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Instituto de Ciências Biológicas
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Além do plantio de árvores: mobilização de redes de produção de restauração do Cerrado

Thaís Franco Montenegro

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Além do plantio de árvores: mobilização de redes de produção de restauração do Cerrado

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Resumo

Um diverso e robusto suprimento de produtos e serviços é essencial para restaurar milhões de hectares de ecossistemas abertos degradados a fim de cumprir compromissos globais de restauração. No entanto, as práticas de restauração são notavelmente limitadas pela inclusão inadequada de biodiversidade nativa e restrição de participação social nas decisões. Neste estudo, nós analisamos como os desenvolvimentos institucionais, operações de mercado e sistemas de suprimento configuram a rede de produção de restauração do Cerrado. Nossas análises revelam assimetrias de poder entre os múltiplos atores, levando a uma distribuição desigual de investimentos, demandas de mercado e recursos tecnológicos ao longo das escalas. As políticas e regulamentações vigentes continuam a priorizar princípios centrados em florestas, desconsiderando os requisitos únicos de ecossistemas savânicos. Em meio a esses desafios, nós identificamos o cumprimento de legislações ambientais nacionais como o mercado de restauração mais influente no Cerrado, embora com demandas regionais que permanecem instáveis e voláteis. Entretanto, comunidades locais, que fornecem produtos e serviços, desencadeiam inovações baseadas no território para co-criar a organização coletiva e as técnicas adequadas ao local, avançando no desenvolvimento de práticas para restauração de savanas. Nossa pesquisa ressalta a importância de promover procedimentos participativos de modo a reconfigurar como as instituições e mercados priorizam engajamentos locais para incorporar plenamente considerações acerca da biodiversidade e garantir a distribuição equitativa dos benefícios da restauração.

Palavras-chave: Restauração ecológica, Restauração de ecossistemas abertos, Compensação de carbono, Pagamentos por serviços ecossistêmicos, Redes comunitárias

Abstract

A diverse and robust supply of products and services is essential for restoring millions of hectares of degraded open-canopy ecosystems to meet global restoration pledges. Yet restoration practices are notably constrained by the inadequate inclusion of native biodiversity and limited social participation in decisions. Here, we analyze how institutional developments, market operations, and supply systems configure the Brazilian Savanna restoration production network. Our analyses reveal power asymmetries between multiple stakeholders, leading to an uneven distribution of investments, market demands, and technological resources across scales. Prevailing policies and regulations continue to prioritize forest-centric principles, disregarding the unique requirements of savanna ecosystems. Amidst these challenges, we identify compliance as the most influential restoration market in the Brazilian Savanna, albeit with regional demands that remain unstable and volatile. Nevertheless, community suppliers spark place-based innovations to co-create collective organization and situated techniques, advancing savanna restoration practices. Our research underscores the significance of promoting participatory procedures to reshape how institutions and markets prioritize local engagements to fully incorporate biodiversity considerations and ensure equitable sharing of restoration benefits.

Keywords: Ecological restoration, Open ecosystem restoration, Carbon offset, Payments for ecosystem services, Community networks

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Introdução geral

A restauração ecológica, que é o processo de auxiliar a recuperação de um ecossistema que foi degradado, danificado ou destruído (SER, 2014), tem emergido como uma intervenção crucial para mitigar os efeitos das mudanças climáticas, com benefícios econômicos e sociais associados (Chazdon et al., 2017; Gann et al., 2019). Diversas organizações internacionais fomentam a restauração ecológica de ecossistemas (Seddon et al., 2020, Fuchs & Noebel, 2022), como por exemplo as Nações Unidas, que em 2019 declararam a Década da Restauração de Ecossistemas no período entre 2021 e 2030. Ainda, o International Union for Conservation of Nature (IUCN) e o World Resources Institute (WRI) lançaram em 2011 e 2014, respectivamente, o Bonn Challenge e a Initiative 20x20, que são compromissos internacionais com a meta de restaurar 350 milhões de hectares até 2030, através da mobilização de diversos países e do setor privado. Enquanto esses incentivos fomentam a restauração em larga escala, ainda há discussões de como estes desconsideram contextos locais e podem, dessa forma, aumentar as desigualdades sociais e levar ao fracasso de projetos de restauração (Temperton et al., 2019; Stevens et al., 2020). Dentre as principais lacunas da restauração em larga-escala estão a falta de incorporação de práticas de ecossistemas abertos (Buisson et al., 2021; Tölgyesi et al., 2021), a limitada inclusão de biodiversidade (Silveira et al., 2022) e a participação restrita de comunidades locais, que não garante a distribuição equitativa dos benefícios sociais gerados a partir da restauração ecológica (Adams et al., 2016; Löfqvist et al., 2023).

Apesar de as discussões e abordagens técnicas recomendarem a inclusão de diversos ecossistemas na restauração ecológica (Temperton et al., 2019; Sacco et al., 2021), ou seja, considerar a restauração de ecossistemas não-florestais, iniciativas para plantar muitos hectares de árvores têm sido colocadas como a principal estratégia para recuperar áreas degradadas (Laestadius et al., 2011; Philipson et al., 2020; Bastin et al., 2019). Dentre os métodos de restauração, o plantio de árvores em larga escala é amplamente adotado por programas influentes, seja em escala internacional, nacional ou regional, devido ao reconhecimento do potencial de florestas em absorver carbono[1] da atmosfera (Seymour, 2020; Fleischman et al., 2020). A Campanha Três Trilhões de Árvores, por exemplo, mobiliza grandes investimentos do setor privado para promover o plantio de árvores em larga escala para absorver carbono, o que atrai financiadores como a Microsoft e a Hyundai, que estão interessados em cumprir metas corporativas socioambientais para compensar as emissões de suas atividades.

[1] O carbono é o representante mais conhecido dos gases de efeito estufa, que devido à sua emissão exacerbada através da queima de combustíveis fósseis, alimenta o mecanismo de aquecimento global, do qual decorrem as mudanças climáticas, que prejudicam principalmente a população mais vulnerabilizada do planeta (IPCC, 2022).

Apesar do reconhecimento do alto potencial de árvores em absorver carbono (e.g., Bastin et al., 2019; Walker et al., 2022), a falta de reconhecimento do potencial de outros ecossistemas, como savanas (Yang et al., 2019) e turfeiras (Bonn et al., 2014) em absorver carbono, além das complexidades socioecológicas dos territórios onde a restauração ecológica é implementada, impulsiona diversos impactos ambientais negativos (Ramprasad et al., 2020; Buisson et al., 2021). De acordo com avaliações recentes, esforços indiscriminados para plantio de árvores em larga-escala podem falhar em sequestrar carbono (Rana et al., 2022), reduzir a disponibilidade de água (Wang et al., 2020), exacerbar a insegurança alimentar (Doelman et al., 2020), e diminuir a área nativa de um ecossistema (Heilmayr et al., 2020; Fagan et al., 2022), o que leva a perdas significativas de biodiversidade regional (Stevens, 2020). Ainda sobre as consequências dessa técnica utilizada de forma indiscriminada, programas que focam no plantio de árvores também têm gerado consequências econômicas e sociais negativas, como por exemplo, a exclusão de práticas de conhecimento local e prejuízos para as comunidades locais (Malkamäki et al., 2018; Reyes-Garcia et al., 2019; Coleman et al., 2021).

O aumento de incentivos para o plantio de árvores em larga escala é particularmente preocupante para ecossistemas abertos, devido às profundas alterações que ações de aflorestamento, ou seja, o plantio de árvores em larga escala em ambientes que originalmente não eram florestas, causam na composição, estrutura e dinâmicas desses ecossistemas (Bond, 2016; Veldman et al., 2019). Os ecossistemas abertos, incluindo savanas e campos, cobrem cerca de um terço da superfície do planeta, e requerem métodos de restauração e de manejo específicos (Veldman et al., 2015; Bond et al., 2019), como por exemplo, a inclusão de espécies não-arbóreas e o uso do fogo. Apesar disso, a maior parte dos projetos de restauração tende a incorporar um número limitado de espécies nativas de relevante valor comercial (Jalonen et al., 2017; Martin et al., 2021), excluindo arbustos e gramíneas (Buisson et al., 2021).

A falta de diversidade também está presente no sistema de suprimento de insumos, que no caso do Brasil, é predominantemente associada a viveiros que se concentram na região sudeste e produzem mudas de árvores de poucas espécies (Moreira da Silva et al., 2017), o que ressalta a defasagem da produção de espécies nativas para a restauração ecológica em território nacional (Freire et al. 2017). Em contraponto, técnicas emergentes têm demonstrado meios alternativos de implementar e monitorar restauração ecológica em ecossistemas abertos, seja através do desenvolvimento de técnicas (Sampaio et al., 2019), expansão da agenda de pesquisa (Buisson et al., 2021) ou avanços tecnológicos (Muumbe et al., 2021). Essas recentes abordagens técnica e científica também ressaltam o papel crucial do engajamento local das comunidades na co-produção de conhecimento sobre práticas de restauração e na geração de múltiplos benefícios ao nível local (Gann et al., 2019).

