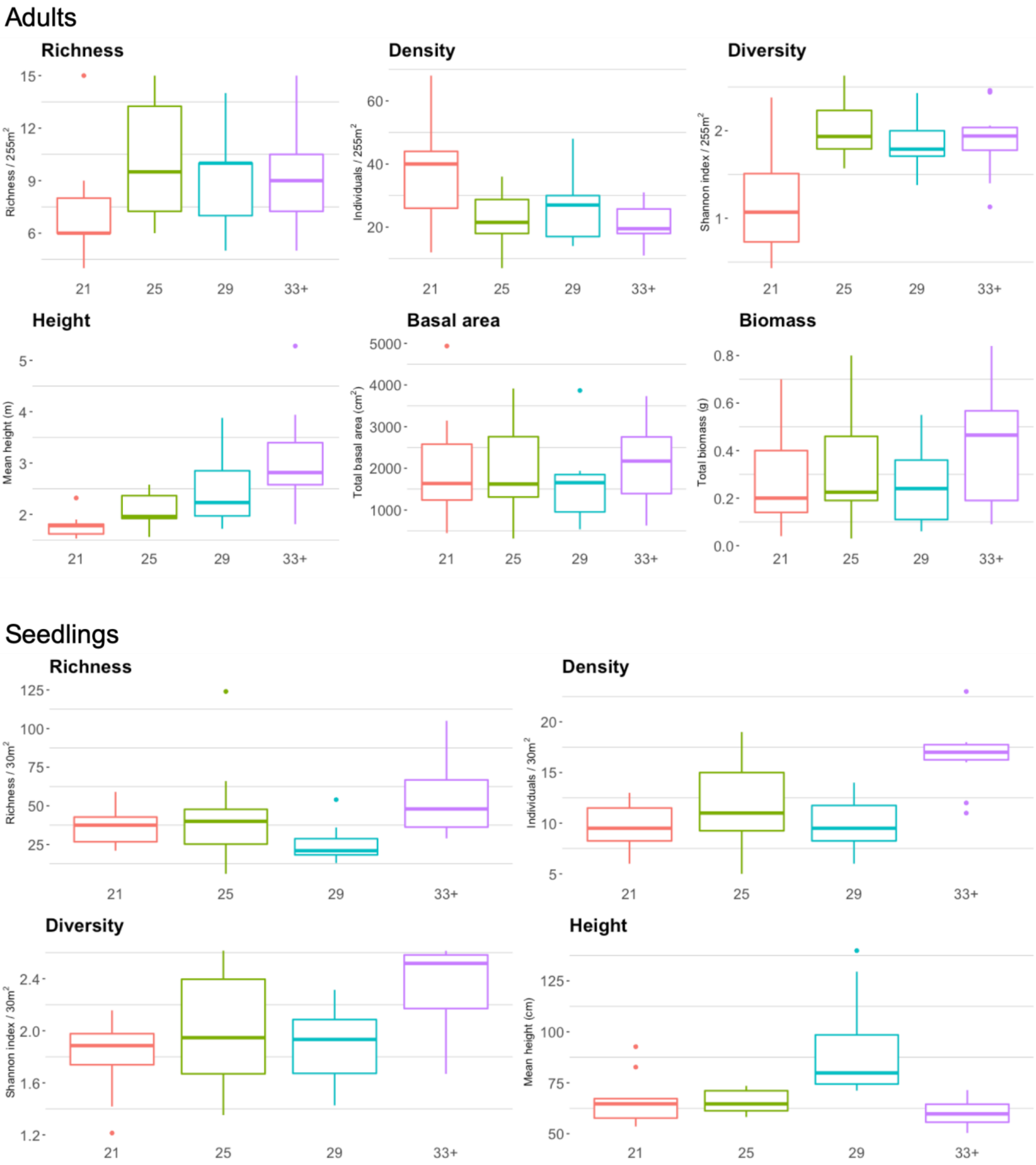
Adults
Richness
Richness / 255m^2
15
12
9
6
21
25
29
33+
Density
Individuals / 255m^2
60
40
20
Diversity
Shannon index / 255m^2
2
1
Height
Mean height (m)
5
4
3
2
Basal area
Total basal area (cm^2)
5000
4000
3000
2000
1000
Biomass
Total biomass (g)
0.8
0.6
0.4
0.2
0.0
Seedlings
Richness
Richness / 30m^2
125
100
75
50
25
Density
Individuals / 30m^2
20
15
10
5
Diversity
Shannon index / 30m^2
2.4
2.0
1.6
1.2
Height
Mean height (cm)
125
100
75
50

Figure 6: Box-plot graphs comparing all the parameters analyzed between all ages of regeneration (in years) for adult and seedling individuals of woody species in the Brasília National Forest, Brasília. Species richness is given as the total number of species; Density as the number of individuals; Diversity as Shannon dissimilarity index; Height as mean height in meters for adults and centimeters for seedlings; Basal area the total area in squared centimeters and Biomass as total aboveground mass of living woody plants in grams. All the parameters are relative to 225m$_2$ for adults and 30m$_2$ for seedlings.

For Seedlings, the species richness was higher in the control site (33+) compared to the 29-year-old site, which presented the lowest species richness (Figure 6). The other sites did not present differences. The 33+ area also showed a density of seedlings significantly higher than all the other sites and a higher diversity index than the 21 and 29-year-old sites (Figure 6). The height was significantly higher in the 29-year-old area than in the other treatments (Figure 6).

4. Discussion

In this study, we considered the two main ecological premises for natural regeneration to evaluate the potential of return of the native Cerrado vegetation in pasturelands. The first premise is the availability of propagules, here represented by the area of native remnants and connectivity at the landscape level (Chazdon and Guariguata, 2016). Our connectivity analysis showed that the northern portion of the biome has a greater IIC what is explained by the fact the most of the native remnants are in this portion of the biome. The IIC presents a non-linear positive correlation with the amount of habitat. Our best-fitted model revealed that there is a breakpoint at 31% of habitat amount in which the IIC increases at a higher rate. This breakpoint seems consistent across many studies about fragmentation in Cerrado, with little variation caused by methodological differences. Grande, Aguiar, and Machado (2020), for example, studied the change in Cerrado’s connectivity over 17 years. They divided the Cerrado area into cells with 2500 km^2 and found a breakpoint at 37% of habitat amount for the year of 2017, and 39% for 2000. This breakpoint indicates that we can significantly improve, at a landscape level, the overall conservation conditions by maintaining above 31% of native vegetation. The current Brazilian Environmental Code stipulates, for the Cerrado biome, at least 20% of the rural property as the legal reserve, which might not be enough to properly sustain the biodiversity according to ours and others findings (Grande, Aguiar, and Machado, 2020; Soares-Filho et al., 2014). This breakpoint at 31% also reveals that a greater effort should be applied to restore areas with low habitat amount, improving general landscape connectivity and conditions to sustain biodiversity e ecosystem processes.

The second premise for natural regeneration is environmental conditions that enable the establishment of seedlings (Chazdon and Guariguata, 2016). We use as a proxy for this premise the Pasture Quality Index (Santos, in prerparation), which, at its core, indicates vegetation vigor based on NDVI values. Many studies review the overall environmental requirements for natural regeneration. Plants present several strategies for seed dispersal. The three most relevant ones are self-dispersal (autochory), wind-dispersal (anemochory) and animal-dispersal (zoochory). In Cerrado, there is not a predominant strategy, however, over 50% of tree species present zoochory as the dispersal strategy (Kuhlmann and Ribeiro, 2016). Different seeds have different requirements for germination and establishment. While larger seeds, like zoochoric ones, are more resistant to dehydration, smaller seeds are susceptible to humidity and light conditions (Zaidan and Carreira, 2008). Shaded sites protect against dehydration and, therefore, increase the survival rate of smaller seeds. Because pastures with a higher quality index have greater vegetation cover, those may provide a better environment for natural regeneration to happen. Sites with degradation signs, however, may benefit more from restoration actions, with an adequate method and species selection, and avoid major conflicts with agriculture expansion.

There is an environmental debt of approximately 4.6 Mha of legal reserve in the Cerrado (Soares-Filho et al., 2016). Our study showed that 6.3 Mha of pastures have a higher potential to regenerate the native vegetation naturally, which covers the environmental debt. Those pastures, however, are highly productive, in biological terms, and the opportunity cost on those areas might be higher once they are suitable for agriculture. Beyond that, we observe a pattern in the geographic distribution of these pastures with higher potential. Most of them are located on the northern portion of the biome, where the environmental debt and restoration demands are not as dramatic as in the southern part (Sano et al., 2019; Strassburg et al., 2017). The south-western portion of Cerrado, mostly in the state of Mato Grosso do Sul, also shows pastures with increasing productivity tendencies (Santos, in preparation). This higher productivity has an effect of increasing the local Potential of Natural Regeneration despite the overall low connectivity at this portion of Cerrado (Figures 2 and 4). This attribute, even if it does not indicate a substantial potential natural regeneration, indicates sites where the restoration process requires fewer interventions and has an increased chance of success.

We observed 51.1 Mha of pastures with an intermediate potential for natural regeneration. A great portion of these pastures are located in the southern portion of the biome, which is also the least connected portion. These pastures may represent a great opportunity to restore those areas, increasing the overall landscape connectivity, with a lower cost and higher rate of success.

The assumption that Natural Regeneration will result in an old-growth Cerrado must be carried with caution, however. Our field validation showed no difference in terms of species composition across the chronosequence for both seedlings and adults. The other community parameters followed the same pattern, except for the youngest area that presented, for adults, fewer species, lower diversity, and higher density of individuals. Structural features showed a similar pattern with no differences between the different ages, except for height that presented an increasing trend across the chronosequence. For the seedlings community, the control area (33+) showed higher richness, density of individuals, and diversity. The only exception was the height that was significantly higher in the 29-year-old area. This pattern of succession resembles the one found by Cava et al. (2018). They modeled the time needed for abandoned pasture to reach the community and structural attributes similar to an old-growth Cerrado area in the state of São Paulo. They found that it took 17 years for tree species richness to reach values similar to old-growth, 24 years for canopy cover, and that tree density would take 28 years to reach old-grows values (Cava et al. 2018).

Our control site presented 36 different species of adult woody plants. According to FLONA's official management plan, the ware 174 Cerrado species, including woody and herbaceous plants, in FLONA (ICMBio, 2016). FLONA has also been occupied for 60 years, while MapBiomas series has only 33 yeas. It means that we do not know the complete historical dynamic of our control site, making it difficult to draw accurate conclusions about the natural regeneration dynamic at FLONA.

Savannas like Cerrado are maintained by a complex regime of disturbances, such as herbivory, but mostly fire (Buisson et al., 2018; Gomes, Miranda, and Bustamante, 2018). Fire exclusion might lead to the encroachment of Cerrado, which is characterized by the increasing presence of woody species (Buisson et al. 2018; Cava et al. 2018). On the other hand, a high frequency of fire might exclude woody species by not allowing the recruitment of new individuals (Gomes, Miranda, and Bustamante, 2018; Vieira and Scariot, 2006). According to remote monitoring made by the Instituto Nacional de Pesquisas Espaciais (INPE), the FLONA-Brasília has burned almost annually since 2003, sometimes twice a year, which is a very high fire frequency (http://queimadas.dgi.inpe.br/queimadas/bdqueimadas/). This high fire frequency might not only have slowed down the succession process but also have altered the community and structure of our control site.

Natural regeneration represents an excellent opportunity to lower the costs of restoration significantly and allowing large-scale planning. Many studies show the benefits of restoration and natural regeneration. Assuming, however, that Cerrado will completely recover its original features is naïve once many environmental and human-related conditions have a significant impact on the succession process. For that, implementing an adequate monitoring and management program is essential to ensure restoration success, and, more important than that, to preserve the native remnants is critical to keep Cerrado as we know it.

