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HISTÓRICO DE USO, PERTURBAÇÕES E RESTAURAÇÃO EM ÁREAS LOCALIZADAS NO SUDESTE DO BIOMA MATA ATLÂNTICA

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Dissertação apresentada ao Instituto de Ciência e Tecnologia, Universidade Estadual Paulista (Unesp), Campus de São José dos Campos; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), como parte dos requisitos para obtenção do título de MESTRE pelo Programa de Pós-Graduação em DESASTRES NATURAIS.

Área: Desastres Naturais. Linha de pesquisa: Desastres associados a eventos extremos, secas, estiagens, incêndios florestais e escassez de água.

Orientador: Doutora Klécia Gili Massi

Coorientador: Doutor Antonio Carlos Varela Saraiva

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IMPACTO POTENCIAL DESTA PESQUISA

A presente pesquisa foi desenvolvida no Vale do Paraíba Paulista, local sob domínio do Bioma Mata Atlântica brasileira. Atualmente, a região é afetada por uma tendência crescente de perturbação por incêndios, agravada pela predominância de pastagens e conta com importantes iniciativas de restauração como o Projeto Corredor Ecológico do Vale do Paraíba, o projeto Conexão Floresta Atlântica - GEF (Global Environmental Facility) e a ROAM (Metodologia de Avaliação de Oportunidades de Restauração). Considerando a importância socioambiental do Bioma Mata Atlântica, que abrange mais de 70% da população brasileira e está presente em 17 estados do país; e a importância da restauração natural para esse bioma devido ao crescente desmatamento decorrente da expansão da agricultura e das pastagens, o presente estudo é de grande relevância por fornecer informações importantes sobre como a trajetória do fogo e do uso da terra afetam as trajetórias sucessionais na área de estudo. O conhecimento desta dinâmica é importante para criar alertas à comunidade e aos gestores públicos, a fim de ampliar a capacidade de conservação/proteção.

POTENTIAL IMPACT OF THIS RESEARCH

This research was carried out in the Vale do Paraíba Paulista, a place under the control of the Brazilian Atlantic Forest Biome. Currently, the region is affected by a growing trend of disturbance by fires, aggravated by the predominance of pastures and has important restoration initiatives such as the Vale do Paraíba Ecological Corridor Project, the Conexão Floresta Atlântica project - GEF (Global Environmental Facility) and ROAM (Restoration Opportunities Assessment Methodology). Considering the socio-environmental importance of the Atlantic Forest Biome, which covers more than 70% of the Brazilian population and is present in 17 states of the country; and the importance of natural restoration for this biome due to increasing deforestation resulting from the expansion of agriculture and pastures, the present study is of great relevance as it provides important information on how the trajectory of fire and land use affect successional trajectories in the area of study. Knowledge of this dynamic is important to create alerts for the community and public managers, in order to expand conservation/protection capacity.

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São José dos Campos, 01 de março de 2024.

“Não é o crítico que importa; nem aquele que aponta onde foi que o homem tropeçou ou como o autor das façanhas poderia ter feito melhor. O crédito pertence ao homem que está por inteiro na arena da vida, cujo rosto está manchado de poeira, suor e sangue; que luta bravamente; que erra, que decepciona, porque não há esforço sem erros e decepções; mas que, na verdade, se empenha em seus feitos; que conhece o entusiasmo, as grandes paixões; que se entrega a uma causa digna; que, na melhor das hipóteses, conhece no final o triunfo da grande conquista e que, na pior delas, se fracassar, ao menos fracassa ousando grandemente”.

Theodore Roosevelt

RESUMO

BORGES, Caio Wesley. **Histórico de uso, perturbações e restauração em áreas localizadas no sudeste do bioma Mata Atlântica**. 2024. Dissertação (Mestrado em Desastres Naturais) - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2024.

A restauração florestal é reconhecida como um instrumento eficaz e rentável para enfrentar as alterações climáticas. No entanto, as práticas de restauração florestal enfrentam desafios, como incêndios florestais e impactos das trajetórias de uso da terra que podem degradar os ecossistemas. No bioma Mata Atlântica, em um único local, a área foi utilizada para diversas atividades e depois degradada. A trajetória do uso da terra pode impulsionar caminhos sucessionais e ter implicações para a restauração das florestas tropicais. Com o objetivo de avaliar como a trajetória do fogo e do uso da terra afeta as trajetórias sucessionais no Bioma Sudeste da Mata Atlântica, combinamos descritores de histórico de uso da terra e área de queimadas de 1985 a 2022 e levantamos a hipótese de que o uso da terra associado à maior duração, cobertura e frequência da agricultura e histórico de incêndios associados com mais área queimada, levaria a uma diminuição na riqueza, estrutura e descritores de funcionamento, e a condições sucessionais iniciais altamente degradadas, com potencial interrupção de iniciativas de restauração. De fato, observamos que os locais que queimaram mais área, tiveram mais mudanças no uso da terra e maior cobertura agrícola também foram os locais com menor riqueza, diversidade, abundância e tamanho de planta (DAP e altura) e mais espécies e indivíduos pioneiros e abioticamente dispersos (especialmente locais E e F, que eram restauração e regeneração natural, respectivamente). Além disso, a riqueza e a diversidade das plantas foram parcialmente explicadas por um aumento na cobertura de mosaico (provável regeneração natural) nos últimos 36 anos e por menos usos da terra e maior duração da cobertura florestal em áreas tampão, respectivamente. Apesar disso, a maioria das variáveis de resposta não foram modeladas pelo histórico de uso da terra e pelas variáveis de perturbação.

Palavras-chave: sucessão ecológica; uso do solo; restauração natural; floresta tropical, Vale do Paraíba Paulista.

ABSTRACT

BORGES, Caio Wesley. ***History of use, disturbances and restoration in areas located in the southeast of the Atlantic Forest biome****. 2024. Dissertation (Master's degree in Natural Disaster) - São Paulo State University (Unesp), Institute of Science and Technology, National Center for Monitoring and Early Warning of Natural Disasters (Cemaden), São José dos Campos, 2024.*

Forest restoration is recognized as an effective and profitable instrument to address climate change. However, forest restoration practices face challenges, such as forest fires and impacts of land use trajectories that can degrade ecosystems. In the Atlantic Forest biome, in a single location, the area was used for several activities and then degraded. The trajectory of land use can drive successional pathways and have implications for tropical forest restoration. Aiming to evaluate how fire and land use trajectory affect successional pathways in Southeast Atlantic Forest Biome, we combined land use history descriptors and burning area from 1985 to 2022 and hypothesized that land use associated with higher agriculture duration, cover, and frequency and fire history associated with more burning area, would lead to a decrease in richness, structure, and functioning descriptors, and to highly degraded early successional conditions, with potential arresting of restoration initiatives. We indeed observed that sites that burned more area, had more land use changes and more agriculture cover were also the sites with lower richness, diversity, abundance and plant size (DBH and height) and more pioneer and abiotically dispersed species and individuals (especially sites E and F, which were restoration and natural regeneration, respectively). Additionally, plant richness and diversity were partially explained by an increase in mosaic cover (likely natural regeneration) in the last 36 years and by less land uses and higher duration of forest cover in buffers, respectively. Despite that, most response variables were not modeled by land use history and disturbance variables.

Keywords: ecological succession; land use; natural restoration; tropical rainforest; Vale do Paraíba Paulista.

SUMÁRIO

1 INTRODUÇÃO

As mudanças climáticas aumentam as perturbações ambientais como os incêndios florestais, e os desastres relacionados podem afetar indiretamente as pessoas em função do impacto econômico e ambiental aos remanescentes florestais, sobretudo os que estão em processo de restauração, contribuindo para a perda ecológica dessas áreas. Portanto, o conhecimento desse risco é importante para criar mecanismos de monitoramento e alertas à comunidade e aos gestores públicos, de forma a ampliar a capacidade de proteção assim como indicado pelo do Marco de Sendai (UNISDR, 2015).