Dentre as diversas experiências de restauração pelo planeta, práticas regionais emergentes em ecossistemas abertos têm demonstrado caminhos para conectar avanços técnicos com engajamento local (Pedrini et al., 2023; Gibson-Roy et al., 2023). Ao longo da última década e atualmente, ações de restauração do Cerrado são sustentadas através de uma rede complexa de múltiplos atores, co-produzindo conhecimento acerca da biodiversidade nativa (Pilon et al., 2023), envolvendo principalmente as comunidades locais. Articulações tais como essa têm contribuído para preencher lacunas de conhecimento (Urzedo et al., 2020; Buisson et al., 2021) e também catalisado sistemas de suprimento regionais, que consideram contextos econômicos e socioecológicos (Schmidt et al., 2019), colaborando com a produção de espécies nativas ao mesmo tempo em que produz benefícios para comunidades locais. Um dos principais avanços técnicos é a adoção crescente da semeadura direta mecanizada, que reduz custos de implementação da restauração e alavanca a demanda por sementes de espécies nativas para compor a muvuca, ou a mistura de sementes, incluindo espécies não-arbóreas (Campos-Filho et al., 2015; Sampaio et al., 2019). Essas práticas regionais de restauração de savanas também têm sustentado a mobilização de redes lideradas pelas comunidades locais para suprimento de sementes, o que pode suprir a crescente demanda por sementes de espécies nativas (Urzedo et al., 2022).

Ao mesmo tempo em que a restauração ecológica de ecossistemas abertos tem práticas emergentes e inovadoras baseadas em características ecológicas e socioeconômicas locais, estas estão associadas a sistemas institucionais e mercados que se desenvolvem além do território e influenciam diretrizes, recursos e demandas da restauração. Sendo assim, ainda há uma lacuna de conhecimento para compreender como essas inovações locais estão associadas a esse contexto mais amplo de sistemas institucionais e mercados, e como essas interconexões podem afetar a configuração da restauração ecológica através de dinâmicas de poder que atravessam diferentes escalas, desde o local até o global.

Dessa forma, o objetivo desta dissertação é compreender como as dinâmicas de poder entre os múltiplos atores envolvidos na restauração ecológica do Cerrado influenciam a organização desta, de modo a viabilizar a inserção de espécies não-arbóreas em um contexto de fomento ao plantio de árvores em larga escala. A partir do dispositivo heurístico de redes de produção global (Henderson et al., 2002), que é uma teoria e estrutura utilizada para compreensão das relações globalizadas que estruturam a produção de bens e serviços, realizamos pesquisa etnográfica com observações participantes e entrevistas semiestruturadas, além da análise de banco de dados de comercialização de sementes nativas para restauração e de documentos institucionais globais, regionais e locais, a fim de elucidar o caso da Chapada dos Veadeiros. Nesta região, comunidades locais se organizam para fornecer biodiversidade para a restauração ecológica do Cerrado através da coleta de sementes nativas, sendo modelo de organização para outros grupos de coletores pelo Brasil. Ainda, nesta região há o desenvolvimento pioneiro de pesquisas de restauração ecológica de ecossistemas abertos com inclusão de biodiversidade de espécies não-arbóreas, com áreas experimentais monitoradas há 12 anos (Sampaio et al., 2019; Pilon et al., 2023).

As hipóteses são de que a restauração ecológica do Cerrado envolve assimetrias de poder entre os diferentes atores envolvidos, desde a escala local à global, como por exemplo, a distribuição desigual de recursos, e que, através das dinâmicas de poder, que decorrem das relações sociais, as comunidades locais viabilizam a inserção de biodiversidade e a geração de benefícios locais, por meio de práticas e arranjos inovadores. Dessa forma, a restauração ecológica de base comunitária no Cerrado (Schmidt et al. 2019), ou seja, aquela em que as comunidades locais se engajam no lugar de tomada de decisão e de liderança, vem transformando o contexto global e regional, promovendo o acesso a recursos e a restauração do Cerrado, com inclusão de biodiversidade e geração de benefícios para comunidades locais.

Conforme regulamento do Programa de Pós-Graduação em Ecologia da Universidade de Brasília, o artigo a seguir, com algumas alterações, foi submetido em língua inglesa ao periódico *Land Use Policy*. No artigo apresentamos detalhadamente os métodos, resultados e discussão da pesquisa desenvolvida durante o mestrado. Ao final, apresento uma conclusão geral da dissertação em língua portuguesa.

Beyond tree planting: Mobilizing restoration production networks in the Brazilian Savanna

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1. Introduction

Ecological restoration has emerged as a critical planetary intervention to reverse land degradation, while promising transformative opportunities to tackle social inequalities across the world (Chazdon et al., 2017). International commitments have ambitiously pledged to restore 350 million hectares of degraded lands by 2030, including the Paris Agreement (UNFCCC, 2015) and the Bonn Challenge (IUCN, 2020). As part of these global endeavors, the United Nations has declared a Decade on Ecosystem Restoration envisions a collaborative platform to mobilize political efforts and technical mechanisms to assist in the implementation of large-scale programs (UN, 2019). While growing incentives and investments are expected to scale up restoration actions across the world (UNFCCC, 2022), there are still substantial concerns about how neglecting the critical place-based conditions of diverse ecosystems can lead to unsuccessful projects and the exacerbation of inequalities (Temperton et al., 2019; Stevens et al., 2020). Significant restoration gaps are particularly related to the lack of incorporation of open-canopy ecosystems (Buisson et al., 2021; Tölgyesi et al., 2021), limited inclusion of regional biodiversity (Silveira et al., 2022), and insufficient participation to ensure the equitable distribution of socioeconomic benefits (Adams et al., 2016; Löfqvist et al., 2023). In this article, we investigate these significant issues by questioning how savanna restoration actions are configured through the interconnections of multiscalar institutions, supply systems, and market arrangements that underpin, reshape, or disrupt the modes of operating practices and their outcomes.

Despite the growing expansion of the technical approaches to include the diverse ecosystem in restoration practices (Sacco et al., 2021), measures to increase global tree cover has been positioned as the primary strategy for recovering degraded lands (Laestadius et al., 2011; Philipson et al., 2020; Bastin et al., 2019). Among the restoration methods, large-scale tree planting has been largely adopted by influential international, domestic, and regional programs due to the acknowledged potential of forests to absorb carbon (Seymour, 2020; Fleischman et al., 2020). The Trillion Tree Campaign, for instance, mobilizes substantial investments to scale up tree-planting interventions to supposedly lock-up carbon in forests. Scaling tree-planting efforts are often hailed as an effective means of sequestering carbon (e.g., Bastin et al., 2019; Walker et al., 2022), while several negative environmental impacts that arise from underestimating the socio-ecological complexity of degraded landscapes are disregarded (Ramprasad et al., 2020; Buisson et al., 2021). The obsessive focus on ambitious tree planting practices can lead to drastic environmental and social consequences, depending on the practices and locations (Holl & Brancalion 2020). According to recent assessments, efforts to indiscriminately plant trees across the world can fail to effectively sequester carbon (Rana et al., 2022), reduce water availability (Wang et al., 2020), and decrease the native ecosystem area (Heilmayr et al., 2020; Fagan et al., 2022) which leads to significant losses of regional biodiversity (Stevens, 2020). In turn, target-based tree planting programs have also generated negative economic and socio-cultural consequences, including the exclusion of local knowledge practices and community livelihood harms (Reyes-Garcia et al., 2019; Coleman et al., 2021).

The growing incentives for tree cover and reforestation expansions are particularly concerning in non-forest regions due to the profound alterations they cause to open-canopy compositions, structures, and dynamics (Bond, 2016; Veldman et al., 2019). These open ecosystems, including savannas and grasslands, cover around one-third of the planet's surface which require specific restoration methods and management practices (Veldman et al., 2015a; Bond et al., 2019). However, most of the global restoration projects tend to incorporate only a limited number of native species with commercial relevance (Jalonen et al., 2017), excluding the consideration of native shrubs, grasses, and forbs (Buisson et al., 2021). In response, emerging techniques have demonstrated alternative ways of implementing and monitoring open ecosystems restoration interventions, whether through the development of planting techniques (Sampaio et al., 2019), expansion of research agendas (Buisson et al., 2021), or technological advancements (Muumbe et al., 2021). These recent significant scientific and technical approaches have also highlighted the critical role of local engagements and community benefits to co-produce restoration knowledge practices to successfully incorporate local biodiversity and generate multiple benefits at the local level (Gann et al., 2019).