5. Conclusion

Two central premises are particularly relevant for the progress of natural regeneration. The first one is a natural propagule source, in other words, native vegetation remnants that can provide enough seeds to colonize the degraded habitat; the second one is the environmental conditions of this habitat to enable the establishment of new seedlings. By combining these two components, we created a spatialized index for Potential of Natural Regeneration in Cerrado's pasturelands with high applicability for large scale restoration planning. Pastures are the main category of human land use in Cerrado and have been historically underused, representing an excellent opportunity for increasing agriculture productivity and accomplishment of restoration goals. Our Potential for Natural Regeneration index, however, must be used with caution, considering local conditions, the high heterogeneity of Cerrado, and applying a proper monitoring and management program to ensure the expected results.

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Capítulo II

Spatial planning for restoration in Cerrado: balancing the trade-offs between conservation and agriculture

Abstract

Habitat loss and degradation is the main driver of biodiversity decline, but also has a major effect on resources availability and climate stability. Agriculture covers most of the ice and desert free land in the world and its production chain is responsible for 26% of carbon emission and uses 65% of all fresh water withdrawn. The Brazilian Cerrado, the most biodiverse savanna in the world with great importance in water related ecosystem services and in underground carbon stock, faces the same threat. The biome officially covers 204 Mha of area, however 43% of its native vegetation has been converted to human use. This scenario is aggravated by the few strictly protected areas, only 3% of the biome, and by the rapid expansion of agriculture over native remnant areas. Pastures are the major land use category in Cerrado, covering 57 Mha, 29% of its area. Most of these pastures are underused and present some degree of degradation, representing an opportunity to restoration programs and agriculture expansion without further deforestation. Here we modeled seven prioritization for restoration scenarios focusing in pasture areas. We considered biodiversity, water related ecosystem services, potential carbon stock and agriculture aptitude to understand the trade-offs between each feature and the conflicts with agriculture. We also applied the same prioritization logic for four Cerrado ecoregions to understand the importance of planning in a regional scale. We identified trade-offs between the scenarios with some overleap of three of more features, which represent areas with a higher conservation value. Conflicts with agriculture are significant and present an obstacle that might be discussed with stakeholders. By regionalizing the prioritization process, we could also identify local scale conflicts and demands, beyond ensuring a more representative cover of Cerrado’s diversity.

Keywords: Biodiversity; ecosystem services; pastures; Cerrado ecoregions

1. Introduction

It is well known that human activity is the main cause of ecosystems collapse and biodiversity loss (Steffen et al. 2015; Pereira et al. 2010; IPCC 2014; Butchart et al. 2010). Habitat loss and fragmentation, over exploitation of natural resources and climate change are not only driving species to extinction, but are also putting the human life on earth on check (Steffen et al. 2015; IPCC 2014). We can already see the effects of climate change on crops yield, water availability and human health (IPCC 2014). There are more extreme events and epidemics that affect mostly the most socially vulnerable leading to a humanitarian crises (IPCC 2014).

Tropical ecosystems, which hold most of world's biodiversity, are especially threatened by deforestation. Brazil alone has cut down over 2.5 Mha on this period (Kim, Sexton, and Townshend 2015). But not only Tropical Rain Forests are in danger. The Brazilian Cerrado, the largest and most biodiverse savanna in the world, lost 663,409 ha of natural vegetation in 2018 (Myers et al. 2000; INPE 2016). This biome is a biodiversity hotspot covering 204 Mha and housing 5% of all plants and animals species of the world (MMA 2015; WWF 2015). It also has a key role on water provision and carbon stock. Eight out of the twelve main basins in Brazil have their springs in Cerrado (Overbeck et al. 2015). The biome is responsible for 94% of the water of the São Francisco basin, 71% of the Tocantins-Araguaia basin, and 71% of the Paraná-Paraguai basin (Overbeck et al. 2015). The combination of deep Oxisoils and vegetation's deep roots also play an important role on recharging national aquifers (Oliveira et al. 2005). The Cerrado biome is also considered a carbon sink, with an estimated carbon stock between 13.8 and 28.8 PgC (Miranda et al. 2014; Leite et al. 2012). This stock, however, has been quickly mobilize duo to deforestation, increased fire regimes and land use change (Leite et al. 2012).

Despite the importance of Cerrado in maintaining both, biodiversity and ecosystem services, only 3% of the biome area is strictly protected (Françoso et al. 2015). The deforestation is also advancing and, according to the Brazilian Forest Code, 40% of current native vegetation can be legally converted to human use (Brasil, 2012; Strassburg et al. 2017; Soares-Filho et al. 2014). This estimative, however, considers that all Cerrado land is in a private property, which is unrealistic once there are non-designated lands and overlaps in declared properties. Even so, around 53% of all Brazil's native vegetation remnants are estimated to be in private properties (Soares-Filho et al. 2014). This vegetation is subjected to the Forest Code, which stipulates that 20% of the property area must be preserved as a Legal Reserve (LR) (Brasil, 2012; Soares-Filho et al. 2014). Besides that, native vegetation must be kept on river banks and hill tops as Permanent Protected Areas (PPAs) (Brasil, 2012; Soares-Filho et al. 2014). Properties that don't fit on this requirements are in environmental debt, being obligated by law to restore the native vegetation area (Brasil, 2012; Soares-Filho et al. 2016). Cerrado has 3.7 Mha of environmental debt in RL, and around 24.4% of riparian PPAs have been converted to other uses (Soares-Filho et al. 2014; E.E. Sano et al. 2019).

In total, around 43% of Cerrado's land has been converted to human use, with 13% destined to agricultural crops, 28% to pasture, 1% to urban areas, and 1% to other activities such as mining (MapBiomas 2019). The rate of deforestation in Cerrado is 2.5% higher than in Amazon, and without actions to change this scenario, 34% of the native remnants will be gone by 2050 (Strassburg et al. 2017). Even though 70% of Brazil's agricultural production comes from the Cerrado biome, making it strategic to the national economy, most of the 57 Mha of pastures in Cerrado are underused or present some degree of degradation (LAPIG 2017a, 2017b; Instituto Brasileiro de Geografia e Estatística (IBGE) 2019). These pastures present a good opportunity to expand the agricultural production without further deforestation and to apply restoration programs to compensate the environmental debt, creating a more sustainable economic development (Strassburg et al. 2017).

In a political scenario where the environmental agenda is neglected and the agrobusiness is developing at a rapid pace, spatial planning is a key tool to avoid conflicts and make sure that the restoration actions will happen in the best possible way. Prioritization tools are widely used for planning Conservation Units worldwide. The prioritization process usually focuses on the distribution of species, however, other targets such as ecosystem services, costs and landscape connectivity can be added on the analysis (Kukkala and Moilanen 2017; Whitehead et al. 2014; Manhães et al. 2018). The relationship between ecosystem services and biodiversity conservation can be positive, negative, or even null depending on the type of ecosystem service and scale (Abreu et al. 2017; Anderson et al. 2009; Chan et al. 2006; Girardello et al. 2019; Manhães et al. 2018). Chan et al. (2006) found that prioritizations focused on ecosystem services might be more efficient in covering multiple targets, including biodiversity. Girardello et al. (2019) also found that a multi-criteria approach for prioritizing areas for conservation would lead to a more efficient planning.

Multi-criteria approaches can also consider the interest and demands of different stakeholders. Uribe et al. (2014) identified the demands of 4 groups of stakeholders, academic, NGOs, government and general public, to find priority areas for restoration in Oaxaca, Mexico. Their model includes socioeconomic and biodiversity variables with different importance given by the stakeholders. Only 1.35% of the study area present an overlap between the scenarios showing that differences in stakeholders preferences. In another study by Orsi and Geneletti (2010) at Chipas, Mexico, the restoration prioritization scenarios ware based on the conservation value and feasibility of restoration. Similarly to our study, Zerger et al. (2011) incorporates agricultural production and farmer interest, beyond biodiversity conservation, in defining property level restoration in Australia. They found that production is a major concern to farmers. However, by conscientization and agreements, farmers seem prone to restore areas with significant conservation importance.

In Brazil, there are many examples of multi-criteria prioritization for Conservation Units planning, however, few studies utilize these tools to plan restoration actions. To understand how different restoration scenarios would impact Cerrado's biodiversity, water availability, carbon stock and agriculture expansion we modeled seven restoration scenarios. We set each one of these variables as a main target for each scenario, so we could understand the trade-offs between them, and created an intermediate scenario that evenly embrace all of them. Our goal is to create a restoration priority map that would help to guide environmental policies for restoration in Brazilian Cerrado.

2. Methods

2.1. Study area

We set our study area in Cerrado's pasturelands, which covered 57 Mha in 2018, according to MapBiomas 4.0 (MapBiomas 2019). Most of it is located on the southern-west and center regions of the biome, especially on the states of Minas Gerais, Goiás and Mato Grosso do Sul, which are also the region with less native vegetation cover (Edson E. Sano et al. 2010; MapBiomas 2019; LAPIG 2017a). For delimitating our study area, we used a mask of Cerrado's pastureland from MapBiomas 4.0 landcover map for 2018. We downloaded the 2018 land cover map for Cerrado from the Google Earth Engine platform. This map was reclassified using ArcMap 10.6.1, so it would have two classes of land cover: pasture and others.

2.2. Data gathering and standardization

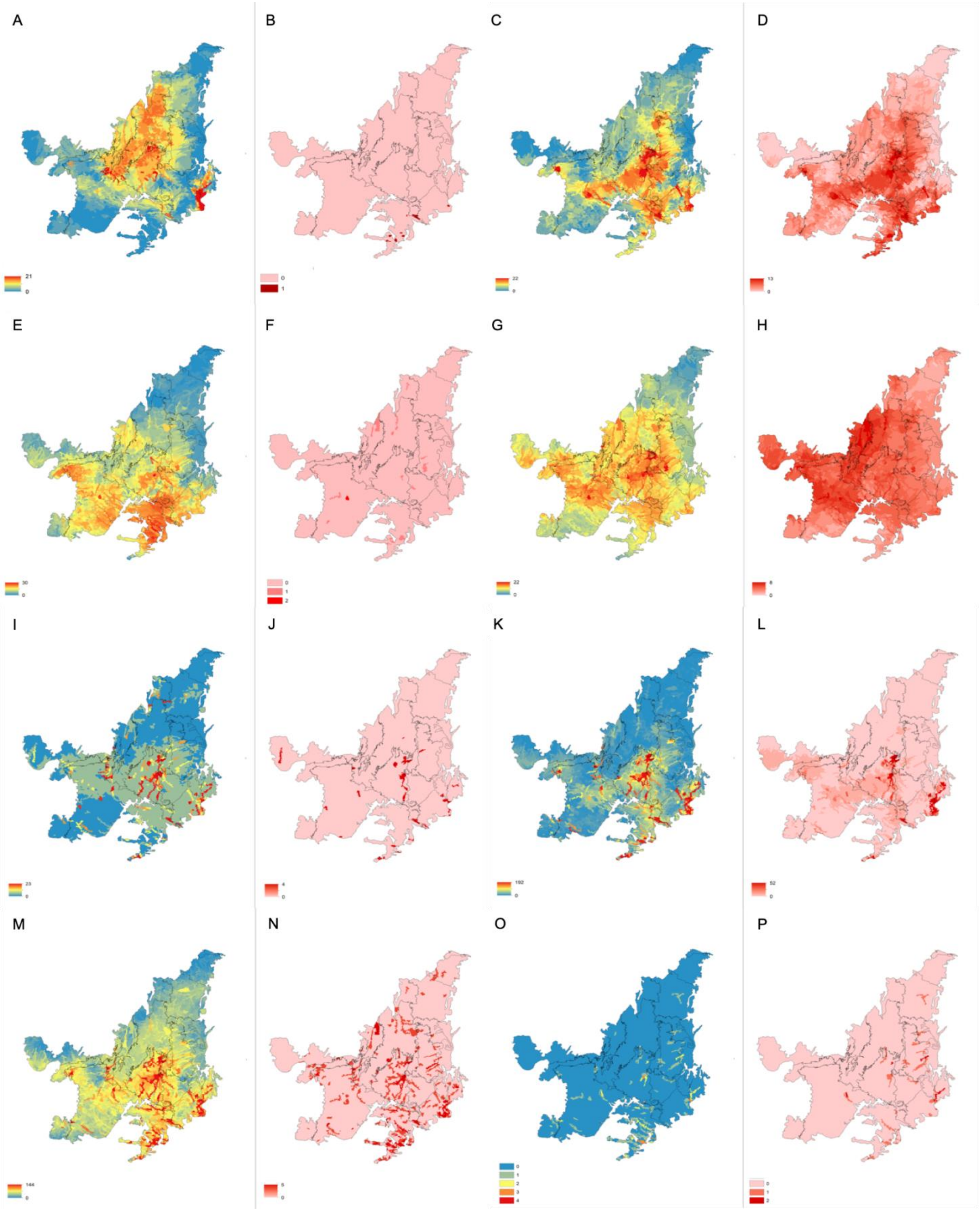
For running our analysis we chose the software Zonation 4.0 (Moilanen et al., 2014) which is largely used for spatial prioritization projects. Zonation This software requires that all the input data are in a raster format, such as GeoTiff, with the same extent, projection and resolution. We gathered available data about biodiversity distribution, hydrography, water yield, hydrological distribution and carbon distribution, that we define as ecosystem services parameters, and agricultural suitability for all the Cerrado biome and standardized them to fit the software requirements. The details about the data sources and resolutions are in Table 1.