O Bioma Mata Atlântica tem grande importância socioambiental pois contempla 72% da população brasileira. Presente em 17 estados, têm os maiores centros urbanos e 7 das 9 maiores bacias hidrográficas do país. Dentre suas principais bacias, a do Paraíba do Sul tem grande destaque por suprir água, energia, diluição de esgoto e irrigação para mais de 15,7 milhões de habitantes dos estados São Paulo, Rio de Janeiro e Minas Gerais (AGEVAP, 2018) e PIB de R$87,1 bilhões (EMPLASA, 2020). Além do histórico de degradação, esta bacia sofre com a constante pressão devida à sua localização entre as duas maiores regiões metropolitanas do país, São Paulo e Rio de Janeiro, acentuada pela grande seca e crise hídrica de 2014-2015 (KELMAN, 2015; MARENGO; ALVES, 2015; NOBRE et al., 2016).

A Mata Atlântica corresponde a 15% do território nacional (FUNDAÇÃO SOS MATA ATLÂNTICA; INEP 2018), abrigando uma grande variedade de plantas vasculares e vertebrados terrestres com alto grau de endemismo (MITTERMEIER et al., 2011; BRASIL, 2009, p. 11), sendo considerado um dos 36 hotspots globais de biodiversidade (REZENDE et al., 2018). Este bioma está fragmentado por toda sua extensão (ARROYO-RODRIGUEZ et al., 2017), com 80% dos remanescentes compostos por menos de 50 ha e distância média de 1.440 m entre os fragmentos (RIBEIRO et al., 2009), o que resulta na perda da biodiversidade em todo o país (FERREIRA et al., 2019), constituindo uma das maiores ameaças à conservação da biodiversidade no Brasil (TABARELLI; GASCON, 2005).

A fragmentação e degradação deste bioma é resultado da superexploração dos recursos naturais e da caça que ameaçam a flora e a fauna (ARCHER, 2011). Além disso, esse bioma sofre com a degradação pelo processo de urbanização (FERREIRA et al., 2019). Em regiões como São Paulo, Rio de Janeiro e Minas Gerais a situação é mais crítica, devido à grande importância histórica desses estados para o desenvolvimento econômico do país, encontrando-se, atualmente, com extensas áreas destinadas à agricultura de larga escala e pastagens (BODDEY et al., 2006). Quanto ao solo nessas regiões, as propriedades físicas, químicas e biológicas encontram-se alteradas, em resposta aos usos inadequados da terra, pelo extrativismo e pelo manejo agrosilvipastoril (BODDEY et al., 2003).

Em escalas regionais, a utilização da terra modifica o contexto do ambiente, isto é, a constituição e a configuração, impactando a chuva de sementes e as condições ambientais – temperatura, umidade, vento, entre outras – sob as quais a sucessão pode acontecer (NEPSTAD et al., 1996; ARROYO-RODRÍGUEZ et al., 2017). Além do tipo de uso da terra (JAKOVAC et al., 2021), a intensidade, extensão, frequência e duração da utilização da terra apresentam-se como moduladoras dos impactos (TURNER, 2010; CHAZDON, 2012), de modo a alterar diretamente as fontes de regeneração, disponibilidade de nutrientes no solo e circunstâncias para plantação de mudas, incluindo a concorrência com espécies cultivadas e ervas daninhas (CHAZDON, 2012). Pesquisas demonstram que diferentes histórias de utilização do solo ocasionam taxas dessemelhantes de recuperação da estrutura da vegetação, bem como da biodiversidade (ZARIN et al., 2005; MESQUITA et al., 2015), de maneira a requerer, assim, estratégias específicas complementares (MORAES; CAMPELLO; FRANCO, 2010).

Além disso, a prática do fogo tem ameaçado a estrutura, composição de espécies e função de novas áreas de floresta na Mata Atlântica que se regeneram sobre áreas agrícolas e de pastagem, criando um estado resiliente ao fogo semelhante a uma savana (SANSEVERO et al., 2020, MATA et al., 2022), tornando-a mais suscetível à incidência de incêndios florestais e à pressão sobre os remanescentes de vegetação nativa.

Embora a manipulação do fogo, sem controle, para limpeza de extensas áreas, em atividades agropastoris seja uma prática secular no Brasil (CAÚLA et al., 2015), o uso do fogo na Mata Atlântica é proibido, levando a alteração da estrutura e composição da floresta (LOPES et al., 2009). Em florestas tropicais, o fogo representa um fator de diminuição da biodiversidade (ALVES; SILVA, 2011) levando ao aumento da degradação e fragmentação de diferentes ecossistemas (ADAMEK et al., 2015). No Vale do Paraíba do Sul, porção paulista, a região sofre com uma tendência crescente de queimadas e a paisagem com grande percentual de pastagens e remanescentes de vegetação nativa de tamanho reduzido com alta probabilidade de queima (INPE, 2020).

A restauração ecológica tem crescido rapidamente no Brasil na última década, devido, principalmente, à demanda cada vez maior pela regularização ambiental das propriedades agrícolas (em virtude do Cadastro Ambiental Rural, Lei 12.651/2012); pela mitigação e compensação de impactos ambientais; e pela atuação intensa de governos e organizações não governamentais na recuperação de ecossistemas nativos, através, por exemplo, da Política Nacional de Recuperação da Vegetação Nativa (Decreto 8.972/2017, que articula, integra e promove ações de recuperação de florestas e demais formas de vegetação nativa).

A restauração dessas áreas, de modo geral, objetiva restabelecer os fluxos biológicos e hidrológicos, reconectar das áreas de habitat, eliminar distúrbios que proporcionam a conjectura de fragmentação (KARLSON; MORTBERG, 2015; MELLO; TOPPA; CARDOSO-LEITE, 2016; METZGER; BRANCALION, 2013; SANTOS et al., 2018), assim como controlar espécies invasoras e incorporar espécies nativas com capacidade de construir condições de sombreamento (NERY et al., 2013). Na restauração ecológica de ambientes tropicais, é imprescindível um planejamento satisfatório, com aplicação a longo prazo, a fim de resguardar a biodiversidade, os serviços ecossistêmicos e os processos ecológicos correlacionados ao desenvolvimento de comunidades (DIAS et al., 2015).

Nos últimos anos, o Vale do Paraíba Sul tem experimentado um aumento significativo nas áreas de regeneração natural (SAPUCCI et al., 2020; SILVA et al., 2017). A chuva de sementes associada a remanescentes florestais tem promovido a chegada de propágulos em áreas de pastagens no território (LORENZON & MASSI, 2023). Em campo, é possível observar que as áreas de restauração passiva estão, em geral, em declividades mais acentuadas e próximas à fragmentos de florestas. No entanto, essa caracterização das áreas não foi ainda sistematizada, bem como a idade das áreas, o levantamento florístico e a disponibilidade de biomassa acima do solo não são conhecidas. No Vale do Paraíba do Sul, diversas pesquisas em relação à estrutura e composição das florestas têm sido realizadas por Santos, 2014; D'Orazio, 2013, e diversos outros pesquisadores, gerando informações acerca dos mecanismos que envolvem a dinâmica do ecossistema em relação às variáveis ambientais e sucessão ecológica (SILVA et al., 2017).

O monitoramento é fundamental, pois permite avaliar os processos envolvidos e as respostas da área degradada aos tratamentos de forma contínua. Apesar da relevância, há pouca ênfase na avaliação e monitoramento de áreas em processo de restauração no Brasil e no mundo, havendo, portanto, espaços a serem preenchidos com pesquisas e trabalhos técnicos. Um meio de monitorar as transformações na paisagem é a utilização de técnicas de sensoriamento remoto, que revelam parâmetros e fatores ambientais sobre as feições da superfície da Terra, através do processamento de imagens de satélite (PONZONI, 2002). A partir desse processamento, é possível obter dados como tipo de culturas, identificação de áreas em processos de degradação, desmatamento, entre outros (MAXWELL et al., 2012), devendo o uso dessas ferramentas estar associado ao uso dos levantamentos em campo.