Among the globally restoration experiences, emerging regional open-canopy practices demonstrate ways of linking technical advancements with local engagements (Pedrini et al., 2023; Gibson-Roy et al., 2023). Over the last decade, Brazilian Savanna restoration actions have been sustained through a complex network of multiple stakeholders, co-producing native biodiversity knowledge (Pilon et al., 2023) and catalyzing regional restoration supply systems that consider environmental and socio-economic contexts (Schmidt et al., 2019b). One of the main technological drivers is the increasing adoption of the mechanized direct seeding technique, reducing planting costs and boosting the inclusion of native grass and shrub species in seed mixtures (Sampaio et al., 2019). These savanna restoration practices have also supported the mobilization of community-led networks and entrepreneurship to lead the native plant material supply (Urzedo et al., 2022). Yet, there is still a lack of understanding regarding how these place-based supply system innovations are associated with broader market operations and institutional systems, and how these interconnections can affect the configuration of restoration interventions through multiscalar power dynamics.

To gain a comprehensive understanding of open ecosystems restoration, this article asks how the interconnected roles of different stakeholders and their power dynamics influence the Brazilian Savanna restoration operations. We adopt the global production networks (GPN) framework as a useful heuristic device to analyze these power dynamics (Henderson et al., 2002) in the process of composing and transforming practices and operations across interconnected scales (Coe et al., 2008; Coe & Yeung, 2019). The GPN framework supports the critical understanding of the complex relationships and political agency of diverse actors and institutions interconnected through production networks (Coe & Yeung, 2019). In this way, these GPN assessments can reveal the commonly invisible interactions that shape the composition of policies, commercial operations, and shaping supply systems (Yeung & Coe, 2015; Coe & Yeung, 2019). This knowledge is particularly relevant for assessing the ecosystem restoration governance (Urzedo et al., 2020), aligned with the growing justice and equity considerations that question the impacts of emerging markets, supply systems and institutions across multiple scales.

In this article, we analyze the ways in which multiscalar institutions, supply systems, and market arrangements influence open ecosystems restoration practices and create, exacerbate, or rework uneven power dynamics and benefits across different scales. We argue that open ecosystems restoration processes are embedded in production networks that interconnect local practices with global regimes through distributed power, shaping and transforming institutional systems, restoration markets and supply systems, which shape restoration practices and outcomes.

2. Material and methods

2.1. Case study region

Between the most diverse ecosystems across the planet, the Brazilian Savanna biome is considered a critical biodiversity hotspot (Myers et al., 2000), including more than 5,000 endemic plant species (Klink & Machado, 2005). This biome originally covered almost one-quarter of Brazil's territory, and is characterized by diverse vegetation types, such as grasslands, savannas and forests (Alencar et al., 2020), encompassing more than 13,000 species of plants. The combination of large territorial extension, soil conditions, along with wildfire regimes (Bueno et al., 2018; Leite et al., 2018; Pennington et al., 2018), creates favorable conditions for the concentration of 5% of the earth's biodiversity, particularly herbaceous and shrub species (Amaral et al., 2022). This great biodiversity is also strongly associated with the management practices of Indigenous and local communities that have been inhabiting these landscapes from hundreds to thousands of years (Resende et al., 2021), especially in grassland ecosystems (Bonanomi et al., 2019). Currently, there are 216 Indigenous, 44 quilombola territories and five other traditional peoples in the Brazilian Savanna region (Aguiar & Lopes, 2020; ISPN, 2021). At the same time, the rapid expansion of mechanized farming over the last 50 years has significantly transformed this tropical biome. From 1985 to 2021, the Brazilian Savanna vegetation area decreased by 20%, while ranching has quickly increased from 61,9 to 90,1 million hectares (MapBiomas, 2022). Almost half of the grassy ecosystems has been completely replaced by other land-use forms (Overbeck et al., 2022). As a result, the Brazilian Savanna is now one of the most threatened biomes globally (Strassburg et al., 2017) with high rates of land clearing and extensive invasion of exotic grasses (Klink & Machado, 2005). These critical land-use changes raise several uncertainties about the current and future conditions necessary to sustain regional biodiversity, climate resilience, and community livelihoods (Bonanomi et al., 2019).

As a geographical representation of the restoration processes in the Brazilian Savanna, this study considers the Chapada dos Veadeiros as the case study region (Fig. 1). Located in the northeast of Goiás State, the region shelters the Chapada dos Veadeiros National Park, which was established in 1961 with 625,000 hectares, and presently covers 240,000 hectares, protecting representative Brazilian Savanna ecosystems (ICMBio, 2021). The National Park boasts one of the oldest rock formations on the planet and a rich fauna and flora, leading to its prestigious listing as a World Heritage Site by UNESCO (ICMBio, 2021). Currently, the National Park encompasses at least 1,359 hectares of degraded land recognised as environmental suitability zone (ICMBio, 2021), which are available to be restored. Apart from the National Park management, the region is also home to Kalunga Quilombola group, representing traditional communities of Afro-Brazilians who sought liberation from enslavement in agricultural plantations and mines hundreds of years ago (Bowen, 2014).

This region was selected as a compelling case study due to its extensive restoration experience, place-based innovations, and capacity to influence practices elsewhere in Brazil and other tropical regions. Restoration interventions in Chapada dos Veadeiros represent one of the longest restoration experiences with continuous monitoring across the Brazilian Savanna, with rigorous assessments to qualify restoration techniques (e.g., Pellizzaro et al., 2017; Coutinho et al., 2019; Sampaio et al., 2019). A wide range of researchers, working collaboratively with community groups, have been adopting and co-creating innovative restoration practices applied to savanna and grassland ecosystems (Sampaio et al., 2019). These experiences have led to the extensive use of mechanized direct seeding as a feasible and accessible way to implement large-scale restoration in the region (Schmidt et al., 2019a). These actions are not merely locally relevant, but regional networks have mobilized influential efforts to disseminate these regional experiences to other places and supported political changes in Brazil (Urzedo et al., 2022).

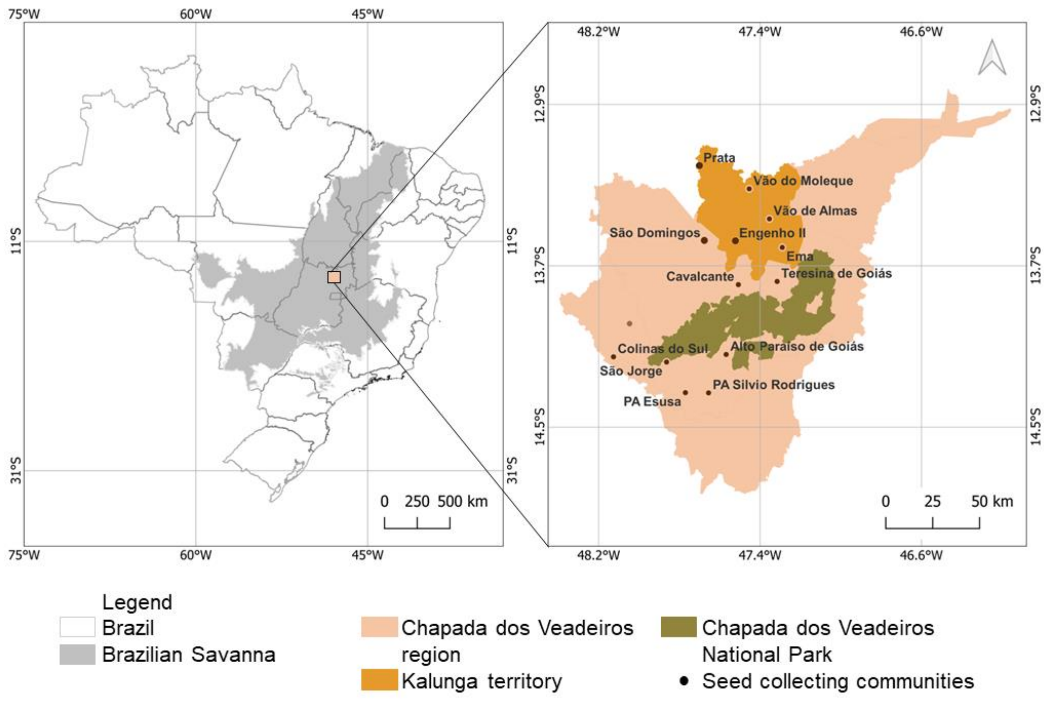

Fig. 1. Brazilian Savanna biome (left side) and Chapada dos Veadeiros region (right side), including the distribution of seed collecting groups (points).