Tabel 1: Input data sources and dates for biodiversity, ecosystem services, land use, resilience, ecoregion and restoration demand.

Theme	**Map**	**Source**	**Date**
Biodiversity	Priority areas for Conservation in Cerrado and Pantanal	MMA	2015
Ecosystem services	Carbon distribution in Cerrado	Roitman, *et al.*	2019
	Hydrographic map	IBGE	2017
	Water Yield	Resende	2018
Land use	Land use and land cover map for Cerrado	MapBiomas 4.0	2018
	Agricultural potential	AgroSatélite	2014
	Degrades pastures in Cerrado	LAPIG	2019
Resilience	Potential for natural regeneration in Cerrado's pasturelands	Schüler et al.	2020
Ecorregion	Cerrado Ecoregions	Sano *et al.*	2019
Environmental debt	Restoration demand for each Ecoregion	Sano *et al.*	2019

2.3. Biodiversity conservation

For the biodiversity conservation input, we used modeled species distribution from Ministério do Meio Ambiente (MMA) (WWF 2015). The data were produced by WWF Brasil and MMA to identify priority areas for conservation in Cerrado and Pantanal. We used the distribution data of 81 species of amphibians, 112 reptiles, 46 birds, 55 mammals, 61 species of grasses 796 herbs, 456 trees and 14 species of palm trees. This data was in shapefile format, so we used the Model Builder in ArcMap 10.6.1 (ESRI, 2018), to convert each shape in a presence and absence raster layer. The species were also classified by their conservation status according IUNC for fauna species and Botanical Garden of Rio de Janeiro for flora species. To simplify our input file in Zonation, we sum the raster layers for each group creating a species richness distribution layer (figure 1). We did the same process for the endangered species of each group so we would double the importance of these species in our prioritization analysis (figure 1).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0
N
5
0
O
0
1
2
3
4
P
0
1
2

Figure 1: Species richness and endangered species distribution for each fauna and flora group. A – amphibians richness; B – endangered amphibians; C – birds richness; D – endangered birds; E – reptiles richness; F – endangered reptiles; G – mammals richness; H – endangered mammals; I – grasses richness; J – endangered grasses; K – herbs richness; L – endangered herbs; M – woodies richness; N – endangered woodies; O – palm trees richness; P – endangered pal trees.

2.4. Water quality and provision

For the water related ecosystem services we used a water yield distribution for Cerrado (Resende 2018), as proxy for groundwater recharge, and the hydrography map by Instituto Brasileiro de Geografia e Estatística (IBGE 2017), as a proxy surface water quality and supply. The annual water yield is the amount of water from precipitation that is not lost by evapotranspiration and may infiltrate on the soil. The water yield distribution map was a made using the InVEST Water Yield model (Sharp et al. 2016) considering precipitation, evapotranspiration, land-use and soil characteristics (figure 2a).

We used the riparian vegetation as proxy to surface water quality, because of its important role in avoiding erosion, leaching and maintaining the water quality. Based on the Brazilian Forest Code, which stipulates that the riparian PPAs must have a size between 30m to 200m according to the river width, we set a buffer around the water courses on the hydrography map. Because the hydrography map consisted on a polyline shapefile, which does not have width information, we set a 200 m buffer around all rivers. We than converted the buffer in a binary raster using ArcMap 10.6.1 (figure 2b).

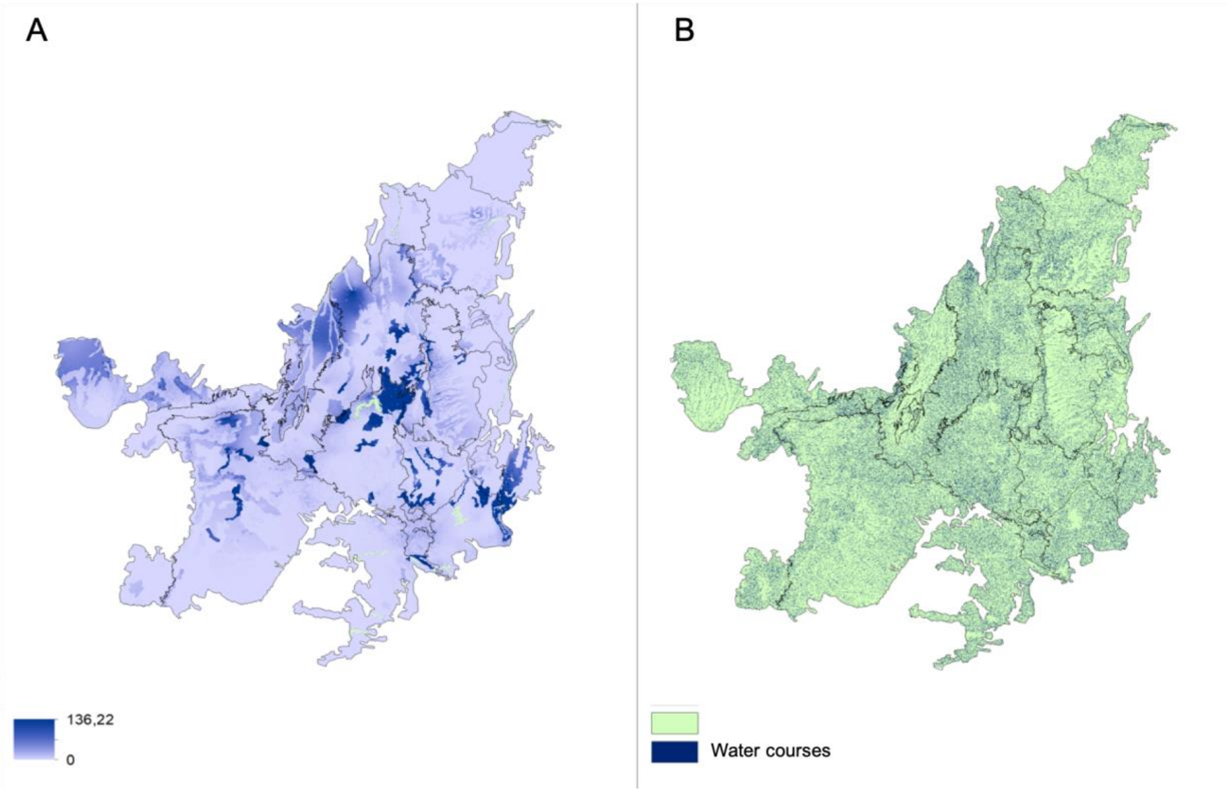

Figure 2: Distribution of water related ecosystem services in Cerrado. A – Annual water yield (mm/ha); B – Riparian vegetation as a 200m buffer around water courses.

2.5. Carbon stocks

To estimate the possible contribution of the restored sites to atmospheric carbon uptake, we used a carbon distribution map for Cerrado (Roitman et al. in preparation)[1]. This map was generated based on the original Cerrado vegetation and considered above and belowground carbon stock for the different vegetation physiognomies found in Cerrado (figure 3).

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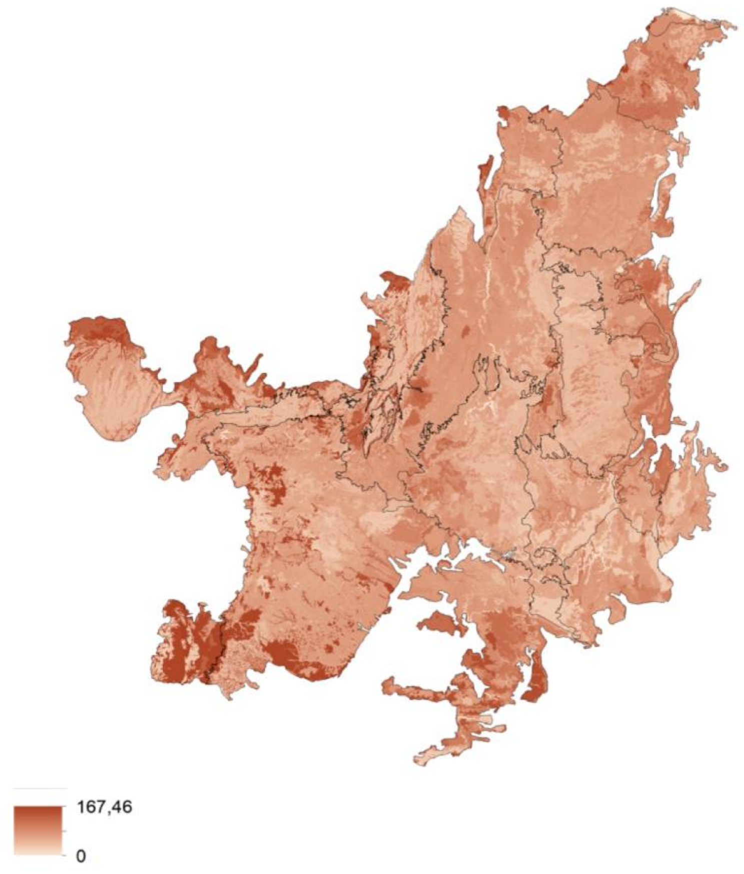

Figure 3: Carbon stock distribution in Cerrado (g/ha).

2.6. Agricultural potential

The agricultural potential was used as an opportunity cost layer. It means that areas with higher potential will present significant barriers (for example, more conflicts related to the use) to restore and should be avoided. This map was produced by Agrosatélite (https://agrosatelite.com.br) based on edaphoclimatic suitability for soybean, the slope, which is an important parameter for mechanized agriculture, the altitude, and the land cover of the region. Areas that already have soybean cultures were excluded. The combination of this information generated 26 categories with higher or lower agricultural potential. These data were also in shapefile format, so we converted it to raster by assigning unique values for each category. The values were stipulated by grading each attribute and summing the grades to produce a single value for the category. The grades were assigned for each attribute according to its suitability for soy production. Higher grades mean higher suitability. From the original 26 categories, we ended up with a raster layer containing seven categories of agricultural potential (figure 4).