2 ARTIGO

2.1 Artigo – Borges, C.W.; Massi, K.G.; Resende, A. F. de; Almeida, C.T. de; Nascimento, N.C.C.; Krainovic, P.M.; Saraiva, A.C.V.; Bongers, F.; Molin, P.G.; Peña-Claros, M.; Rodrigues, R.R.; Poorter, L.; Almeida, D.R.A de; Simões, L.H.P.; Souza, V.C.; Toledo, C.A.P.; Brancalion, P.H. Riqueza e diversidade vegetal explicadas por mudanças no uso do solo em quatro tipologias de restauração na Mata Atlântica Sudeste / Plant richness and diversity explained by land use changes in four restoration typologies in Southeast Atlantic Forest

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Plant richness and diversity explained by land use changes in four restoration typologies in Southeast Atlantic Forest

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Abstract

Forest restoration is recognized as an effective and profitable instrument to address climate change. However, forest restoration practices face challenges, such as forest fires and impacts of land use trajectories that can degrade ecosystems. In the Atlantic Forest biome, in a single location, the area was used for several activities and then degraded. The trajectory of land use can drive successional pathways and have implications for tropical forest restoration.

Aiming to evaluate how fire and land use trajectory affect successional pathways in Southeast Atlantic Forest Biome, we combined land use history descriptors and burning area from 1985 to 2022 and hypothesized that land use associated with higher agriculture duration, cover, and frequency and fire history associated with more burning area, would lead to a decrease in richness, structure, and functioning descriptors, and to highly degraded early successional conditions, with potential arresting of restoration initiatives. We indeed observed that sites that burned more area, had more land use changes and more agriculture cover were also the sites with lower richness, diversity, abundance and plant size (DBH and height) and more pioneer and abiotically dispersed species and individuals (especially sites E and F, which were restoration and natural regeneration, respectively). Additionally, plant richness and diversity were partially explained by an increase in mosaic cover (likely natural regeneration) in the last 36 years and by less land uses and higher duration of forest cover in buffers, respectively. Despite that, most response variables were not modeled by land use history and disturbance variables.

KEYWORDS

burnings, ecological succession, land use, natural restoration, tropical rainforest, Vale do Paraíba Paulista

INTRODUCTION

Forest restoration is acknowledged as an effective and cost-efficient instrument to address climate change in the form of mitigation and adaptation strategies (Bustamante et al., 2019; Koch & Kaplan, 2022; IPCC, 2023). Moreover, diverse restoration models can yield significant benefits for biodiversity and offer alternative income sources for local populations (as for example timber: Krainovic et al., 2023). However, far from being a straightforward strategy, forest restoration practices face challenges, for example, forest fires, which tend to escalate with climate changes, and the impacts of land use trajectories that can degrade ecosystems. This reality may pose significant challenges to restoration, particularly in regions with a long history of land use changes and fire occurrences.

The Atlantic Forest biome is considered an important biodiversity hotspot (Myers et al., 2000; Brancalion et al., 2019) due to the high species diversity and level of endemism and anthropogenic threats. Originally, the biome embraces 17 Brazilian states, from Rio Grande *do Sul to Rio Grande do Norte, on the Brazilian coast. The former distribution of the Atlantic Forest has now become heavily populated, with the overall area accounting for 70% of Brazil's Gross Domestic Product (GDP) (MMA, 2013). Thus, currently, only a small proportion (12.4%) of the former forest cover remains (SOS Mata Atlântica & INPE, 2019). The biome landscape is very fragmented (Ribeiro et al., 2011) and the remnants are surrounded by commodities agriculture areas of agricultural commodities. For instance, 32% of the biome area is occupied by pastures (Mapbiomas, 2021). Lately, a net gain in native forest cover has occurred in some portions (for example in Paraíba do Sul river valley, according to Sapucci et al. (2021), but there is a concern that the ongoing loss of older native forests, mostly on flatter terrains, have been hidden by the increasing gain of younger native forest cover, mostly on lands not suited for mechanized agriculture (Rosa et al., 2021). Combined with market, social, and policy forces, recent forest restoration initiatives have increased in the Atlantic Forest biome (observatoriodarestauracao.org.br), especially in the UN Decade on Ecosystem Restoration.*

The Atlantic Forest was the first biome in post-colonial Brazilian history to be degraded and deforested, mainly for commodities agriculture, and urban settlements (Dean, 1996). In this biome, in a single site (as in Paraíba do Sul river valley), for decades forests were removed for timber, then burned to give place to sugarcane, coffee, eucalyptus silviculture, or low-intensity pasture, and after all, forests might still be regrowing if some old-growth and conserved vegetation remained nearby. Land use trajectory might drive successional pathways and have implications for tropical forest restoration (Jakovac et al., 2022). Locally, after intense use, soils may become highly compacted and nutrient-deprived, but also landscape factors, such as the surrounding land uses, might affect the abundance and composition of native flora and fauna, invasive species arrivals, pathogens, and the risk of fire spreading from adjacent land uses (Tucker et al., 2023). Additionally, differences in the same landscape might occur and influence succession, i.e., landscapes dominated by intensive agriculture have lower forest regrowth potential than pasture-dominated landscapes due to a lower likelihood of abandonment, and limited rates of seed availability and seedling growth (Crouzeilles et al., 2020; César et al., 2021; Schweizer et al., 2022). Lastly, each land use's intensity, frequency, and duration might influence succession differently (Jakovac et al., 2021).

Disturbances, such as fire, might alter the successional pathway of regeneration sites (Sansevero et al., 2020; Mata et al., 2022). In Brazil, most fires are related to commodity-

driven deforestation and/or agriculture (Curtis et al., 2018; Baião et al., 2023). Tropical forest fires are not natural events and affect regenerating forest patches, and non-adapted species can be selectively excluded from the community, generating a drastic change in species composition, biomass, and vegetation cover (Prestes et al., 2020, Carvalho et al., 2023), indicating that these ecosystems are fire-sensitive (Pivello et al., 2021). The increase in fire activity in the Atlantic Forest biome has been occurring in recent decades (causing 3.7% of forest loss in this biome: Mapbiomas Fogo, 2022). Landscapes dominated by pastures, with small forest patch sizes, edge effects, and degraded forest vegetation are more likely to burn (Guedes et al., 2020), those which characterize and increase the vulnerability of Southeast Atlantic forest to burning.

The degradation status of forest remnants in the Atlantic Forest and the lack of sufficient forest cover demand actions to restore forest ecosystems, aiming both to increase forest cover in the biome and to increase the resilience of remaining forests to episodes of fire and other effects of climate change. Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004). Restoration efforts in some parts of Brazil have grown in the last decades (Santos et al, 2023) and the recent revisions to the national Forest Code (Lei 12.651/Brasil, 2012) increased legal requirements (using a rural environmental registration policy) for forest recovery and conservation in areas with forest deficits (Soares-Filho et al., 2014). The National Policy for the Recovery of Native Vegetation of 2017 (Decreto 8.972/Brasil, 2017) promotes actions for the recovery of forests and other forms of native vegetation across Brazil. Additionally, the National Policy for using and protecting native forest in the Atlantic Forest Biome of 2006 (Lei 11.428/Brasil, 2006) imposes more restrictions to the Forest Code and created a funding for restoration. In states, as in São Paulo, legislations can also promote restoration (Resolução SMA 32/São Paulo, 2014; Resolução Conjunta SAA/SIMA 03/2020 São Paulo, 2020). Lastly, intense efforts by international (as the World Resources Institute and The Nature Conservancy) and regional and local nongovernmental organizations to recover native Brazilian ecosystems also are occurring.