2.2. Data collection

This study adopted mixed methods to collect qualitative and quantitative data associated with restoration institutional systems, market operations, and supply systems. Firstly, we conducted a search for formal restoration institutions in online specialized databases, including domestic (e.g., http://www4.planalto.gov.br/legislacao/) and international depositories (e.g., https://treaties.un.org/). We used the following keywords in both English and Portuguese to survey relevant international agreements, Brazilian national, and subnational policies and regulations: restoration, reforestation, afforestation, planting, or recovery, combined with land, ecosystem, nature, or habitats. These documents were screened to select only the ones that include: (i) ecological restoration content; (ii) address current political debates and practices; and (iii) are endorsed by the Brazilian government. In total, we selected 28 formal institutions from global to national to subnational levels (Appendix A).

Secondly, we undertook participatory observations in the Chapada dos Veadeiros region to understand the different processes that interconnect regional supply systems with restoration markets and institutions. The first author conducted participant observations in this region from March 2022 to January 2023 with plant material suppliers, restoration practitioners, consultants, funders, public environmental analysts and researchers in 24 events. These regional events covered a wide range of restoration activities, including organizational meetings, capacity-building workshops, and implementation actions. In this process, we also performed semi-structured interviews with 10 key stakeholders with great knowledge of the regional supply arrangements, market demands, and restoration techniques and strategies.

Additionally, we analyzed secondary data provided by regional organizations to further support the understanding of their restoration operations. We accessed the seed trading databases from the Brazilian Savanna Seed Network (Rede de Sementes do Cerrado), covering the buyers, number of species, collectors, and the amount of seed traded from 2017 to 2022. The Brazilian Savanna Seed Network is the principal trader of Brazilian Savanna native seed for direct seeding in Brazil, with coverage mainly in the Central Brazil region. We also gathered a set of organizational reports and sites to understand the performance of restoration projects and programs in the case study region (Appendix B). Additionally, we searched for savanna restoration suppliers through the list of Araticum participants, the seed trading database and the Caminhos da Semente initiative platform.

2.3. Data processing and analysis

We analyzed qualitatively the selected formal institutions using the Atlas.ti software (version 4.5.1-2022-11-23). We examine the content of these documents by querying a set of questions related to technical, economic, and sociocultural factors (Appendix C). We coded this information to understand how different institutions shape the forms of approaching and driving incentives for ecological restoration. By adopting a co-occurrence analysis, we developed Sankey diagrams to determine the distance, embeddedness, and overlapping of the coded segments across the studied institutions. This approach allowed us to gain a more comprehensive understanding of how institutional formulations approach different factors across global, domestic, and subnational levels.

We transcribed and analyzed the data collected during participant observations and interviews to characterize and qualify different modes of regional engagement, technical developments, and trading arrangements. We analyzed the supply systems by identifying different modes of organizational operations that offer restoration products and services. This allowed us to recognize modes of building partnerships, engagements, and commercial relationships to implement restoration practices. Additionally, we described and analyzed markets according to the specific characteristics of each of the existing buyers who are associated with compliance, research and development, payments for ecosystem services, and voluntary carbon offset.

We analyzed the quantitative datasets obtained from the Brazilian Savanna Seed Network to further characterize where, which motivation and how buyers and suppliers are performing their restoration actions in the Brazilian Savanna region. We classified the seed trading data according to each one of the identified markets to represent their estimated area restored (when not informed by the buyers), purchases, and costs of seed. We converted seed costs from the Brazilian currency (R$) to US dollars using the quotation on July 11, 2023 (US$1.00 = R$ 4.87). We also analyzed this seed database to characterize plant material suppliers in the studied region. We considered suppliers as the stakeholders who sell products and/ or services for Brazilian Savanna restoration. We unfold the supply system by quantifying the number of tree and non-tree species supplied and the number of seed collectors engaged over the period from 2017 to 2022.

3. Results

Our findings show that savanna restoration in Brazil is organized through complex, diffuse, and multiscalar production networks. Different savanna localities are interconnected with a wide range of stakeholders who play various roles in shaping, disrupting, and transforming the supply, purchase, and regulation of the restoration products and services (Fig. 2). While these engagements influence the development and flow of knowledge, technologies, investments, and resources, we identify how these emerging operations shape the uneven distribution of decision-making processes. In the following subsections, we present the findings associated with the dimensions of institutions, markets and supply systems that compose the savanna restoration production network, focusing on the Chapada dos Veadeiros region as a case study.

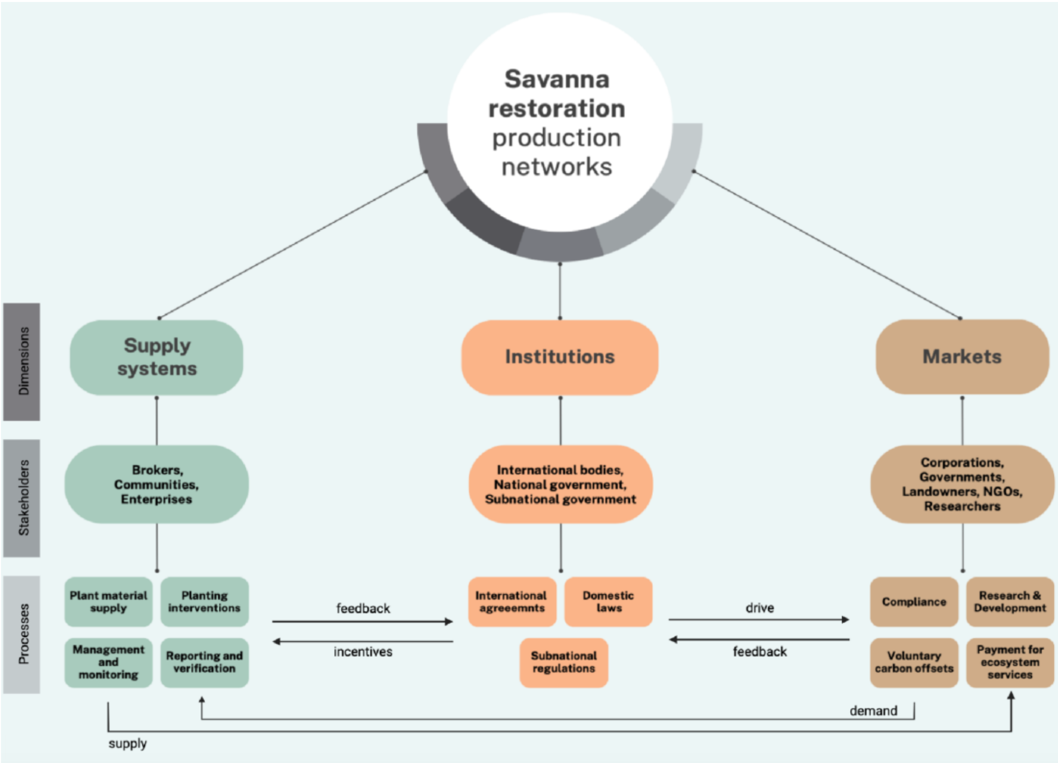

Fig. 2. Savanna restoration Global Production Network (GPN) in Brazil interconnecting multiple stakeholders in the different processes associated with supply systems, institutions, and markets across geographical scales.

3.1. Savanna restoration institutional drivers

Policies and regulations assert a significant influence on driving the incentives, demands, and socio-technical operations of ecological restoration. We identified the adoption of different restoration approaches to deal with degraded ecosystems across the 28 formal institutions analyzed. From global to domestic to subnational policies, forest-centric formulations are the most prominent way of conceptualizing, implementing, and evaluating restoration practices. These forest restoration strategies comprise more than half of the identified approaches across all analyzed documents (Fig. 3). International agreements and Brazilian domestic regulations and plans strongly adopt forest-related proposals and visions, reinforcing the notion of tree-cover recovery as the most crucial intervention for improving socio-ecological conditions at various landscapes. These understandings are particularly common in influential commitments, such as The Glasgow Declaration on Forests (COP26, 2021) and Sustainable Development Goals (UN, 2015), as well as in national policies (e.g., Law 12,651/2012; Planaveg, 2017).

While influential formal institutions position forest restoration approaches as the primary solution for reversing degraded ecosystems, specific recommendations for savanna restoration represented only 10% of the approaches identified across the studied institutions. At the same time, our results reveal that the recognition of open ecosystems requirements is gradually emerging in policymaking, predominantly found in subnational regulations (Fig. 3). In the Brazilian states, a set of regulations has recently been formulated to consider the specific conditions of open ecosystems in the development of compliance restoration and environmental management practices. For instance, the Federal District enacted Law 6,364 (2019) to ensure the implementation of technical mechanisms that promote the use and protection of the Brazilian savanna, considering the region's diverse ecosystem formations, such as grasslands, savannas, and forests. This regulation also requires the adoption of specific technical procedures to assess the savanna regeneration through the use of specific indicators and criteria. Examples also cover Law 18,104/2013 and NI 4/2022 in the state of Goiás in central Brazil. As a result, these institutional recognitions of the open ecosystems can enable not only the reorientation of technical approaches but also reshaping the ways that investments and incentives are promoted and implemented.