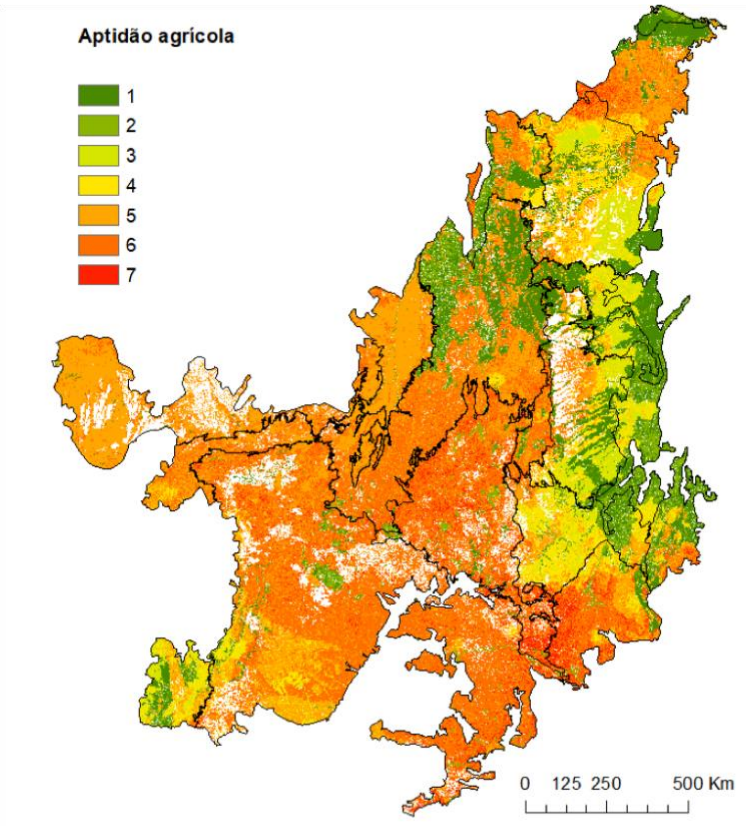

Figure 4: Agricultural potential classes in Cerrado. Warmer colors represents higher agricultural potential and therefore a higher opportunity cost.

2.7. Prioritization scenarios

We used the Additive Benefit Function (ABF) in Zonation 4.0 software (Moilanen et al., 2014) to create seven prioritization scenarios for five different spatial cuts. This function considers the weighted values of all input data to generate the scenarios. To determine scenarios, we established values ranging from 1 to 100 to each feature, so the sum of all values equals 100. For the biodiversity scenario, we group all the biodiversity groups as one variable for the analysis by dividing the assigned weight among all groups. Each scenario set greater importance for one feature, except the potential for natural regeneration, and one scenario has equivalent weights for all. For the agriculture potential, we made two different scenarios, one with a negative value that avoids areas with high agricultural potential, and one with positive value to understand the conflict between agriculture and the other features. For all the other scenarios, we considered a negative value for agriculture potential. The scenarios ware named as Biodiversity, for greater importance in biodiversity features, Surface Water, for the riparian vegetation, Groundwater, for groundwater recharge services, Carbon, for potential carbon stock, Agriculture Avoidance, for lower conflict areas, Agriculture Conflict, for higher conflict areas, and Equivalent Weights. We also selected three ecoregions with the greatest environmental debt according to Sano et al. (2019): Alto São Francisco, Basaltos do Paraná e Depressão Cárstica do São Francisco. Also, we include the Planalto Central ecoregion, which one that better represents Cerrado’s general characteristics. Finally, we also ran the prioritization for the Cerrado as a whole.

The output prioritization map gives a raster map with the relative importance of each pixel for restoration. We selected the most important pixels to meet the restoration demand for each ecoregion and the Cerrado as a whole. Finally, we summed the scenarios for biodiversity, groundwater, surface water and carbon to determine areas where more features overlap. All the scenarios ware generated in Zonation 4.0 and analyzed with ArcMap 10.6.1 and the software R 3.5.0.

3. Results

3.1. Cerrado biome

Cerrado has a restoration demand of 20 Mha, which represents around 10% of the biome’s area and 35% of pasture areas. Our restoration scenarios show very different spatial patterns for each selected feature (Figure 5 B to G). The areas with higher importance for biodiversity are concentrated in the southeastern and central portion of the biome. In comparison, areas with higher priority for groundwater recharge are located in the western part, closer to the Amazon biome. For carbon stock, we can observe a more disaggregated spatial distribution with hotspot areas in the northern, southern, eastern, and central portions of Cerrado. The equivalent weights and surface water scenarios show a very similar pattern with the distribution spread across all the biome. The agriculture avoidance scenario also shows a disaggregated distribution where the areas with lower conflict concentrated in the western, southmost, and eastern portions of the biome. In contrast, the agriculture conflict scenario shows a very spread distribution pattern (Figures 5 B to G and 6 B).

The different prioritization scenarios show the proportion of land, relative to 20 Mha over pastures, covered by each feature. It means that, by restoring these pasture areas according to the scenarios, each feature will occupy a certain proportion of the area. When we compare the perceptual of area gained or lost by each feature, we can also observe trade-offs between the scenarios, especially with the agriculture conflict scenario (Figure 5 A). Gained area means that a certain feature increases its representation on the landscape, while lost area means that agriculture would decrease its representation. The agriculture conflict scenario shows that biodiversity and ecosystem services features are represented in 70% of the priority areas, but agriculture would lose 80% of its area relative to the 20 Mha over pastures. The agriculture avoidance scenario, on the other hand, shows a loss of only 20% of agricultural area with a gain of 30% for most biodiversity groups (20% for reptiles and 53% for palm trees) and carbon, and 40% for water related services.

When we merge the biodiversity (all taxonomic groups) and ecosystem services maps (carbon and water related services), we can see overlaps of features in some areas. Areas that encompass three or more features represent 17 % of pasture area or 9.8 Mha. Those areas, however, are mostly in highly suitable areas for agricultural use, representing a conflict between restoration and agriculture expansion (Figure 6). There are exceptions in the western and southmost portions of Cerrado where many features are contemplated, and the conflict can be avoided.

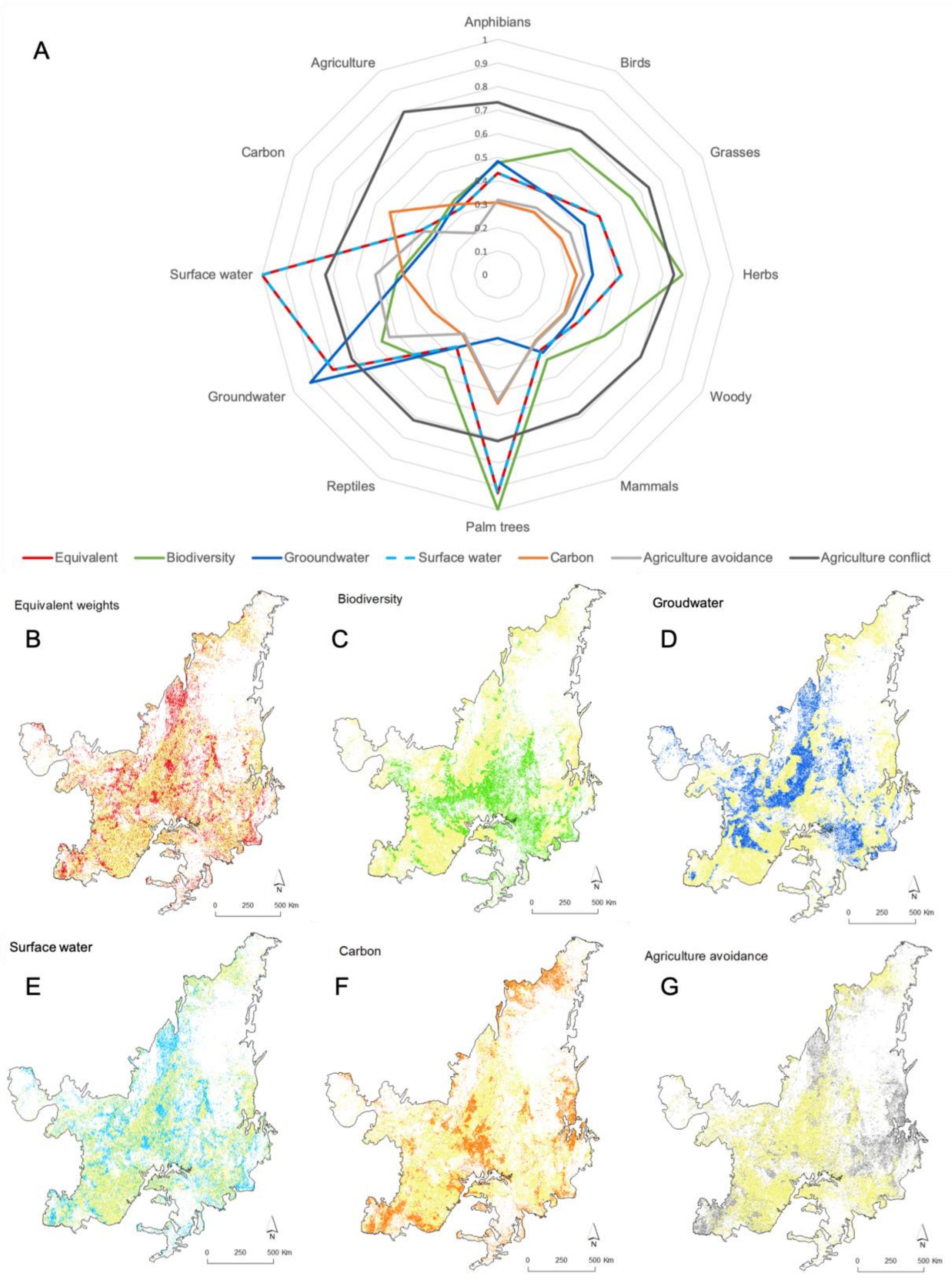

Figure 5: Radar graph (A) and spatial distribution maps of the prioritization scenarios for the whole Cerrado (B to G). The maps show the spatial distribution for the equivalent weights (B),

biodiversity (C) , groundwater (D), surface water quality (E), carbon (F) and agriculture avoidance (G) scenarios (Agriculture conflict scenario is shown in Figure 6B). The radar graph shows the proportion of area (considering the extension of pastures in the Cerrado) gained by each feature, or lost for agriculture feature, in each scenario.