Active (planting) and passive (natural regeneration) restoration are two important strategies to aid the recovery of large areas of deforested and degraded tropical lands (Morrison and Lindell, 2010; Resende et al., 2024). In general, the presence of nearby old-growth forest remnants and high levels of seed dispersal make succession and recovery (passive restoration) possible; however, under high disturbance conditions and with an *absence of forest remnants, a site may never return to a state similar to the original, and active restoration is needed (Rodrigues et al., 2009; Brancalion et al., 2015). In both cases, a landscape with more native vegetation cover may represent greater restoration success (Jordano et al., 2006). These forest remnants might function as seed sources (through seed rain) for forest succession (Holl, 1999; Nuñez et al., 2021). It is well-known that native forest remnants positively influence tropical forest regeneration in abandoned pasture areas (Aide et al., 2000, Charles et al., 2019) through seed rain (Lorenzon & Massi, 2023). Natural forest restoration should be prioritized in landscapes with low socioeconomic conditions (Crouzeilles et al., 2020) and high environmental debt (Murakami et al., 2023).*

Aiming to evaluate how fire and land use trajectory affect successional pathways in Southeast Atlantic Forest Biome, we combined land use history descriptors and burning area from 1985 to 2022. Specifically, in this work, we want to answer the following question: What is the relationship between fire and land use and land change history to the quality (floristic and structure) of forests in restoration? We hypothesized that land use associated with higher agriculture duration, cover, and frequency and fire history associated with more burning area, would lead to a decrease in richness, structure, and functioning descriptors, leading burned forests to highly degraded early successional conditions, with potential arresting of restoration initiatives.

METHODS

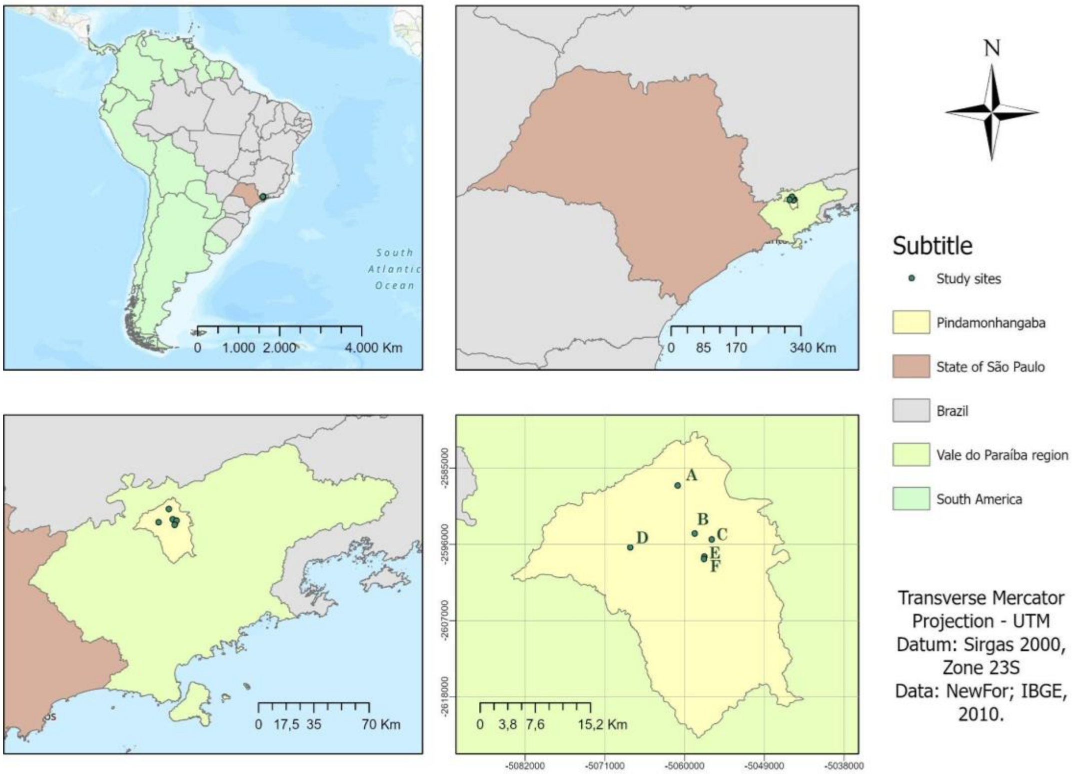
Study area

The Vale do Paraíba Paulista is a region located in the east of São Paulo state. The region holds 39 municipalities reaching 16,178 km² and around 2.5 million inhabitants (IBGE, 2011). In this region, land exploitation began with the gold cycle in the 17th century, followed by cultivation of sugar cane in the 18th century and was consolidated with the expansion of coffee in the mountains in 1780, later being replaced by pastures in 1880 and by eucalyptus forestry in 1990 (Devide et al., 2014).

The region's climate, according to the international Köppen classification, is Cwa category: Subtropical dry winter climate, characterized by hot summers and cold, dry winters (Ribeiro, et al., 2019). The Vale do Paraíba Paulista is inserted in the morphoclimatic domain of 'seas of hills' (Ab'sáber, 2000) of the Atlantic Forest biome, constituting a landscape of very altered tropical forests and with few preserved areas (Dean 1996; Devide, 2013). The region is dominated by pastures with a predominance of exotic grass species such *as Brachiaria spp., eucalyptus forestry, and growing urban areas, but lately, natural regeneration has increased native forest cover (Sapucci et al., 2021). The Vale do Paraíba Paulista is having a growing trend of disturbances such as fire (INPE, 2020) and is covered by important restoration initiatives such as the Vale do Paraíba Ecological Corridor Project, the Conexão Mata Atlântica Project - GEF (Global Environmental Facility) and ROAM (Restoration Opportunity Assessment Methodology).*

Pindamonhangaba is a municipality located in the central region of Vale do Paraíba Paulista (Figure 1), in a transition area between Serra da Mantiqueira mountains, located to the north of the municipality, and Serra do Quebra Cangalha – foothills of Serra do Mar, located to the south (Devide et al., 2019).

Figure 1. Study area, located in Pindamonhangaba, state of São Paulo, southeast Brazil.



Study plots

The study area comprised six 30 x 30 m plots (figure 1) located in Pindamonhangaba, comprising four land typologies (preserved forest remnant: site A, restoration area: sites B and E, natural regeneration area: sites C and F, and remnant of degraded forest: site D).

Data collection followed the NewFor project protocol (available at https://drive.google.com/file/d/1v-rXsdHSZnZ0mwldREiC5j-LrDylkR5v/view?usp=sharing). NewFor project aims to evaluate the multifunctionality of forests in São Paulo state (funded by FAPESP n. #2018/18416-2). Around each plot we designed a buffer of 500 m from a centroid added. In addition, we evaluated the land use and disturbance trajectories.

Data collection

According to the NewFor project protocol, plots were 30 x 30 m and with a minimum distance of 60 m from each other, avoiding plots close to edges of polygons (> 30 m from the edge). Vertices of plots were georeferenced with a geodetic Global Navigation Satellite System (GNSS) device. Regarding flora collection, we identified and measured all individuals of woody species and tree ferns with at least one stem with a diameter at breast height - DBH ≥ 5 cm. The collection of botanical material consisted of branches, preferably with reproductive material for making exsiccata, containing at least some complete and well-developed leaves. All samples were deposited in the Laboratório de Ecologia e Restauração Florestal (LERF-Esalq-USP) herbarium (in Piracicaba).

Burning and land use history

Fire scars were obtained from the MapBiomas Fire Collection 2 database (Souza Jr et al., 2020). Fire scar mapping is based on annual mosaics from Landsat satellites imagery, with a spatial resolution of 30 meters, collected between 1985 and 2020 (Carrilho & Machado, 2022). The geospatial data were designed and processed in ArcGIS 10.3 (ESRI: Environmental Systems Research Institute; Silva & Machado, 2010).