Restoration policies are not only associated with technical recommendations but they also consider how economic formulations can influence funding mechanisms, commercial arrangements, and financial investments distribution. Across the studied institutions, international agreements presented the highest frequency of funding formulations and mechanisms, representing 52 % of the formal institutions that addressed this dimension (Fig. 3). This result reflects the international adoption of the principle of "Common But Differentiated Responsibilities", formalized during the UNFCCC's Earth Summit in 1992 (UN, 1992). International agreements, such as the Kyoto Protocol (1998), highlight the central role of high-income countries in providing financial resources to enable developing countries to undertake emissions reduction activities. More recently, policies are increasingly expanding the ways of attracting investments to cover the high costs associated with large-scale restoration programs (e.g., REDD+ and Agenda 2030). A growing number of market-based strategies consider strong engagement with the private sector's investments to boost restoration actions as a business opportunity. For instance, the country-led 20x20 Initiative (WRI, 2014) in Latin America and the Caribbean seeks to restore 50 million hectares of degraded landscapes by 2030, considering three billion dollars of corporate investments that expects to create commercial value for restoration products. Part of these emerging market incentives, voluntary carbon offsets is one of the most frequent commercial opportunity to mobilize the private sector, despite the poor inclusion of the contributions of diverse ecosystem types, biodiversity, and local community impacts.

Our institutional analysis also reveals the strong inclusion of social-cultural factors in the composition of international restoration policies, which is present in more than half of the international institutions analyzed. Poverty reduction, human rights, and livelihood enhancements are considered critical foundations of how restoration actions should create benefits at the local level. For example, the UN Decade on Ecosystem Restoration (2019) positions substantial strategies to eradicate poverty and achieve sustainable development goals through the engagement of Indigenous people and local communities. However, domestic institutions often tend to reinforce technical solutions, disregarding how interventions can potentially affect participation, equity, and livelihood outcomes. For example, the Planaveg (2017), a Brazilian plan for native vegetation recuperation, superficially addresses the impact on traditional communities, considering only the jobs that will be generated in restoration operations, without recognizing the role of local knowledge in building bottom-up actions.

Our institutional analysis demonstrates the influential power of international bodies, domestic, and subnational governments in shaping the ways of restoration technical approaches, economic strategies, and sociocultural considerations are driving market demands and propelling supply systems (Fig. 2). Although the restoration is increasingly being approached by political formulations to attract resources, create investments and social benefits across scales, most of these solutions focus on forest-centric and market-based formulations, missing critical considerations of open ecosystems (Fig. 3). Therefore, this context requires regional and local actors in savanna regions to develop strategies to reach resources and enable the restoration of open environments with biodiversity and local benefits.

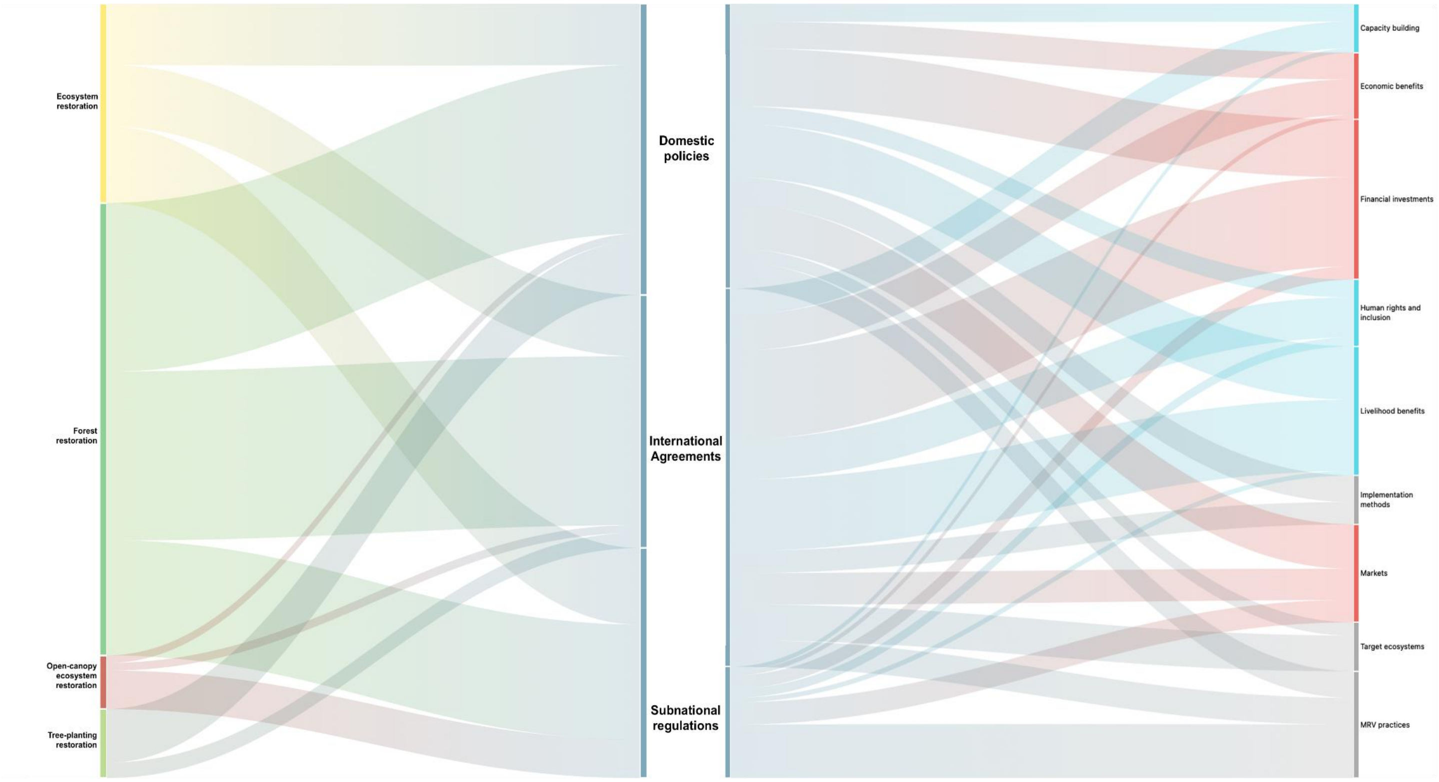

Fig. 3. Formal institutions analysis. The formal institutions are represented by the domestic policies, international agreements and subnational regulations (n = 28 documents). The left side depicts the type of ecosystems recognized by the studied formal institutions. The right side shows the inclusion of technic-scientific, economic and sociocultural dimensions in the analyzed formal institutions (Appendix C).

3.2. Savanna restoration markets

Our assessment reveals the influential operations of four main restoration markets in the Brazilian Savanna biome, including (i) compliance, (ii) research and development, (iii) voluntary carbon offset, and (iv) payments for ecosystem services (Table 1). We identified that these buyers, together, restored 758.29 hectares of degraded areas in Brazilian Savanna over the last five years, particularly in Central Brazil, by including up to 88 native species in their restoration planting activities. The incorporation of this high biodiversity cost ranged from 213 to 583 dollars/ha (Table 1), representing only between 5% and 16% of the total regular restoration costs (see Schmidt et al., 2019b). Each one of these identified markets are associated with specific restoration demands and buyers that shape the ways of implementing restoration actions in the Brazilian Savanna.

The largest consolidated savanna restoration demands in Brazil are directly associated with compliance markets. At least 5.3 million hectares of degraded Brazilian Savanna require restoration interventions to meet domestic regulations on private lands (Soares-Filho et al., 2014). By assessing the market in Central Brazil, we identified that approximately 39% of the restored area and 36% of seed production were purchased by compliance buyers from 2017 to 2022. Around 95% of these compliance restoration actions took place to offset environmental impacts following the National Environmental Law. Although compliance markets offer significant commercial opportunities, local stakeholders highlighted that the lack of law enforcement and poor landholders' efforts remains a critical limitation to ensure consistent and continuous demands.