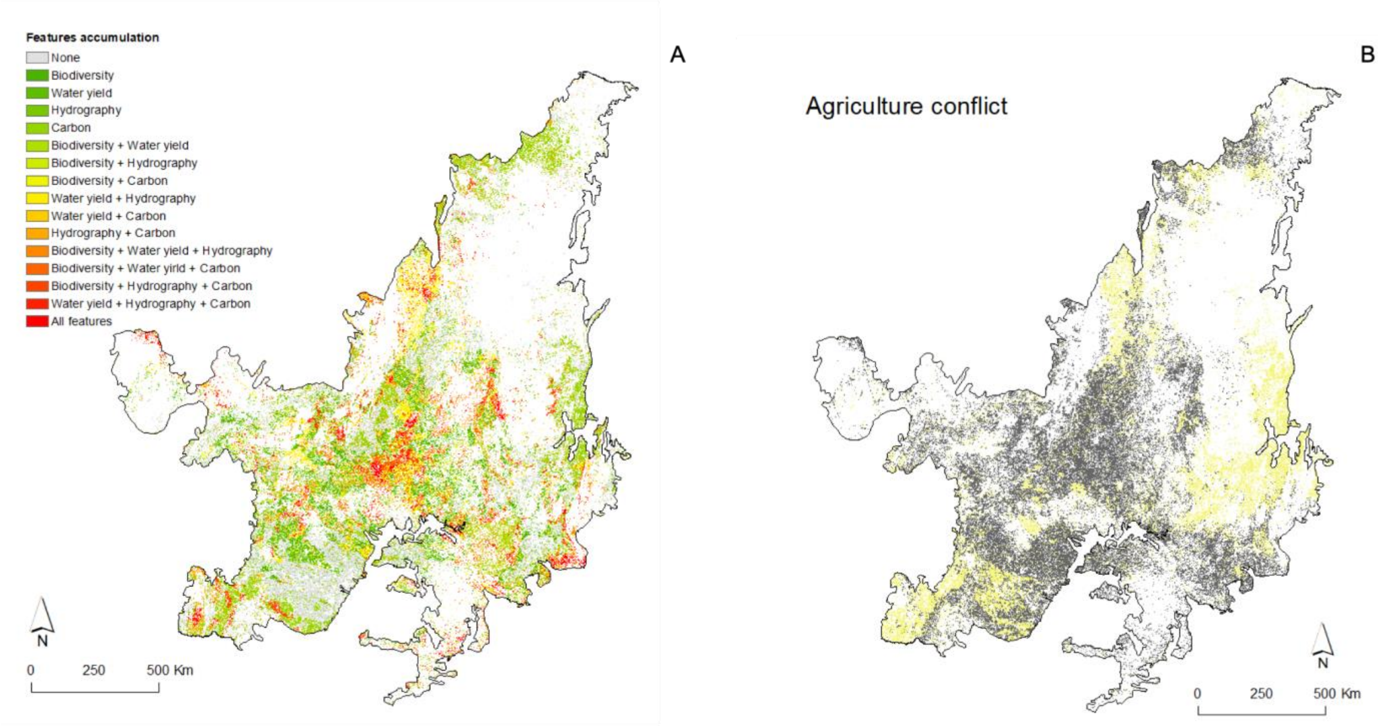

Figure 6: Maps representing the accumulation of features (A), and the agriculture conflict prioritization scenario (B) for the whole Cerrado.

3.2. Cerrado Ecoregions

When we analyzed the spatial patterns and trade-offs for the ecoregions, we follow the same logic of the whole Cerrado: different prioritization scenarios show the proportion of land, relative to the specific restoration demand over pastures, covered by each feature. So, when we restore these pasture areas according to the scenarios, each feature will be represented a certain proportion of the area.

For the ecoregions, we can also observe spatial differences in each scenario. Alto São Francisco ecoregion has a restoration demand of 1.6 Mha, around 20% of its total area, and 31% of its pasture areas. On this ecoregion, we can observe some spatial congruence among all scenarios. Biodiversity, groundwater, and carbon have a very aggregated distribution, concentrated on the eastern and western portions of the ecoregion (Figure 7 C, D and E). The equivalent weight and surface water scenarios also present a more dispersed and similar distribution (Figure 7 B and G).

Despite that, Alto São Francisco also shows a conflict between areas with high agricultural potential and the other features (Figures 7G and 8B). In the agriculture conflict scenario we have an area gain around 70% for all features with a loss of almost 80% of agriculture area (Figure 7A). On the other hand, in the agriculture avoidance scenario, we may lose only 20% of areas suitable for agriculture, but with a gain of 30% in areas for carbon uptake and surface water services and 60% for water yield. In the agriculture avoidance scenario, the biodiversity features present a greater variation in the gained area among them (Figure 7A). Conservation of reptiles, mammals, grasses, woody plants, and birds have a gain of 30% of the area, while palm trees gain over 60% of the area and herbs 40% (Figure 7A).

In the Alto São Francisco ecoregion, there is an overlap of features mostly on the eastern and western portions Figure 8A). The areas with three or more features represent 18.7% of pasture areas or 0.9 Mha. Different from the pattern found for the entire Cerrado, most of those areas are not located in areas with high agriculture potential, which means less conflict between land demands for restoration and for agriculture (Figure 8B).

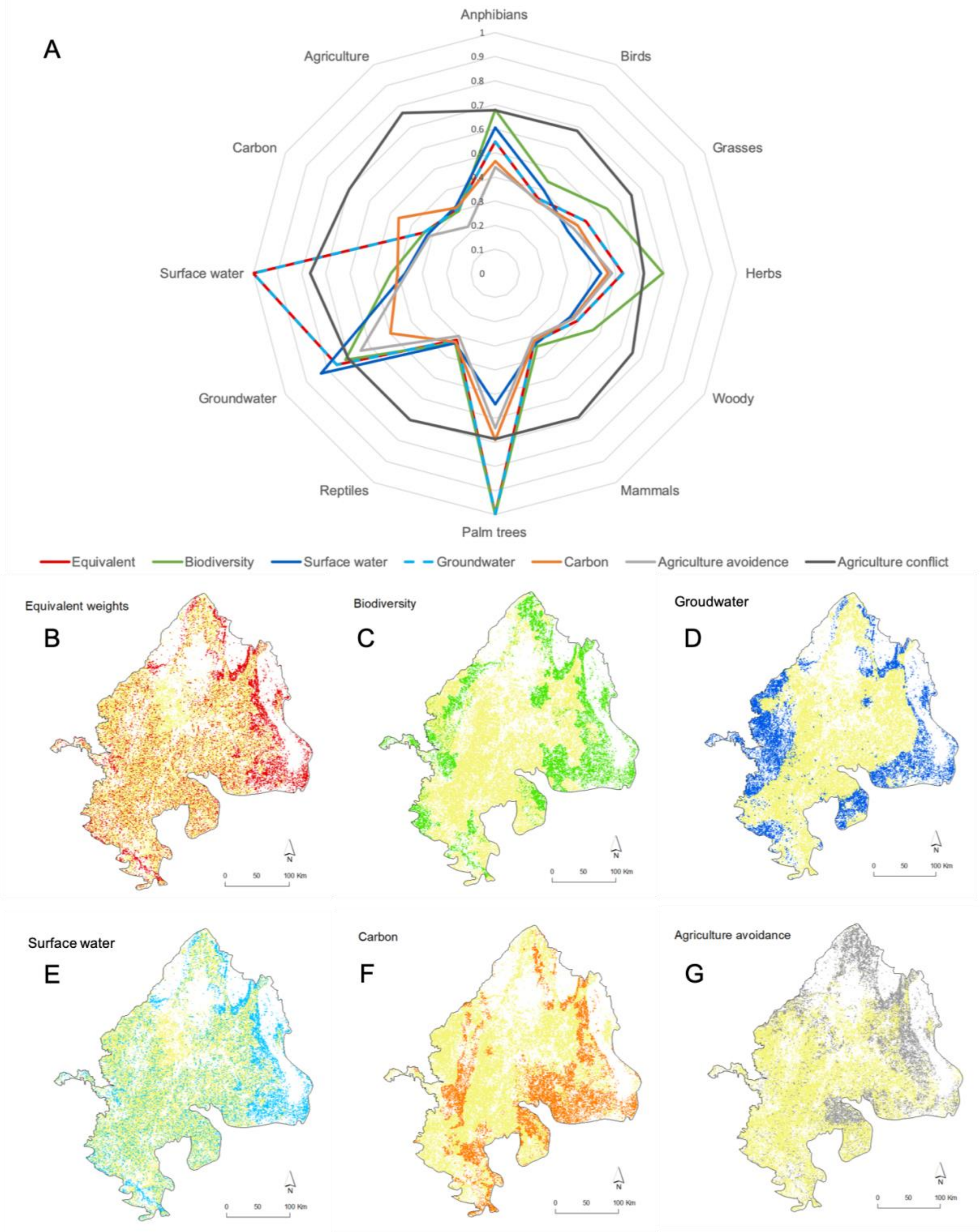

Figure 7: Radar graph (A) and spatial distribution maps of the prioritization scenarios for the Alto São Francisco ecoregion (B to G). The maps show the spatial distribution for the equivalent weights (B), biodiversity (C), groundwater(D), surface water (E), carbon (F) and

agriculture avoidance (G) scenarios (Agriculture conflict scenario is shown in Figure 8B). The radar graph shows the proportion of area (considering the extension of pastures) gained by each feature, or lost for agriculture feature, in each scenario.

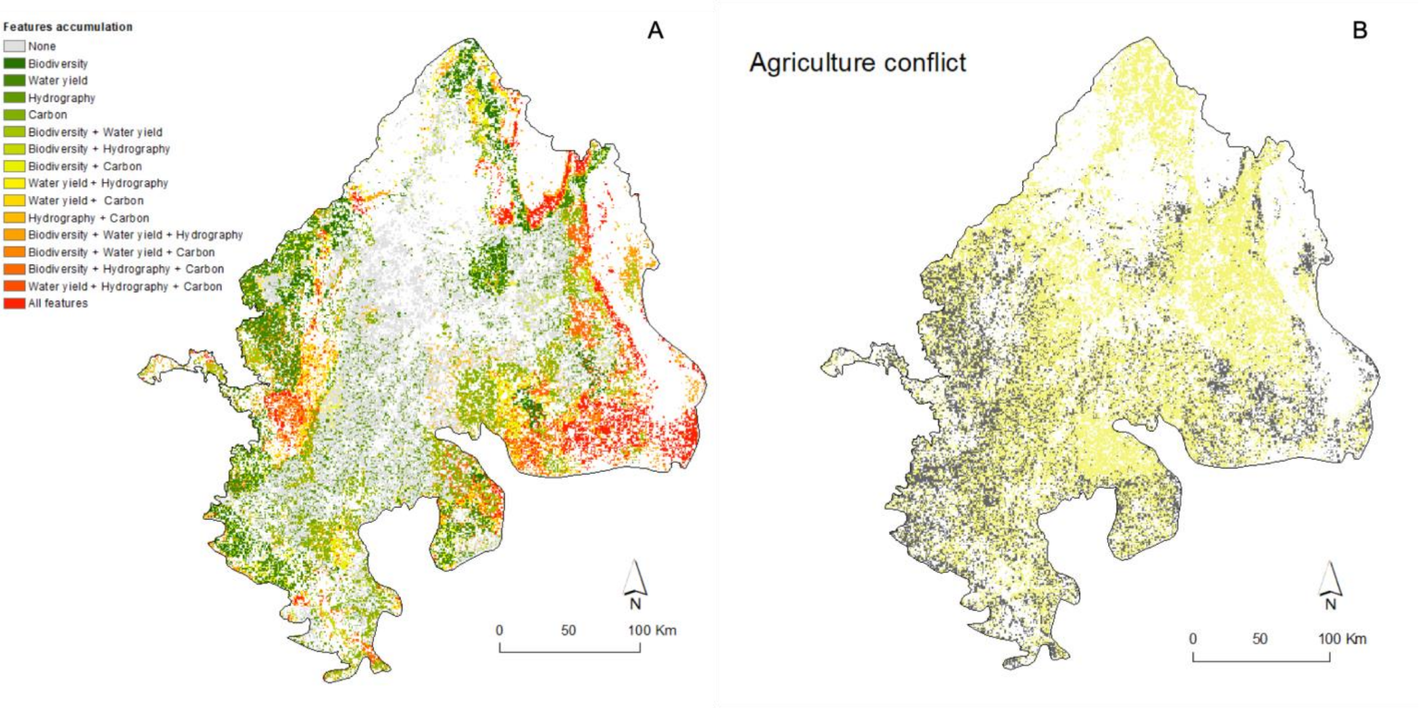

Figure 8: Maps representing the accumulation of features (A), and the Agriculture conflict prioritization scenario (B) for Alto São Francisco.

The restoration demand for Basalto do Paraná ecoregion is 2.5 Mha, 18% of its total area, and 57% of its pastures area. This ecoregion presents some congruence between the biodiversity, surface water and equivalent weight scenarios, while the groundwater and carbon scenarios show different spatial patterns (Figure 9 B to F). The first three have a more dispersed distribution, with some concentration on the northern and eastern portions of the ecoregion. Groundwater present a very concentrated distribution in the north and eastern parts, and carbon shows some hotspots across all the ecoregion (Figure 9 E and F).