Land use history was assessed using MapBiomas Collection 7 (Souza Jr et al., 2020), which, as well as fire data, is produced from pixel-by-pixel classification of Landsat satellite images. We aggregated Land use classes (https://x.gd/lrBfGW) into six new classes: i) native forest (old-growth and secondary forest remnants), ii) pasture, iii) mosaic of uses (hereafter called mosaic, which might be natural regeneration, according to Mapbiomas platform), iv) soybeans, v) other temporary crops, and vi) forestry. After data processing, we analised and calculated descriptors of land use history that influence succession (Table 1) and metrics (based on Jakovac et al. 2021).

Table 1: Descriptors and metrics analyzed.

Land use history descriptors	*Metrics*
Use	*Native forest, pasture, mosaic of uses, soybeans, other temporary crops, forestry, etc*
Burned area - MAPBIOMAS	*Number of polygons of burned area*
Frequency	*Number of times that a given use remained uninterruptedly*
Duration	*Time in which a given use was present in the time series*
Spatial extent	*Territorial size of each use*
Transition Extension	*Difference between final and initial land use extension in time series for a given use*

Data analysis

From forest inventory data we calculated the species richness and diversity (Shannon index), individuals abundance, average DBH per site, average total height of individuals per site and richness and abundance rate between pioneer and non-pioneer species (p/np) and between biotic (zoochory) and non-biotic (b/nb) dispersed species (anemochory and autochory), classified according to Barbosa et al. (2017), which summed nine response variables. In addition, we had eight explanatory variables calculated in each buffer: number of land uses, number of burned polygons, frequency rate (calculated between average of *forest and mosaic frequency and average of agriculture frequency), duration rate (calculated between average of forest and mosaic duration and average of agriculture duration) and extension rate (calculated between total forest and mosaic extension and total agriculture extension), transition extension of mosaic, native forest and agriculture. Relationships between each response variable and transition extension of mosaic, native forest and agriculture and number of burned polygons individually were calculated using regression analyses. Relationships between each response variable and the other four explanatory variables together (land use history) were calculated using generalized linear models. All data analyses were performed using R software and models were fitted using 'lm' and 'glm' functions in the 'stats' package for R (R Development Core Team 2019). When possible, the Akaike information criterion assessed the best model relative performances.*

RESULTS

Concerning burned areas (table 2), fire scars were identified at site B, in 1988 and 1994, at site F in 1995 and 1996, and at the intersection between sites E and F in 1997, resulting in 16 polygons present at site B, 13 polygons at site E, and 6 polygons at site F. Regarding frequency, agriculture, mosaic and forest were present the whole time in most buffer around plots; exceptions were forest formation and mosaic verified two times in site F, and agriculture verified three times in site C and two times in sites E and F (table 2). Regarding duration, agriculture, mosaic and forest were present the whole time in most buffers around plots (36 years); exception was forest and mosaic that lasted 33 years at site F (table 2). Land use extension in 2020 varied according to plots and land uses, but forest extension was greater in site D (753,774.6 km²), mosaic in site A (137,804.6) and agriculture in site F (527,079.3 km²: table 2). From 1985 to 2020, most plots had forest increase (forest losses only in sites B and C), mosaic losses (mosaic increase was found only in site B), and agriculture increase (only site A had agriculture decrease).

Table 2: Explanatory variables in each plot in the southeast Atlantic forest, between 1985 and 2020.

Sites	Use	Burned area	Frequency - Forest	Frequency - Mosaic of uses	Frequency - Agriculture	Duration - Forest	Duration - Mosaic of uses	Duration – Agriculture	Spatial extent - Forest (2020)	Spatial extent - Mosaic of uses (2020)	Spatial extent - Agriculture (2020)	Transition - Forest (2020-1985)	Transition - Mosaic of uses (2020-1985)	Transition Agriculture (2020-1985)
A	Forest, Mosaic of uses, Agriculture.	-	1	1	1	36	36	36	573632.5	137804.6	71392.7	126062.3	-20796.2	-109628.1
B	Forest, Mosaic of uses, Agriculture.	16	1	1	1	36	36	36	485636.7	53959.6	225800.3	-244259.6	24896.6	224139.6
C	Forest, Mosaic of uses, Agriculture.	-	1	1	3	36	36	36	301343.8	48978.7	434167.5	-161173.0	-254106.7	413408.2
D	Forest, Mosaic of uses, Agriculture.	-	1	1	1	36	36	36	753774.6	28225.0	82833.5	78682.8	-45678.0	31555.2
E	Forest, Mosaic of uses, Agriculture.	13	1	1	2	36	36	36	444959.5	10791.9	438232.5	111154.2	-160264.5	50564.7
F	Forest, Mosaic of uses, Agriculture.	6	2	2	2	33	33	36	499749.2	17433.1	527079.3	258941.5	-266553.8	4910.1

Richness varied from 19 (site F) and 29 (sites B and D), diversity from 1.58 (site E) to 2.73 (site B), abundance from 139 (site F) to 264 (site C), mean DBH from 8.66 (site E) to 11.16 (site A), mean height from 7.04 (site F) to 9.63 (site D: table 3). In addition, more pioneer species and individuals were found in site E and more non-pioneer species and individuals in both sites A and C, respectively (table 3). Lastly, more biotically dispersed species and individuals were both found in site C and more abiotically dispersed species and individuals in sites F and E, respectively (table 3).

Table 3: Response variables in each plot in the southeast Atlantic forest. DBH is diameter at breast height, HTOT, total height, p/np is the rate pioneer-non pioneer and b/nb is the rate biotic-non biotic.

Sites	*Richness*	*Diversity*	*Abundance*	*Mean DBH*	*MeanHTOT*	*Richness rate p/np*	*Abundance rate p/np*	*Richness rate b/nb*	*Abundance rate b/nb*
A	*25*	*2.39*	*154*	*11.16*	*9.26*	*0.31*	*0.54*	*10.50*	*32.25*
B	*29*	*2.73*	*175*	*9.09*	*8.36*	*0.81*	*0.50*	*2.37*	*1.08*
C	*23*	*2.36*	*264*	*8.78*	*8.53*	*0.38*	*0.27*	*21.00*	*258.00*
D	*29*	*2.09*	*210*	*10.54*	*9.63*	*0.70*	*0.34*	*8.66*	*13.00*
E	*22*	*1.58*	*204*	*8.66*	*7.43*	*1.50*	*13.42*	*0.90*	*0.14*
F	*19*	*1.89*	*139*	*9.60*	*7.04*	*1.42*	*8.14*	*0.50*	*0.22*

In general, the species with the greatest abundance found in the plots were represented by individuals of Sebastiania brasiliensis Spreng. (122), found exclusively at site E; Euterpe edulis Mart. (137) found in sites A and D, being the most abundant species in these sites; Mimosa bimucronata (DC.) Kuntze (108), present in sites D, E and F, constituting the most abundant species in site F; Myrcia splendens (Sw.) DC. (85) and Pleroma granulosum (Desr.) D. Don (52) with specimens in sites B and C, with P. granulosum being the most abundant species in site B and M. splendens in site C.

Table 4: Species found with greater abundance in study plots in the southeast Atlantic forest. Position number (from one to five, according to abundance) and individual number (in parentheses).