In order to improve these regional mobilizations, research and development strategies expect to boost regional demands by supporting the creation of feasible restoration practices. According to the trading databases in Central Brazil, the Researchers were responsible for undertaking over one-quarter of the restoration area implemented over the last five years (Table 1). Research and development demands are associated with diverse scientific experiments that test and improve modes of planning, conducting, and monitoring savanna restoration practices, increasing the seed establishment and developing invasive species control techniques. These buyers included 88 native species in their restoration areas, half of which were non-tree plants. Their contributions are not merely associated with knowledge production but also with assisting in the development of regional strategies to strengthen production network operations. This includes the establishment of partnerships with plant material suppliers and building regional networks to offer capacity building, training, and access to new technological practices. However, research buyers are unable to sustain high demands for the long-term, considering the short timeframe of their grants and research projects.

Opportunities to diversify restoration demands also emerge from the growing interest of corporations in setting environmental targets as part of their business strategies. We found several corporations purchasing carbon offsets from transnational suppliers that target tree-planting initiatives in the Global South (Appendix B). In this process, companies can donate funds for restoration projects to fulfill their ESG and net-zero commitments through planting trees. For instance, more than 1,200 companies, including Microsoft and Hyundai, fund the Eden Project, a restoration supplier based in California, that expects to plant 50 billion trees in developing countries by 2030. In Brazil, their actions over the last two years resulted in the reforestation of more than 1,640 hectares, including the Brazilian Savanna biome. Although this market mobilizes international stakeholders to negotiate and purchase these commercial operations, voluntary offsets demands are still poorly developed at the regional and domestic levels. According to the analyzed restoration market in Central Brazil, the carbon offset buyers only represented 8% of the restored area over the last five years (Table 1). While the voluntary carbon markets offer potential opportunities to boost demands for Brazilian Savanna restoration, there is still uncertainty about the engagement of domestic stakeholders, particularly considering the lack of specific mechanisms for measuring, reporting, and verifying carbon credits in savanna regions.

Carbon credits are not the only environmental market offering opportunities to boost restoration demands, but the growing consideration of ecosystem services has also attracted emerging investments. The payments for ecosystem services (PES) market was responsible for almost one-quarter of the area restored in Central Brazil. The Brazilian government, in partnership with the private sector, was mainly responsible for these payments for ecosystem services demands through national programs for protecting water resources, such as the Produtor de Água and the Semeando Águas programs. The Semeando Águas program funds restoration actions in priority river basins in Brazil through a public-private partnership. For instance, this investment supports the Águas Cerratenses project, which allocated more than two million dollars to restore 600 hectares of degraded land in the Brazilian Savanna over three years. Although PES demands represent a growing opportunity in savannas and grasslands, the financing is still limited to a few projects running in short periods. These conditions limit sustaining long-term operations and the development of approaches and mechanisms to value the diverse benefits of non-forest ecosystems.

Table 1. Savanna restoration markets in Central Brazil Savanna, including information about buyers, restored area, number of species and native seed costs. (Source: Brazilian Savanna Seed Network).

Restoration markets	**Definition**	**Main buyers**	**Estimated restored area (ha)**	**Total species (n)/ % of non-tree species**	**Seed amount (kg)**	**Seed costs (US$)**	**Seed costs (US$/ha)**
Compliance	Mandatory ecosystem protection on private lands (Law 12,651/2012) and offset of environmental impacts (Law 6,938/1981 and Law 9,605/1989).	Landholders, Regional enterprises	301.2	88/40	17,641.13	127,218.22	422.37
Research and Development	Scientific knowledge production to advance restoration techniques and production network operations	Researchers, practitioners and NGOs	219.29	88/44	15,509.13	127,916.09	583.32
payments for ecosystem services	Government funding mechanisms for enhancing or protecting ecosystem services, especially water resources.	Domestic government	171.7	81/53	5,330.96	83,005.07	483.43
Voluntary carbon offset	Voluntary acquisition of carbon offsets outside government regulation to fulfill ESG and netzero commitments.	International corporations, Regional enterprises	66.1	66/37	3,033.36	14,126.28	213.71
Total			**758.29**		**41,514.58**	**352,265.67**	

3.3. Savanna restoration supply systems

We identified different suppliers offering diverse Brazilian Savanna restoration products and services. Among the 29 regional suppliers, brokers, enterprises, and community-led organizations are responsible for offering plant material supply, planting assistance, monitoring, reporting, and verification services (Appendix D). These suppliers adopt different modes of organization, technologies, and engagements that shape how restoration is performed and how benefits are distributed in Central Brazil. Among them, enterprises provide a wide range of savanna restoration products and services primarily based on their capacity to implement technical requirements. We identified twenty restoration enterprises in Central Brazil, seldom having their headquarters located in other regions. Typically, these enterprises provide services to buyers who lack the necessary knowledge and technical conditions to comply with compliance restoration or voluntary carbon offsets. These organizations employ practitioners who adopt highly technical approaches mainly to deliver planting, monitoring, and verification services. One example is Semeia Cerrado, a small enterprise that develops, implements and monitors restoration projects based on technical knowledge. Although these enterprises offer relevant services and products to boost restoration actions, they have limited capacity to access the savanna market demands, and their technical practices do not necessarily include local knowledge and socioeconomic benefits for local communities.

The private sector is not the sole restoration supplier, but various brokers also assist in linking local groups with external stakeholders to support the flow of their products and services in the Brazilian Savanna. These operations are often carried out by NGOs that possess the technical knowledge and extensive relationships to connect local capabilities with broader demands. For example, the Eden Reforestation Project suggests supporting impoverished communities to provide restoration services to their global corporate partners, who primarily fund tree-planting activities (Eden Reforestation Project, 2022). In Central Brazil, this NGO collaborated with the Kalunga community as a potential opportunity to enhance employment, income, and local livelihoods. After two years, the Eden Reforestation Project finalized the partnership with this Quilombola community due to their interest in allocating investments to other countries. These international operations are not entirely transparent, not only regarding how investments, responsibilities, and benefits are distributed but also whether partnerships and investments will last for long periods. Their indicators usually do not report on how financial resources are allocated, and brokers restrict communication between suppliers and buyers.

Brokering systems are also operated by regional NGOs that work to support the engagement of community groups in the co-creation of new savanna restoration opportunities. Examples of these regional brokering operations are led by the Brazilian Savanna Seed Network and Redário (see Appendix D). These organizations address gaps in communication, commercialization, and the co-development of place-based technical capacity to boost restoration actions and socio-economic benefits at the local level. Through the support of regional brokers, community-led organizations recently emerged as an opportunity for local groups to participate in restoration supply practices through participatory processes (Fig. 4). As a result, a growing number of community organizations have begun to provide savanna restoration products and services in Central Brazil over the last decade.

Between community suppliers, the Cerrado de Pé Association is an exemplar case that demonstrates the leadership of local groups in operating production activities that include diverse biodiversity and local participation. Over the last six years, this community organization was consolidated as the most prominent plant materials supplier of diverse savanna species, particularly for direct seeding restoration. In 2022, this association encompassed 77 collectors from local communities in the Chapada dos Veadeiros region and Kalunga territory (Fig. 1), able to supply around 10 tonnes of seed annually. Their local and traditional knowledge played a pivotal role in co-developing technical and collective organizational approaches. These community groups led species identification, seed collection, processing, and storage of 122 native plant species of which almost half are non-tree species (Fig. 4). As a result, community-led techniques increased the availability and quality of small and inconspicuous seeds (Schmidt et al., 2019b), particularly herbaceous species such as *Paepalanthus chiquitensis* Herzog, *Aristida riparia* Trin., and *Echinolaena inflexa* (Poir.) Chase.

These collaborations between communities and regional brokers also led to important gains in the adaptation of savanna planting practices and the distribution of socio-economic benefits in the region. Notably, community-based seed processing methods translated into significantly higher germination rates and greater seed yields per unit volume in this region (Brazilian Savanna Seed Network, unpublished data). These practices improved the technical and economic feasibility of regional restoration actions through direct seeding (Sampaio et al., 2019), involving the use of a mix of native seed (Fig. 5). In this way, these innovations extend beyond the Chapada dos Veadeiros region, with a significant impact on the process of building community groups and informing policy-making throughout Brazil. These local experiences were disseminated among other suppliers through workshops and training sessions, fostering engagement with savanna restoration practices across different regions. Moreover, these lessons set a critical example that supported the government in changing regulations to permit native seed collection inside protected areas for ecological restoration purposes (IN 6/2022). Similarly, environmental government agencies consider these experiences as an evidence to incorporate the consideration of the direct seeding technique as a restoration method to fulfill compliance requirements in savanna regions (Ordinance 118/2022).