Differently from Alto São Francisco ecoregion, Basaltos do Paraná presents a relatively lower conflict between agriculture and restoration (Figures 9G and 10B). In this ecoregion, the agriculture avoidance scenario has a greater loss of agriculture area than the agriculture conflict, 51% and 49%, respectively (Figure 9A). The agriculture avoidance scenario also shows a gained area, for all features, 20% higher than the agriculture conflict scenario (Figure 9A).

Biodiversity and ecosystem services features overlap mostly on the northern and eastern portions of Basaltos do Paraná ecoregion (Figure 12A). The areas with three or more features represent 48.5% of pasture areas or 2.1 Mha. These areas, however, also present a conflict with agriculture (Figure 10).

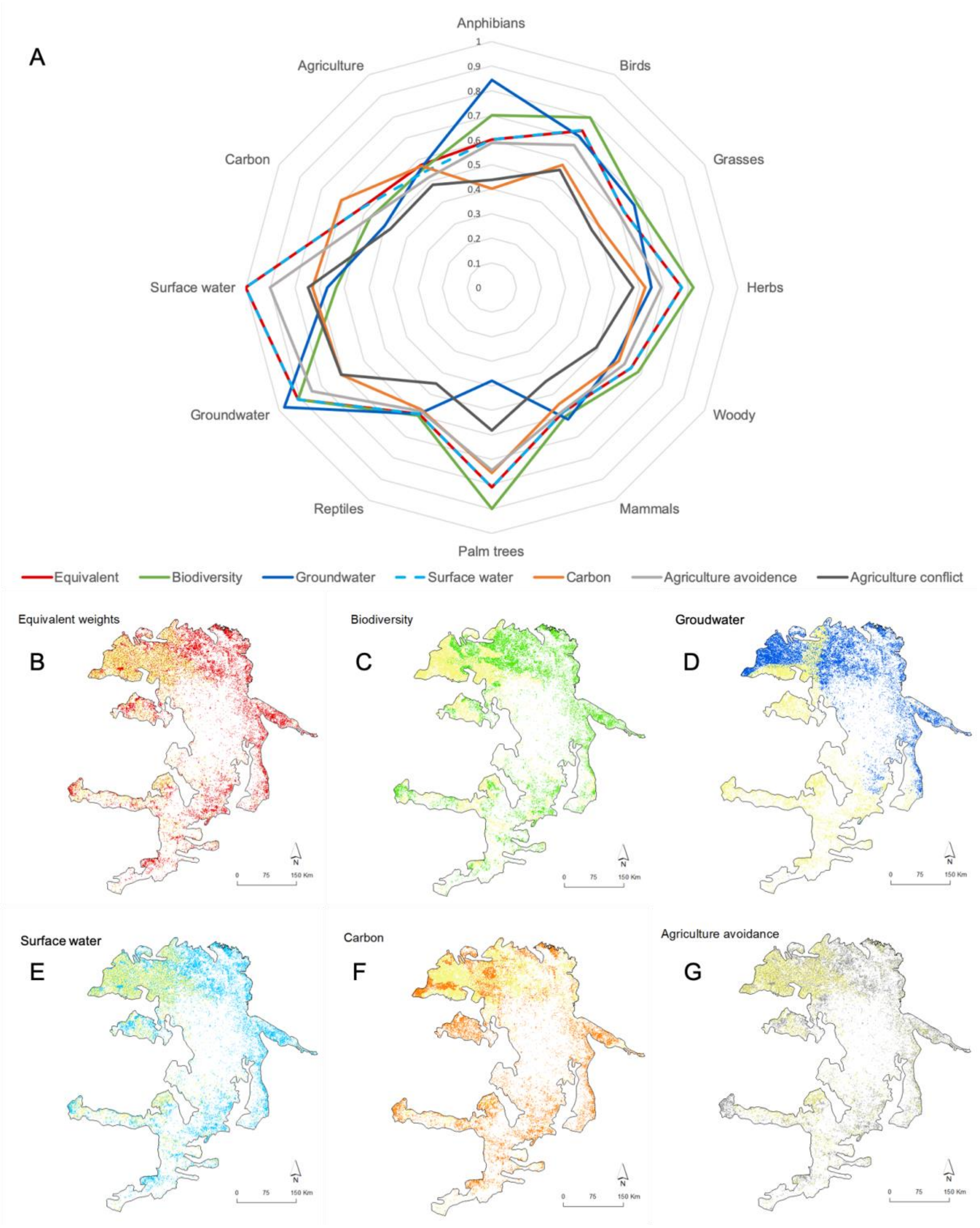

Figure 9: Radar graph (A) and spatial distribution maps of the prioritization scenarios for the Basaltos do Paraná ecoregion (B to G). The maps show the spatial distribution for the equivalent weights (B), biodiversity (C), groundwater (D), surface water (E), carbon (F) and agriculture avoidance (G) scenarios (Agriculture conflict scenario is shown in Figure 10B). The radar graph

shows the proportion of area (considering the extension of pastures) gained by each feature, or lost for agriculture feature, in each scenario.

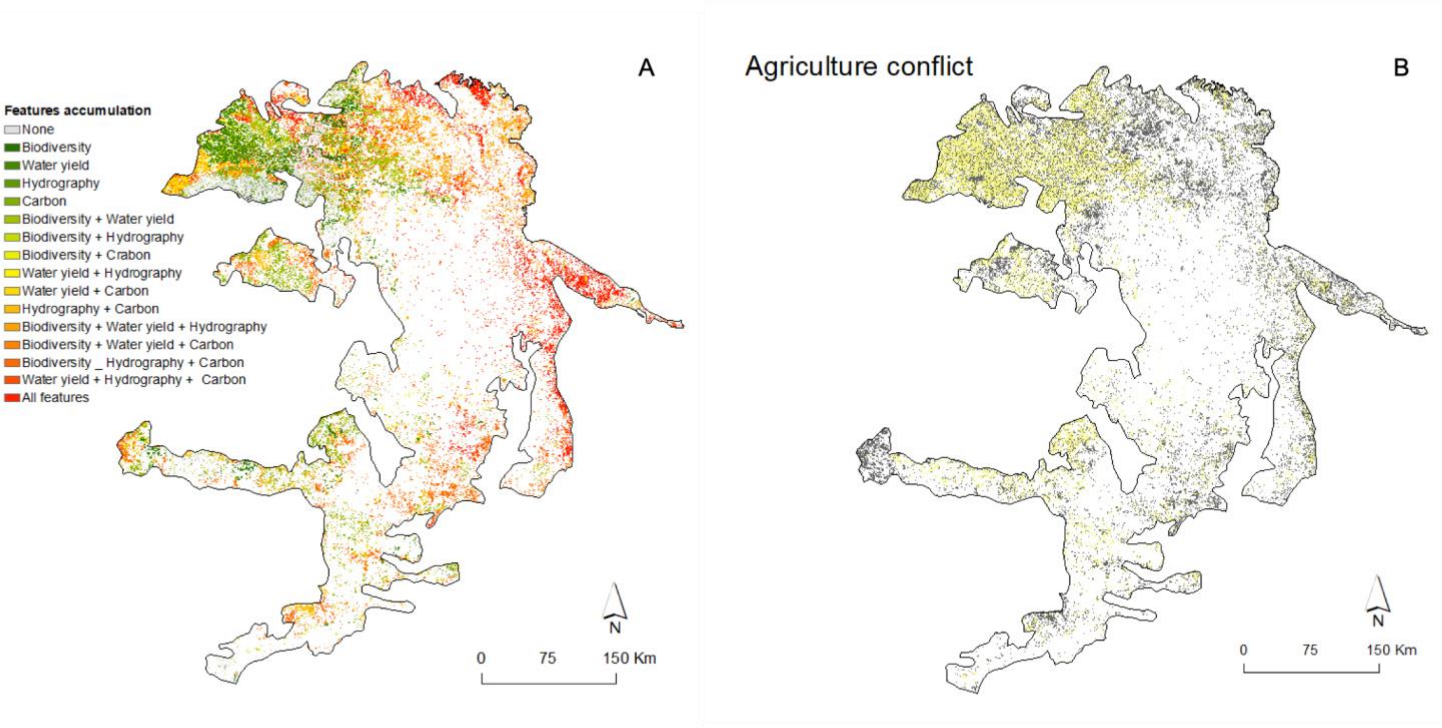

Figure 10: Maps representing the accumulation of features (A), and the Agriculture conflict prioritization scenario (B) for Basaltos do Paraná.

Among the ecoregions, the Depressão Cárstica do São Francisco shows the greatest discrepancy between the scenarios. This ecoregion has a restoration demand of 0.47 Mha, around 6% of its total area, and 14.7% of its pasture area. Areas with greater importance for biodiversity are concentrated on the southern and eastern portions of the ecoregion, while areas important for groundwater recharge are located mainly on the south (Figure 11 C and D). Carbon, surface water, and equivalent weight scenarios have a more dispersed spatial pattern (Figure 11 A, E and F).

The Depressão Cárstica do São Francisco has the greatest conflict between agriculture and restoration (Figures 11G and 12B). In the agriculture conflict scenario, biodiversity and ecosystem services cover around 90% of the priority area (Figure 11A). However there is a lost of 95% of areas suitable for agriculture. The agriculture avoidance scenario shows a loss of agriculture area below 10%, Biodiversity and ecosystem services, however, have a much lower representation (Figure 11A). All biodiversity groups have an area gain below 20%. Carbon also shows a gain of only 20% of area, while the water-related ecosystem services present a higher gain, with 30% for surface water and approximately 60% for groundwater (Figure 11A).

The merged map for biodiversity and ecosystem services show few areas of convergence due to the differences on the spatial distribution of the features (Figure 12A). Areas that encompass three or more features represent only 3.8% of the pasture areas, 0.14 Mha, mostly on the southmost portion of the ecoregion. These areas, however, are not located in highly suitable areas for agriculture, having a great restoration value (Figure 12).