Familia	*Species*	*A*	*B*	*C*	*D*	*E*	*F*
Arecaceae.	*Euterpe edulis Mart.*	*1 (41)*			*1 (96)*		
Bignoniaceae	*Jacaranda micrantha Cham.*				*5 (6)*		
Cordiaceae	*Cordia superba Cham.*						*5 (6)*
Euphorbiaceae	*Alchornea glandulosa Poepp. & Endl.*				*3 (14)*		
	Alchornea sidifolia Müll.Arg.				*4 (13)*		
	Alchornea triplinervia (Spreng.) Müll.Arg.						*3 (11)*
	Croton urucurana Baill.					*4 (5)*	*2 (17)*
	Sebastiania brasiliensis Spreng.					*1 (122)*	
	Tetrorchidium rubrivenium Poepp.	*5 (9)*					
Fabaceae	*Clitoria fairchildiana R.A.Howard*		*5 (13)*				
	Inga striata Benth.					*3 (8)*	
	Lonchocarpus cultratus (Vell.) A.M.G.Azevedo & H.C.Lima	*3 (13)*					
	Mimosa bimucronata (DC.) Kuntze					*2 (35)*	*1 (71)*
	Peltophorum dubium (Spreng.) Taub.					*5 (4)*	
Lauraceae	*Ocotea pulchella (Nees & Mart.) Mez*			*4 (39)*			
Lythraceae	*Lafoensia glyptocarpa Koehne*		*3 (14)*				
Melastomataceae	*Miconia cinnamomifolia (DC.) Naudin*		*4 (14)*				
	Miconia petropolitana Cogn.			*2 (39)*			
	Pleroma granulosum (Desr.) D. Don		*1 (47)*				
Meliaceae	*Guarea macrophylla Vahl*				*2 (35)*		
Moraceae	*Ficus adhatodifolia Schott in Spreng.*		*2 (15)*				
Myrtaceae	*Myrcia splendens (Sw.) DC*			*1 (81)*			

	Syzygium cumini (L.) Skeels			*4 (6)*
Phyllanthaceae	*Hieronyma alchorneoides Allemão*		*3 (37)*	
Piperaceae	*Piper arboreum Aubl.*	*4 (10)*		
Primulaceae	*Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.*		*5 (12)*	
Salicaceae	*Casearia sylvestris Sw.*	*2 (37)*		

Richness showed a positive association with more natural regeneration in the studied buffer (mosaic transition from 1985 to 2020; R2=0.747, P=0.026; Figure 2).

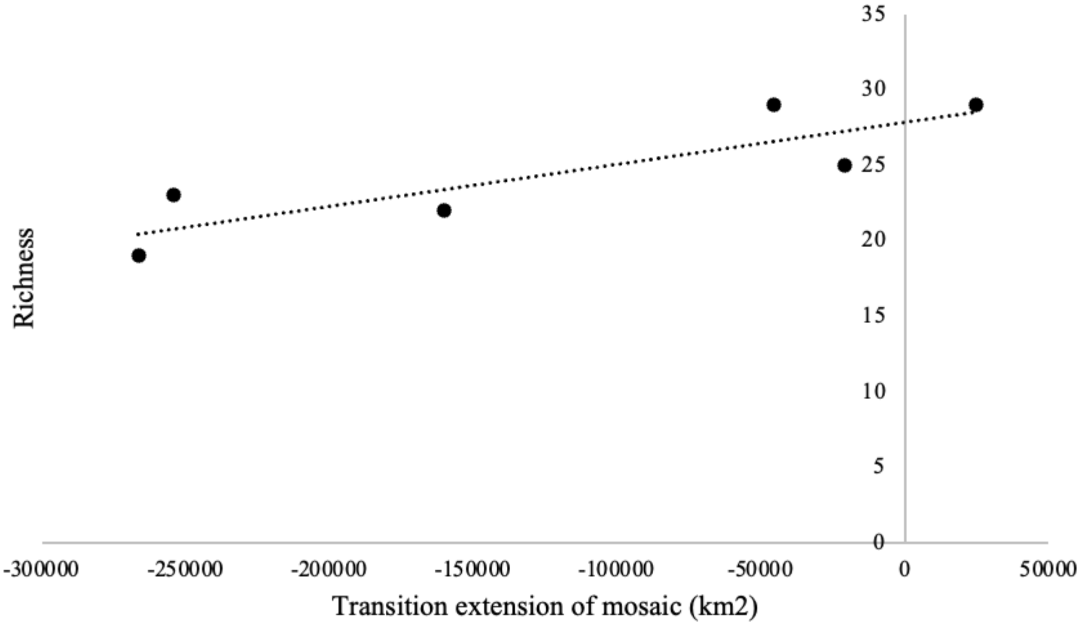


Figure 2. Variation in plant richness in relation to transition (from 1985 to 2022) extension of mosaic in the southeast Atlantic forest.

Richness, abundance, total height, average diameter, richness and abundance rate of pioneer-non pioneer species and of biotically-non biotically dispersed species were not modeled by land use history and disturbance variables (Supplementary Material 1). The best model for diversity included the interaction between uses and duration rate (Supplementary Material 1), with both predictors showing the highest importance values among those included in the original model (Figures 3 a and b, respectively: P< 0.01; Supplementary Material 1). More land uses (different agricultural uses, mosaic, and native forest) were linked to lower plant species diversity (Supplementary Material 1, Figure 3 a), while more *duration of native forest and mosaic in relation to agriculture was associated with greater diversity (Supplementary Material 1, Figure 3 b).*

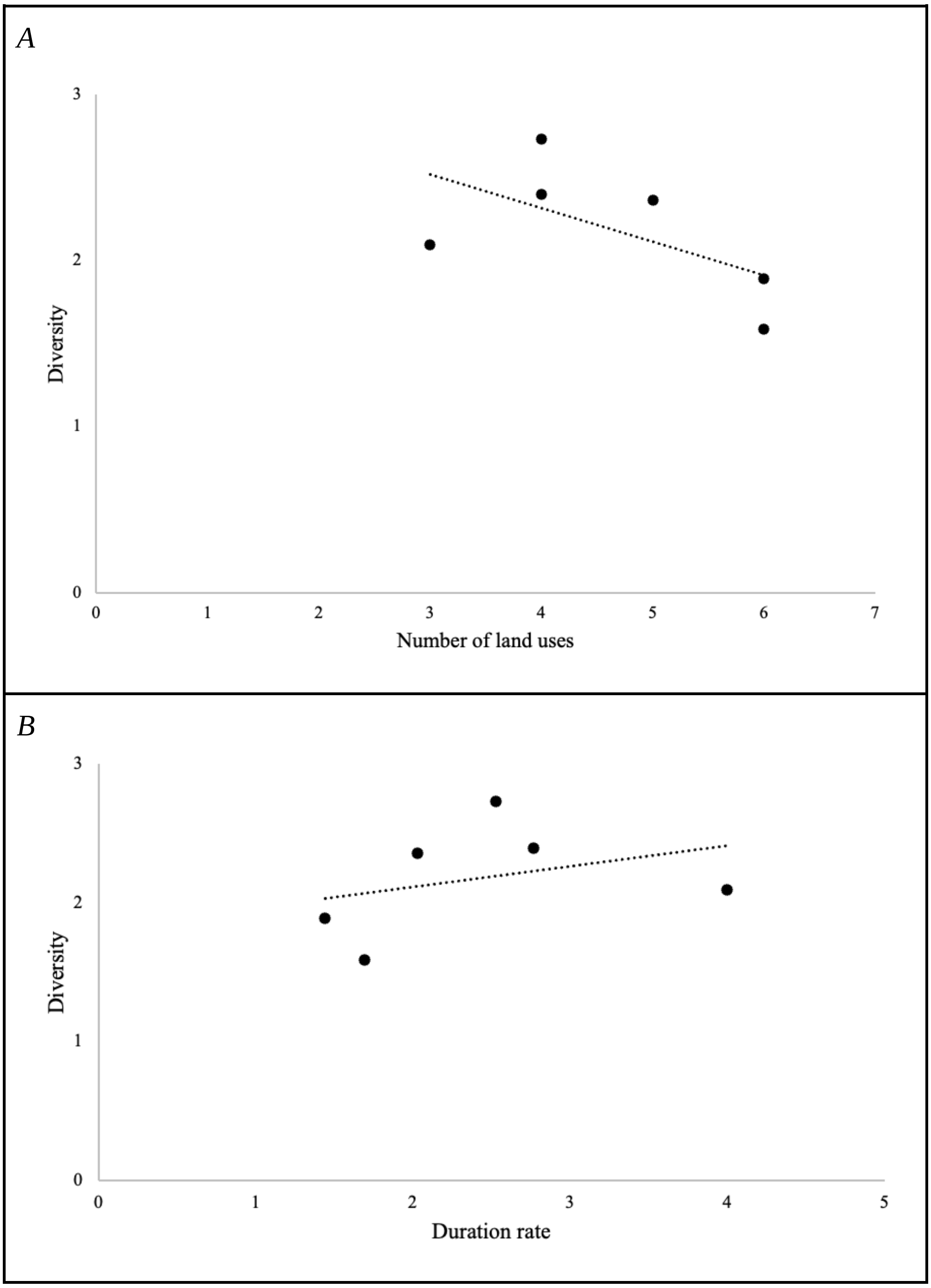


Figure 3. Variation in plant diversity in relation to number of land uses (A) and duration rate between native forest and mosaic in relation to agriculture (B) in the southeast Atlantic forest.