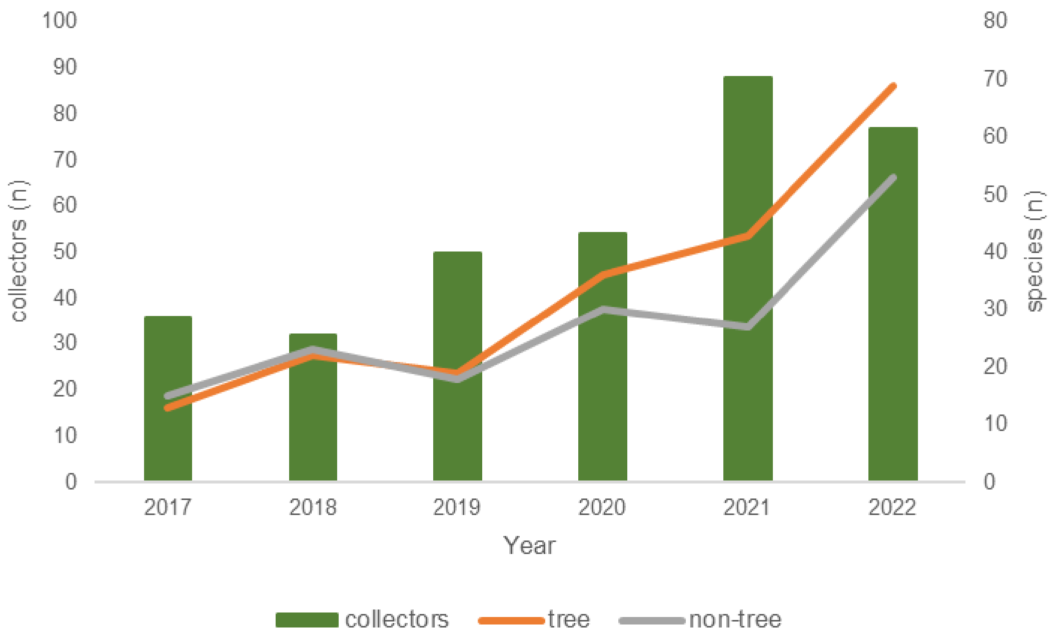

Fig. 4. Number of seed collectors of the Cerrado de Pé Association and the number of tree and non-tree species supplied between the years 2017 and 2022 in the Chapada dos Veadeiros region, Brazil. The bars show the number of seed collectors and the lines illustrate the number of tree and non-tree species collected and commercialized with the assistance of the Brazilian Savanna Seeds Network.

Fig. 5. Savanna restoration practices in Chapada dos Veadeiros region, Brazil. (A) degraded savanna area with predominance of exotic grasses (*Urochloa decumbens* Stapf); (B) seed collection of *Paepalanthus chiquitensis* Herzog.; (C) co-creation of seed processing techniques during a community workshop; (D) preparation of a savanna native seed mix (*muvuca*); (E) mechanical soil preparation for direct seeding; (F) area in restoration processes after two years of direct seeding implementation. Sources: A, E, F: Ana Wiederhecker/ Universidade de Brasília/ UnB (2020, 2022, 2022); B: personal archive (2022); C, D: Jaqueline Orlando/ Associação Cerrado de Pé (2022, 2020).

4. Discussion

The Brazilian savanna production network operates and shapes institutional, market, and supply systems that reveal power asymmetries and uneven risks across geographical scales.

The power dynamics across multiple stakeholders in decision-making influence the allocation of financial resources, incentives, and technologies through multi-scalar and interconnected processes. Likewise, the unequal access and distribution of benefits reinforce inequalities that constrain participation in savanna restoration practices. At the same time, the distributive nature of this productive network also raises the role of local agency in mobilizing diverse ways of influencing or contesting the conditions of practices and policies (Yeung & Coe, 2015).

Formal institutional restoration developments frequently reinforce forest-centric approaches (Dudley et al., 2020; Silveira et al., 2022) that overlook the specific requirements of savanna ecosystems (Veldman et al., 2019). Similarly, the economic power derived from global voluntary carbon offset markets underpins the adoption of large-scale tree planting to meet private sector demands. By combining these institutions and markets, savanna restoration practices can be composed and delivered through reforestation actions, which carries the risk of excluding the biodiversity of varied landscapes (Bond, 2016; Gómez-Gonzalez et al., 2020). Consequently, the adoption of tree-planting in open ecosystems can lead to afforestation processes (Veldman et al., 2015a; 2015b) that can increase greenhouse gas emissions (Veldman et al., 2015a) and to reduce the organic carbon density in carbon-rich soils (Hong et al., 2020). Negative socioeconomic consequences, such as the deprivation of local livelihoods (Malkamäki et al., 2018; Coleman et al., 2021) and the exacerbation of food insecurity (Doelman et al., 2020; Gopalakrishna et al., 2022), are also critical issues that arise from inappropriate restoration interventions.

However, local engagements also offer opportunities to consider place-based needs and reconfigure the modes of operating production networks (Henderson et al., 2002). In the Brazilian Savanna, community-led suppliers contest and transform how institutional and economic powers influence their organization and technological development (Schmidt et al., 2019b; Pedrini et al., 2023). By embracing local and traditional knowledge, these local groups co-create innovative approaches to implementing restoration actions that consider the specific conditions of regional biodiversity. These situated engagements extend beyond the local level and impact political changes and the development of techniques to enhance the economic and technical performance of these practices (Urzedo et al., 2020). For example, the Araticum platform (https://araticum.lapig.iesa.ufg.br/) is a digital innovation that spread Brazilian Savanna restoration information. This collective power demonstrates how partnerships and collaborations can assist in coordinating and facilitating the co-creation of context-specific techniques that elevate local benefits (Löfqvist et al., 2023). Other examples of participatory restoration supply systems also showcase how community groups can innovate carbon-farming accounting (Russel-Smith et al., 2017), improve local livelihoods (Löfqvist et al., 2023), and create household income opportunities through payments for ecosystem services (Reyes-Garcia et al., 2019).

While these communities assert their political power to configure the savanna restoration production network, their capacity to shape changes are also directly linked to restoration demands (Urzedo et al., 2020). The interactions between suppliers and buyers can either limit, constrain, or expand how different forms of restoration practices, incentives, and technologies are implemented (Holl & Brancalion et al., 2020). The compliance restoration market, for instance, represents the largest demand in Brazil (Soares-Filho et al., 2014), despite the poor engagement of landholders to implement this requirement (Guariguata & Brancalion, 2014). The limited government capacity to support the implementation of large-scale mandatory restoration demands demonstrates critical concerns associated with law enforcement, lack of incentives, and technical support to mobilize this demand (Maron et al., 2012). In this way, it is important that the local context inform national policies, enabling the negotiation of policies on international scale.

Despite governments historically having centralized conservation decisions (Chazdon et al., 2017), the growing engagement of the private sector with environmental markets influences alternative forms of shaping production networks (Martin et al., 2021). Through carbon offset and payments for ecosystem services markets, several restoration economic opportunities arise to amplify savanna demands and investments globally (Fleming et al., 2019). However, there are still substantial limitations for adopting nature accounting practices that consider the necessities of non-forest ecosystems (Bonn et al., 2014). These challenges of adopting payments for ecosystem services markets are described in several Global South regions, such as Latin America (Murcia et al., 2015) and Africa (Bond et al., 2019). It is necessary reconsider the carbon offsets and the payments for ecosystem services in order to encompass biodiversity, social benefits and open ecosystems.

The interconnected relationships between markets, institutions, and supply systems illustrate how distributed power shapes the configuration technologies, policies, participation, and outcomes (Vicol et al., 2019). Partnerships and collaborations among community groups, farmers, corporations, governments, and researchers play pivotal roles in negotiating divergent restoration needs and requirements to formulate opportunities, priorities, and strategies (Chazdon et al., 2017). In Brazil, numerous restoration networks have emerged over the last two decades (Piña-Rodrigues, et al., 2020), fostering collaborations and trust among diverse stakeholders to enhance restoration practices that consider place-specific conditions (Sanches & Futemma, 2019). Likewise, initiatives in Australia (Russel-Smith et al., 2017), Madagascar (Mansourian et al., 2016), Malawi (Djenontin & Zulu, 2021), and Brazil (Campos-Filho et al. 2013) exemplify how the development of relationships between restoration suppliers and buyers can serve as mechanism to assist in negotiating power asymmetries and democratic political decisions. While participatory processes demonstrate ways to improve the performance of regional networks towards equitable outcomes (Ceccon et al., 2020; Padovezi et al., 2022), these processes are intricate and necessitate ongoing reconsideration and renegotiation of practices, agreements and relationships (Reed et al., 2018).