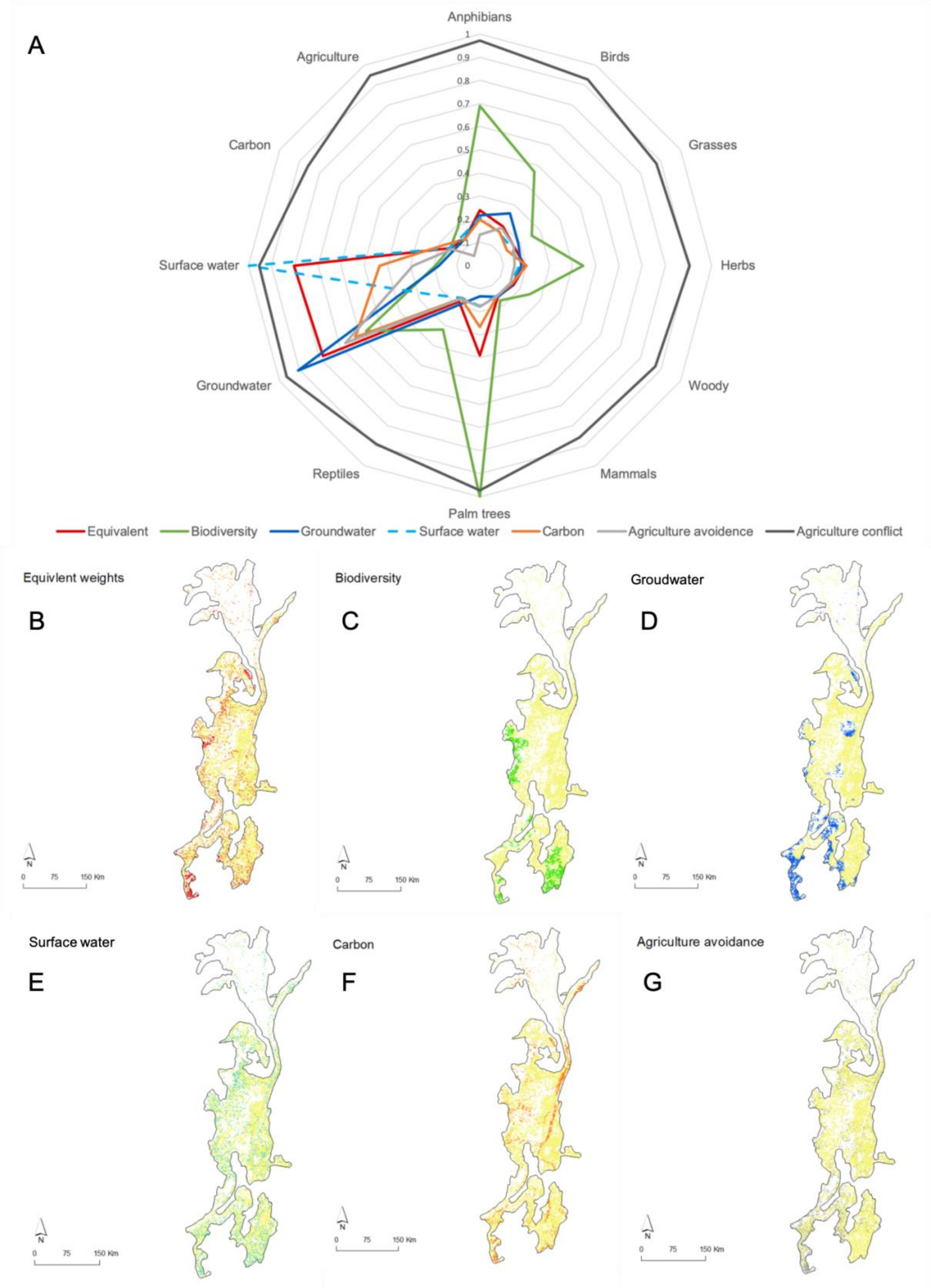

Figure 11: Radar graph (A) and spatial distribution maps of the prioritization scenarios for the Depressão Cárstica do São Francisco ecoregion (B to G). The maps show the spatial distribution

for the equivalent weights (B), biodiversity (C), groundwater (D), surface water (E), carbon (F) and agriculture avoidance (G) scenarios (Agriculture conflict scenario is shown in Figure 12B). The radar graph shows the proportion of area (considering the extension of pastures) gained by each feature, or lost for agriculture feature, in each scenario.

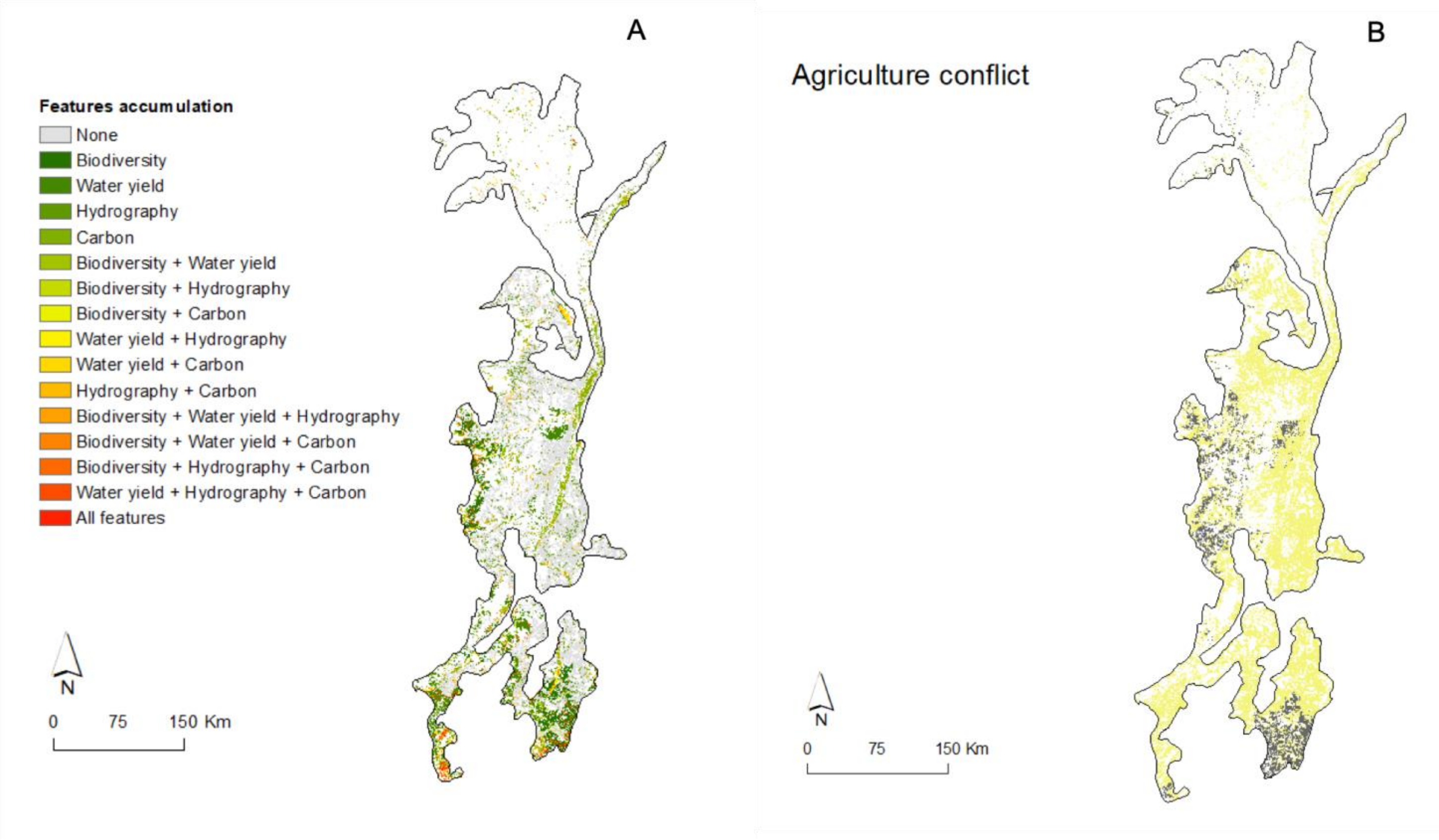

Figure 12: Maps representing the accumulation of features (A), and the Agriculture conflict prioritization scenario (B) for Depressão Cárstica do São Francisco.

Planalto Central has a restoration demand of 2.6 Mha, 15% of its total area which represents 26% of its pasture areas. In this ecoregion, we could not observe much convergence between the scenarios. The suitable areas for biodiversity are mostly located on the central portion of the biome (Figure 13C). In contrast, carbon areas are concentrated on the western portion and groundwater in the northwestern and southern portions of the ecoregion (Figure 13

D and F). As in the other cases, surface water and the equivalent weight scenarios show a very similar disaggregated spatial pattern (Figure 13 B and E).

As in most ecoregions ecoregion, in Planalto Central, restoration has a high conflict with agriculture. In the agriculture conflict scenario, there is an agriculture area loss of 85%, with an area gain above 70% for all biodiversity and ecosystem services features (Figure 13A). In the agriculture avoidance scenario, we can observe a loss around 15% of the agriculture area with a gain around 30% of area for amphibians, reptiles, birds, mammals, grasses, herbs and woody plants, and nearly 40% for palm trees (Figure 13A). Carbon shows a gain of 25% of area, groundwater of 35%, and surface water of 30% (Figure 13A).

When we merged the biodiversity and ecosystem features, we observe a few areas of congruence (Figure 14A). Only 6.7%, 0.67 Mha, of the pasture areas show an overlap of three or more features. Those areas are also in areas with high agriculture suitability, which represents a greater conflict between agriculture and restoration (Figure 14B).

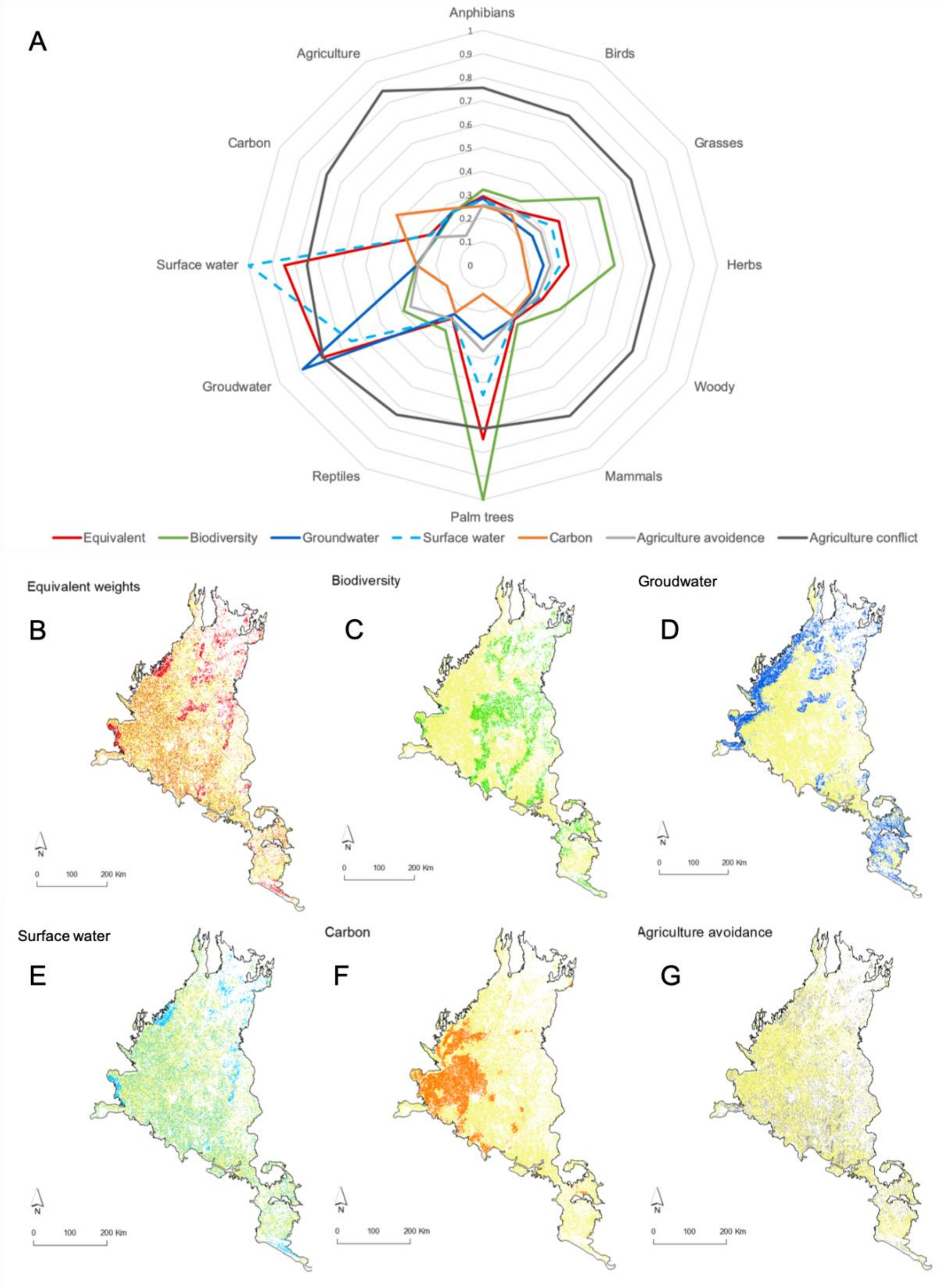

Figure 13: Radar graph (A) and spatial distribution maps of the prioritization scenarios for the Planalto Central ecoregion (B to G). The maps show the spatial distribution for the equivalent

weights (B), biodiversity (C), groundwater (D), surface water (E), carbon (F) and agriculture avoidance (G) scenarios (Agriculture conflict scenario is shown in Figure 10B). The radar graph shows the proportion of area (considering the extension of pastures) gained by each feature, or lost for agriculture feature, in each scenario.