The number of burned polygons was not related to any response variable (Supplementary Material 1).

Besides mosaic transition related to richness, response variables were not explained by the change from 1985 to 2020 in the extension of native forest, mosaic, and agriculture (Supplementary Material 1). We also observed that the rate between biotically and non-biotically dispersed individuals was marginally influenced by transition extension of agriculture (R^2=0.578, P=0.079; Figure 4).

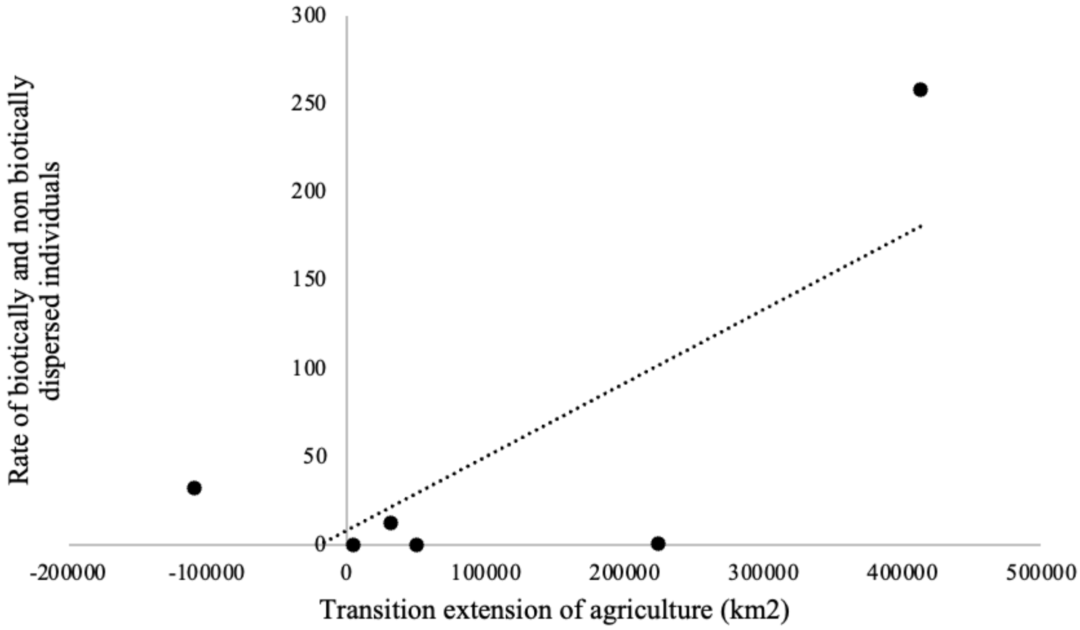


Figure 4. Variation in rate between biotically and non-biotically dispersed individuals in relation to transition extension of agriculture in the southeast Atlantic forest.

DISCUSSION

Aiming to evaluate how fire and land use trajectory affect successional pathways in Southeast Atlantic Forest Biome, we combined land use history descriptors and burning area from 1985 to 2022 and hypothesized that land use associated with higher agriculture duration, cover, and frequency and fire history associated with more burning area, would lead to a decrease in richness, structure, and functioning descriptors, and to highly degraded early successional conditions, with potential arresting of restoration initiatives. We indeed observed that sites that burned more area, had more land use changes and more agriculture cover were also the sites with lower richness, diversity, abundance and plant size (DBH and height) and more pioneer and abiotically dispersed species and individuals (especially sites E *and F, which were restoration and natural regeneration, respectively). Additionally, plant richness and diversity were partially explained by an increase in mosaic cover (likely natural regeneration) in the last 36 years and by less land uses and higher duration of forest cover in buffers, respectively.*

Despite that, most response variables were not modeled by land use history and disturbance variables. Land use trajectory might drive successional pathways and have implications for tropical forest restoration (Jakovac et al., 2021) and studies have been showing that (Crouzeilles et al., 2020; César et al., 2021; Schweizer et al., 2022). However, we showed here that different land typologies (preserved forest remnant, active restoration area, natural regeneration area and remnant of degraded forest) can not be explained altogether by the same land use variables and disturbance variables, indicating different successional pathways and ecological processes. In addition, the small number of sites studied (six) imposes a constraint that must be considered and more plots should be added for a precise and accurate evaluation (Lieberman, 1996).

We found a positive association between plant richness and greater mosaic cover (likely natural regeneration). Thus, the expansion in natural regeneration in buffers around plots can be related to changes in biotic and abiotic conditions (as, for example, soil conditions, fauna, vegetation), which can bring biodiversity and provide a wide array of ecosystem goods and services (Chazdon et al., 2020). Thus, our results suggest that, no matter the restoration or land typologie in a certain region (as the studied ones), the presence of natural regeneration sites would affect seed arrival and seedling establishment, lastly improving plant richness.

We also verified that more land uses along the 36 years of observations were associated with a lower diversity of plant species. In addition, more duration of forest and mosaic inside buffers did relate to higher plant diversity. Both results may mean the same thing, i.e., that changes in land uses (for example from forest to agriculture to mosaic) can lead to soil practices and landscape configuration in buffers that turn into decreased biodiversity inside evaluated plots. On the other side, a forest remnant that lasted 36 years and that has several ecological processes associated is linked to greater plant diversity. In tropical regions, low-intensity land use, small areas, fertile soils, and presence of nearby forest remnants have accelerated recovery rates, while areas subjected to intense use, *grazing, repeated slash and burn processes or land disturbance for long periods, showed slow recovery (Chazdon, 2003).*

Lastly, we noticed a marginal influence of agriculture cover on biotically dispersed plant individuals inside plots. In general, changes in forest structure and composition after different uses and abandonment of land impact different animal populations (DeWalt et al. 2003), responsible for the dissemination of seeds in a large part of tropical tree species (Howe & Smallwood, 1982), affecting forest regeneration. Furthermore, animals constitute mobile links that connect regenerating forests in anthropogenic landscapes, possibly explaining our results (Chazdon, 2014).

Although the number of burned polygons was not related to any response variable, floristic richness and consequently diversity can be affected by burnings, generating a drastic change in species composition, biomass, and vegetation cover (Prestes et al., 2020, Carvalho et al., 2023), indicating that these ecosystems are fire-sensitive (Pivello et al., 2021), which alter the successional pathway of regeneration sites (Sansevero et al., 2020; Mata et al., 2022).