5. Conclusion

This study delves into the power dynamics inherent in mobilizing the Brazilian Savanna restoration production network across geographical scales. We conducted an analysis to understand how various forms of formal institutional developments, market operations, and the supply of products and services can influence restoration actions and outcomes. Our findings underscore the presence of power asymmetries that hinder the equitable distribution of benefits and impede democratic decision-making processes among diverse stakeholders. However, we identified that innovative practices emerge through place-based engagement and partnerships, challenging and disrupting existing restoration methods. In the Chapada dos Veadeiros region, collective power led to the reconfiguration of conventional restoration approaches, promoting the integration of biodiversity and fostering more equitable organizational models. This underscores how savanna restoration production networks function through distributed power, which can either facilitate, support, or exclude local voices, democratic procedures, and equitable agreements.

The assessment of power embedded within emerging restoration production networks is essential for comprehending and reshaping the formulation and evolution of institutional systems, market operations, and supply systems over time. Within the context of the UN Decade on Ecosystem Restoration, it becomes crucial to untangle restoration actions from anticipated positive environmental and social outcomes to uncover potential injustices and inequalities. An ongoing debate in the literature has underscored the numerous damages and harms caused by large-scale tree planting efforts globally (Heilmayr et al., 2020; Kumar et al., 2020). This paper seeks to extend these discussions by demonstrating how the development of restoration practices is not solely the outcome of top-down technical or bureaucratic decisions; it is also intricately intertwined with complex power dynamics that span markets, institutions, and interconnected supply operations across various scales.

Collaborations and partnerships among diverse stakeholders are imperative to ensure the visibility of local needs, enabling the co-creation of context-specific technical and participatory mechanisms that can foster equitable and democratic production networks. This framework holds significance in facilitating local community involvement and promoting biodiversity inclusion within the savanna ecosystem.

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Conclusão geral

Esse estudo analisou as dinâmicas de poder inerentes à mobilização das redes de produção de restauração do Cerrado ao longo das diferentes escalas geográficas, com base no entendimento de que a restauração ecológica se dá nas escalas local, regional e global. Nós conduzimos as análises para compreender como várias formas de i) desenvolvimentos institucionais formais, ou seja, as legislações e acordos/decisões internacionais; ii) operações de mercado, que são aquelas que criam demandas de restauração e distribui recursos; e o iii) suprimento de produtos e serviços, como as sementes nativas e os serviços de implementação e monitoramento, podem influenciar as ações e os resultados da restauração ecológica. Nossos resultados ressaltam a presença de assimetrias de poder que obstruem a distribuição equitativa de benefícios e impedem processos de tomada de decisão democráticos entre diversos atores. Por exemplo, o poder econômico tem focado o investimento em plantio de árvores em larga-escala por meio de projetos *top-down*, ou seja, que são impostos por atores que não estão presentes no território, desconhecendo suas características ecológicas e subestimando o papel de comunidades locais na restauração ecológica. No entanto, nós identificamos que práticas inovadoras emergem através de parcerias e engajamentos baseados no território onde a restauração é implementada, desafiando e interferindo métodos de restauração existentes. Na região da Chapada dos Veadeiros, o poder coletivo leva à reconfiguração de abordagens convencionais da restauração, promovendo a integração de biodiversidade e fomentando modelos organizacionais mais justos. Isso ressalta como as redes de restauração de savanas funcionam através da distribuição do poder da escala local à global em, i) institucional, que é associado às legislações e acordos/ decisões internacionais; ii) econômico, que é associado aos mercados e aos recursos; e o iii) coletivo, que é associado a atores locais e regionais que se organizam através de arranjos inovadores. As dinâmicas de poder podem então facilitar, apoiar ou excluir vozes locais, procedimentos democráticos e acordos justos.

A avaliação do poder incorporado dentro de redes de produção de restauração emergentes é essencial para a compreensão e reconfiguração da formulação e evolução de sistemas institucionais, operações de mercado e sistemas de suprimento ao longo do tempo. Dentro do contexto da Década da Restauração de Ecossistemas é crucial dissociar as ações de restauração de resultados ambientais e sociais previstos para descobrir potenciais injustiças e disparidades. Um debate atual na literatura tem ressaltado os numerosos perigos e danos causados pelos esforços globais de plantio de árvores em larga escala (Heilmayr et al., 2020; Kumar et al., 2020). Neste trabalho buscamos estender essas discussões demonstrando como o desenvolvimento de práticas de restauração não são somente o resultado de decisões burocráticas e técnicas implementadas de forma *top-down*; a restauração ecológica também é intrinsecamente entrelaçada com dinâmicas de poder complexas que abrangem mercados, instituições e operações de suprimento interconectadas ao longo de várias escalas geográficas. Ou seja, diferentemente da literatura que ressalta o papel relevante e influente do Estado na definição de diretrizes, demandas e distribuição de recursos (Ostrom, 2010), a configuração da rede de restauração ecológica envolve diversos atores, que através das dinâmicas de poder, tem viabilizado a restauração ecológica com engajamento local e inclusão de biodiversidade através do poder coletivo, desenvolvendo abordagens *bottom-up*, que são aquelas que se baseiam em características locais e são capazes de influenciar além da escala local.

Colaborações e parcerias entre múltiplos atores são imperativas para garantir a visibilidade de necessidades locais, viabilizando a co-criação de técnicas específicas ao contexto local e mecanismos participativos que podem fomentar redes de produção equitativas e democráticas. Essa estrutura tem papel significativo em facilitar o envolvimento de comunidades locais e promover a inclusão de biodiversidade dentro de ecossistemas savânicos.

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Supplementary material

Appendix A. List of formal institutions analysed in the study.

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Appendix C. Questions adopted to analyze formal institutions.

Dimension	Factor	Analysis question
Technical	Target ecosystems	Which kind of ecosystems are considered or included?
	Implementation methods	What are the recognized restoration techniques?
	MRV practices	What are the recognized methods to measure outcomes?
Economic	Financial investments	What are the sources of funding to implement ecological restoration?
	Markets	Which kind of private sector participation in ecological restoration is encouraged?
	Economic benefits	How does it aim to create jobs and income?
Sociocultural	Livelihood benefits	How does it aim to enhance local community livelihoods?
	Human rights and inclusion	What is the role of society and vulnerable groups in implementing ecological restoration?
	Capacity building	What are the actions considered to enable implementation of capacity building?

Appendix D. List of savanna restoration suppliers operating in Central Brazil, Savanna biome.

Supply system type	Organisation's name	Source
Brokers	Eden Reforestation Projects	https://www.edenprojects.org/
Brokers	Imaflora	https://www.imaflora.org/
Brokers	Iniciativa Verde	https://www.iniciativaverde.org.br/
Brokers	Redário	https://redario.org.br/
Brokers	Rede de Semente dos Cerrado	https://rededesementesdocerrado.com.br/
Community-led organisations	Aprospera	https://novamata.org/iniciativa/aprospera/
Community-led organisations	Associação Cerrado de Pé	https://www.cerradodepe.org.br/
Community-led organisations	Cooperativa de Agricultores Familiares e Extrativistas do Vale do Peruaçu/ Cooperuaçu	https://novamata.org/iniciativa/cooperuacu
Community-led organisations	Rede de Coletores Geraizeiros	https://www.coletoresgeraizeiros.com.br/
Community-led organisations	Rede de Sementes do Xingu	https://www.sementesdoxingu.org.br/
Community-led organisations	Sementes do Paraíso	https://www.caminhosdasemente.org.br/redes-de-sementes/sementes-do-paraiso
Consultancy enterprises	Agroícone	https://agroicone.com.br/
Consultancy enterprises	Ambiental do Brasil	without website
Consultancy enterprises	BioFlora	http://www.viveirobioflora.com.br/

Consultancy enterprises	Ceres Seeding	https://www.ceresseeding.com/
Consultancy enterprises	Ciclo Azul	https://cicloazul.com.br/
Consultancy enterprises	Ekonus	without website
Consultancy enterprises	Funtec DF	https://www.funtecdf.com/
Consultancy enterprises	Geológica	without website
Consultancy enterprises	GHB Revegetação Ambiental	https://ghbrevegetacao.com.br/
Consultancy enterprises	Implantar Soluções Ambientais	https://implantarsa.com.br/
Consultancy enterprises	Inga Engenharia e Consultoria	https://www.ingaengenharia.com.br/
Consultancy enterprises	Mantiqueira Reflorestamento	without website
Consultancy enterprises	Prismati	https://prismaticonsultoria.com.br/
Consultancy enterprises	Progaia Engenharia e Meio Ambiente	http://progaia.com.br/
Consultancy enterprises	Semeia Cerrado	without website
Consultancy enterprises	Serraverde Bioengenharia e Serviços	https://serraverde.eng.br/
Consultancy enterprises	Tikré Brasil	https://www.caminhosdasemente.org.br/prestadores-de-servico/tikre-tikre-brasil-solucoes-ambietais-eireli
Consultancy enterprises	Verde Novo	https://consultoriaverdenovo.weebly.com/