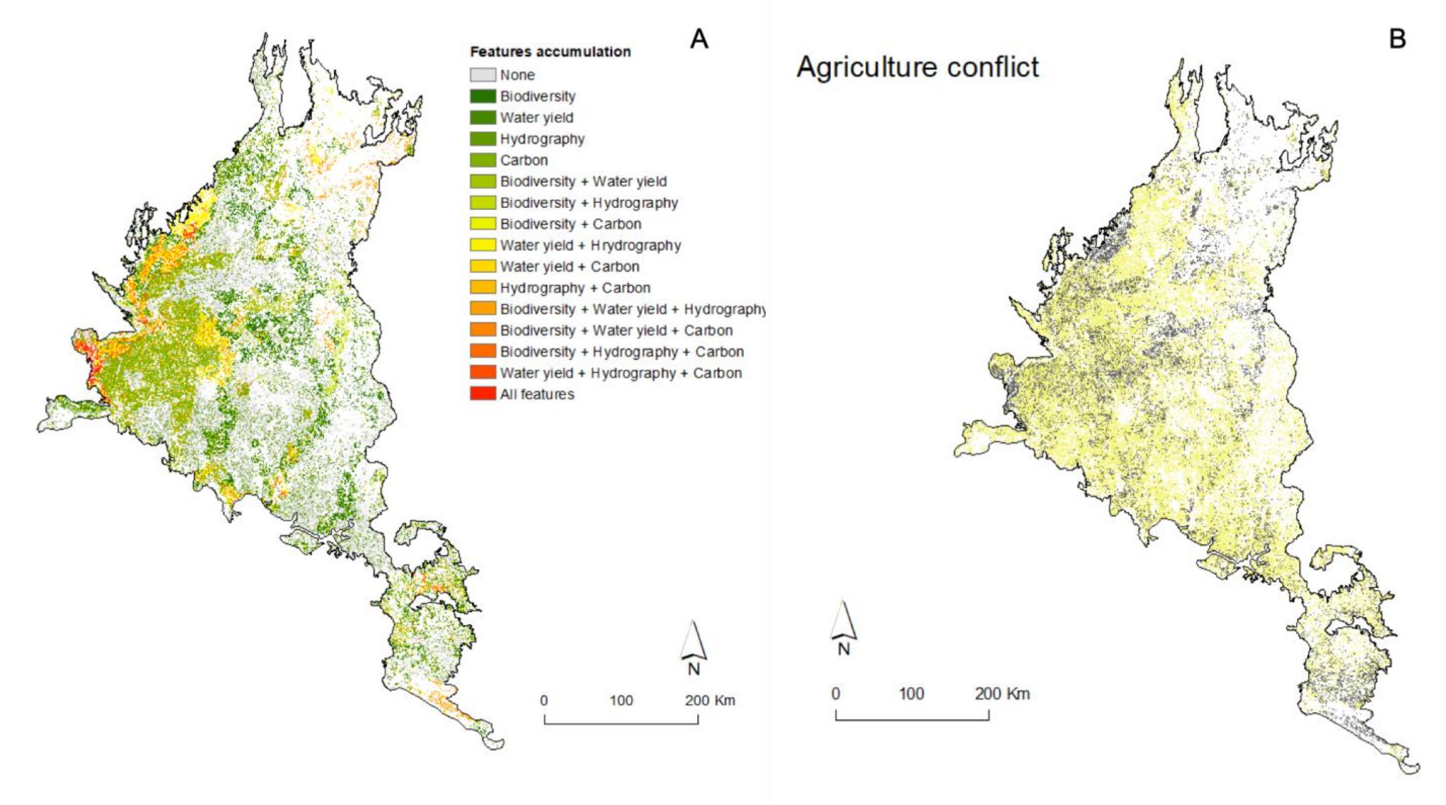

Figure 14: Maps representing the accumulation of features (A), and the Agriculture conflict prioritization scenario (B) for Planalto Central.

4. Discussion

Our main goal with this study was to identify areas where restoration would bring more benefits to biodiversity groups and ecosystem services and where the restoration presents a more significant conflict with agriculture. Our results show that the spatial distribution of priority areas for restoration varies according to the restoration goal with an intermediate overlap of the scenarios. For the Cerrado, 9.8 Mha present an overlap of three or more features.

This area represents 49% of the 20 Mha of Cerrado's restoration demand; thus, the remaining restoration areas may be selected according to more specific goals, such as potential carbon stock, biodiversity conservation, or lower conflict with agriculture. Despite an overlap of almost 50% we can still observe trade-offs between the scenarios, where, by prioritizing one feature, we lose representation of others.

In our study, the trade-off between agriculture and conservation is especially strong. The Agriculture conflict scenario, for the whole Cerrado, shows a greater and more equal representation of all biodiversity groups and ecosystem services. However, this scenario also shows that restored areas would occupy 16 Mha suitable for agriculture. On the other hand, the Agriculture avoidance scenario has a much lower and variable representation of biodiversity and ecosystem services features while it occupies only 4 Mha of agricultural land. According to Agrosatélite (2014), the Cerrado biome has approximately 82 Mha with high suitability for soybean production, 51% of this area, 42 Mha, are located in pasturelands in the south of the biome. It means that pastures have significant conservation and agricultural value, increasing the conflict between agriculture expansion and restoration.

We include the Agriculture potential as an opportunity cost layer in our analysis. Incorporating other factors such as agriculture and population density, besides providing an estimated cost for restoration and conservation, allow us to further understand the conflict involved in these projects. Manhães et al. (2019) studied these conflicts for the Caatinga biome in Brazil. They found that incorporating agriculture suitability and population density when selecting conservation areas have a relatively low impact on biodiversity and a more significant impact on ecosystem services provision. In a much broader study, for the whole South America, Durán, Duffy, and Gaston (2014) found that the exclusion of areas with high potential for agriculture have a more substantial impact in biodiversity and a lower impact on carbon stock.

Our study, on the other hand, shows a notable trade-off between agriculture and both biodiversity and ecosystem services.

Durán, Duffy, and Gaston (2014) and Manhães et al. (2018) also show that the scale of the prioritization matters. We run the prioritization process for four Cerrado ecoregions, aiming to address their specific restoration demands. We found very different behavior for the distribution of the priority areas and the trade-offs for each ecoregion. Alto São Francisco and Planalto Central ecoregions present a high overlap between highly suitable agricultural areas and biodiversity and ecosystem services features, which means a conflict between agriculture and restoration. The ecoregion Depressão Cárstica do São Francisco presents the most significant conflict because there is a loss of almost 90% of the agricultural area on the agriculture conflict scenario. It happens mostly because this ecoregion has unique soil characteristics and very few areas suitable for agriculture, restricting the distribution of the features (Agrosatélite 2014; Sano et al. 2019). The Basaltos do Paraná ecoregion showed a different behavior compared to the other ecoregions with a low conflict with agriculture. The Agriculture avoidance scenario presents a more significant loss of agricultural area than the Agriculture conflict scenario. This ecoregion is located on the very south of the Cerrado biome and has been heavily deforested. Most of its area is already covered by sugar cane and soybean with a lower proportion of pastures which might explain the scenarios (MapBiomas 2018).Cerrado is highly heterogeneous, and each ecoregion has unique features that must be considered when planning for restoration. By doing so, we can have a better representation of the diversity of species and ecosystems in the Cerrado, while solving conflicts on a regional scale.

Seventy percent of Brazil’s agricultural production takes place in Cerrado, and the agricultural frontier is expanding at a rapid pace (Instituto Brasileiro de Geografia e Estatística (IBGE) 2019). However, this expansion is happening in less suitable areas, mostly in the MATOPIBA region (Agosatélite, 2014). Considering the high potential for agriculture and the low productivity of Cerrado's pastures, these pasture present a significant opportunity for increasing production without further deforestation. At the same time, by identifying areas with higher conservation value, we may achieve restoration demands in strategic areas avoiding conflicts with agriculture. As presented above, this multi-criteria approach, including biodiversity, ecosystem services and economic variables, has been widely used for the planning of protected areas. As others, our study uses the same logic to prioritize restoration areas in Brazilian Cerrado, a national and worldwide demand to mitigate the impacts of human activities on our planet.

The benefits of ecological restoration are not limited to conservation only. Syktus and McAlpine (2016) showed that the restoration of savannas increase local evapotranspiration, regulating the local climate and reducing the intensity and duration of the dry season. Biodiversity also has a positive impact on agricultural production by providing pollination and pest control. Dainese et al. (2019), showed that agriculture expansion is responsible for a 50% decline in services providers organism, with a direct effect on crops yield. Finally, large scale restoration projects may also have a positive impact on socioeconomics and livelihood of local communities by increasing off-farm job opportunities and reducing poverty (Adams et al., 2016). These examples show that agriculture and restoration do not need to be at conflict and that a proper spatial planning can guarantee benefits for both conservation and agriculture.

5. Conclusion

Our study aimed to understand the trade-offs between multiple features involved in multi-criteria prioritization for restoration models. We used biodiversity, ecosystem services and agricultural potential to generate scenarios for restoration in Cerrado's pastures and for four Cerrado ecoregions. We identified overlaps between ecosystem services and biodiversity scenarios, which indicate areas with higher restoration and conservation value. We also found a significant conflict between agriculture expansion and restoration. Proper spatial planning may mitigate this conflict enabling the restoration of key areas for biodiversity and ecosystem services while increasing the agricultural production without further deforestation.

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Conclusão geral

Nossos objetivos centrais para este trabalho foram gerar um índice espacial de potencial de regeneração natural para as pastagens do Cerrado assim como gerar cenários de priorização para a restauração dessas pastagens visando conservação de serviços ecossistêmicos, da biodiversidade e redução de conflitos com a produção agrícola. Nossa primeiro capítulo estima o potencial de regeneração das pastagens a partir da quantidade de habitat remanescente e a conectividade dos fragmentos e do estado de degradação dessas pastagens. Nossas análises revelam que 44% das pastagens tem um potencial de regeneração abaixo de 0.25 e apenas 1% tem potencial acima de 0.75. Contudo, 55% das pastagens estão em classes intermediárias. Estas pastagens estão concentradas na porção sul do bioma, já bastante degradada, e representam uma oportunidade para a implementação de projetos de restauração visando, inclusive, melhora a qualidade geral das paisagens na região.

No nosso segundo capítulo, construímos cenários de priorização para serviços ecossistêmicos, biodiversidade e redução de conflitos com a agricultura. Nossas análises também mostram que há *trade-offs* entre os cenários, em que, ao focarmos em um elemento, temos perdas em outros. Os cenários que priorizaram reduzir ao máximo o conflito com a agricultura, mostram poucos ganhos em conservação da biodiversidade e serviços ecossistêmicos, enquanto o cenários que possuem mais conflito com a expansão da produção agrícola apresentaram um ganho significativo em todos os outros aspectos analisados. Ainda assim, apesar dos *trade-offs*, identificamos 9.8 Mha que, ao serem restauradas, trariam benefícios para a conservação sem grades perdas de áreas agricultáveis. Ao regionalizarmos as priorizações para as quatro ecorregiões, observamos que há um forte viés espacial e que regionalizar a priorização adequa esse processo às demandas e realidade locais, além de melhor abranger a grande diversidade do Cerrado.

Por fim, o processo de priorização multi-critério, isto é, considerando diversos aspectos ambientais e socioeconômicos, se mostra eficiente em mediar esse conflito e garantir que as demandas de restauração sejam alcançadas. Com essa abordagem a restauração pode ocorrer de maneira eficiente ao mesmo tempo em que permite a expansão da produção agrícola para áreas já desmatadas, evitando uma maior devastação do bioma Cerrado já fortemente ameaçado.

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