In general, richness, abundance and diversity found in the studied plots were lower than of other studies in land typologies in the region (Fiore et al., 2019; de Paula Silva et al., 2021; Carvalho et al., 2023). That might be explained by the degree of anthropization of Vale do Paraiba Paulista, linked to an old history of environmental degradation (Devide et al., 2014) and a current pasture-dominated landscape (Sapucci et al., 2021) that might be affecting the potential areas for restoration (Ribeiro et al., 2023). Thus, this study should be replicated with more tropical sites having different land use histories and configurations. Additionally, families with more abundant species, Euphorbiaceae, Fabaceae and Melastomataceae confirm the degraded nature of this landscape. Alchornea triplinervia (Euphorbiaceae), for example, is a pioneer species, common in altered environments, and is an important food resource, due to its abundant fruiting, for dispersers such as birds (Lorenzi, 2000). Fabaceae play an important role in fixing nitrogen in the atmosphere, making them capable of colonizing degraded environments and, Melastomataceae, mainly Miconia genera, is mainly a pioneer genera, abundant in tropical forest, which fruits dispersed by birds contain several small seeds (Lorenzi, 2000).

CONCLUSIONS

Research on tropical secondary forests is important for understanding the long-term effects of land use history and disturbance on forest composition, structure and functioning, and implications to goods and services. We examined four restoration tipologies in Brazil that have experienced variable degrees of land uses and disturbances and both passive and assisted natural regeneration in the process of recovery since agricultural abandonment many decades ago. Our results suggest differences among tipologies and a greater number of land uses associated with a lower diversity of plant species, as well as a positive association of richness in relation to greater natural regeneration, partially confirming the hypothesis of the present study. Most of the response variables were not modeled by the explanatory variables, nor to the burning area.

AUTHOR CONTRIBUTIONS

CWB, KGM, and ACVS designed the study, conducted the analysis, and wrote the manuscript. AFR, CTA, NCCN, PMK, FB, PGM, MPC, RRR, LP, DRAA, LHPS, VCS, CAPT and PHB participated in data collection and organization. CWB, KGM, AFR, CTA, NCCN, PMK, ACVS and PHB actively participated in reviewing the manuscript.

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3 CONSIDERAÇÕES FINAIS

A investigação sobre florestas secundárias tropicais é importante para compreender os efeitos a longo prazo da história do uso da terra e das perturbações na composição, estrutura e funcionamento das florestas, bem como as implicações para os bens e serviços. Examinamos quatro tipologias de restauração no Brasil que sofreram graus variáveis de uso e perturbação da terra e regeneração natural passiva e assistida no processo de recuperação desde o abandono agrícola, muitas décadas atrás. Nossos resultados sugerem diferenças entre tipologias e maior número de usos do solo associados a menor diversidade de espécies vegetais, bem como associação positiva de riqueza em relação a maior regeneração natural, confirmando parcialmente a hipótese do presente estudo. A maioria das variáveis respostas não foram modeladas pelas variáveis explicativas, nem pela área de queimada.

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APÊNDICE – Material Suplementar

GLMs

Response variable	**Explanatory variable**	**Estimate**	**Error**	**P**	**AIC**
Richness	Intercept	55.52	75.76	0.597	32.57
	Uses	-4.75	8.28	0.669	
	Frequency rate	-2.65	6.26	0.745	
	Duration rate	-2.76	15.40	0.887	
	Extension rate	0.01	0.08	0.942	
Diversity	Intercept	9.87	0.63	0.000554 ***	-11.91
	Uses	-1.05	0.08	0.000988 ***	
	Duration rate	-1.16	0.11	0.001622 **	
Abundance	Intercept	1240.52	379.31	0.189	51.90
	Uses	-97.20	41.45	0.257	
	Frequency rate	-185.65	31.34	0.106	
	Duration rate	-191.36	77.09	0.244	
	Extension rate	1.13	0.39	0.212	
DBH Media	Intercept	-16.02	21.34	0.590	17.37
	Uses	2.36	2.33	0.496	
	Frequency rate	2.67	1.76	0.372	
	Duration rate	5.39	4.34	0.431	
	Extension rate	-0.02	0.02	0.455	
HTOT Media	Intercept	6.07	13.72	0.735	12.068
	Uses	-0.06	1.50	0.976	
	Frequency rate	-0.58	1.13	0.701	
	Duration rate	1.38	2.79	0.708	
	Extension rate	-0.006	0.01	0.731	
Density	Intercept	13783.47	4215.23	0.189	80.79
	Uses	-1080.02	460.60	0.257	
	Frequency rate	-2062.74	348.31	0.106	
	Duration rate	-2126.23	856.65	0.244	
	Extension rate	12.53	4.33	0.212	
Richness P/NP	Intercept	-3.79	13.78	0.829	12.12
	Uses	0.66	1.51	0.736	
	Frequency rate	0.57	1.14	0.704	
	Duration rate	0.39	2.80	0.910	
	Extension rate	0.002	0.01	0.920	
Abundance P/NP	Intercept	-119.26	97.60	0.437	35.61
	Uses	15.79	10.66	0.378	
	Frequency rate	3.48	8.06	0.741	

	Duration rate	20.04	19.84	0.497	
	Extension rate	-0.06	0.10	0.653	
Richness B/NB	Intercept	148.10	290.50	0.700	48.70
	Uses	-14.93	31.74	0.720	
	Frequency rate	-20.52	24.00	0.550	
	Duration rate	-22.88	59.04	0.765	
	Extension rate	0.09	0.30	0.807	
Abundance B/NB	Intercept	2895.41	3192.37	0.531	77.46
	Uses	-287.89	348.83	0.561	
	Frequency rate	-325.05	263.79	0.434	
	Duration rate	-528.93	648.78	0.565	
	Extension rate	2.25	3.28	0.617	

LMs

Response variable	**Explanatory variable**	**Estimate**	**Error**	**P**	**Adjusted R2**
Richness	Burned polygon	0.14	0.29	0.664	-0.185
	Extension transition of native forest	0	0	0.245	0.146
	Extension transition of mosaic	0	0	0.027	0.683
	Extension transition of agriculture	0	0	0.870	-0.241
Diversity	Burned polygon	0.01	0.03	0.768	-0.2196
	Extension transition of native forest	0	0	0.100	0.416
	Extension transition of mosaic	0	0	0.266	0.118
	Extension transition of agriculture	0	0	0.464	-0.0743
	Burned polygon	-1.25	3.31	0.724	-0.207
	Extension transition of native forest	0	0	0.274	0.107
Abundance	Extension transition of mosaic	0	0	0.620	-0.166
	Extension transition of agriculture	0	0	0.084	0.457
	Burned polygon	-0.08	0.06	0.259	0.128
	Extension transition of native forest	0	0	0.393	-0.017
DBH Media	Extension transition of mosaic	0	0	0.343	0.030
	Extension transition of agriculture	0	0	0.116	0.374
	Burned polygon	-0.06	0.07	0.425	-0.044
	Extension transition	0	0	0.602	-0.158

	of native forest				
HTOT Media	Extension transition of mosaic	0	0	0.183	0.242
	Extension transition of agriculture	0	0	0.916	-0.246
	Burned polygon	-13.94	36.74	0.724	-0.207
	Extension transition of native forest	0	0	0.274	0.107
Density	Extension transition of mosaic	0	0	0.620	-0.166
	Extension transition of agriculture	0	0	0.084	0.457
	Burned polygon	0.03	0.03	0.382	-0.007
	Extension transition of native forest	0	0	0.354	0.019
Richness P/NP	Extension transition of mosaic	0	0	0.468	-0.077
	Extension transition of agriculture	0	0	0.643	-0.176
	Burned polygon	0.24	0.40	0.578	-0.145
	Extension transition of native forest	0	0	0.272	0.11
Abundance P/NP	Extension transition of mosaic	0	0	0.358	0.016
	Extension transition of agriculture	0	0	0.585	-0.149
	Burned polygon	-0.73	0.46	0.190	0.230
	Extension transition of native forest	0	0	0.439	-0.056
Richness B/NB	Extension transition of mosaic	0	0	0.735	-0.21
	Extension transition of agriculture	0	0	0.282	0.098
	Burned polygon	-6.46	6.91	0.402	-0.0255
	Extension transition of native forest	-0.0002	0.0002	0.354	0.019
Abundance B/NB	Extension transition of mosaic	-0.0004	0.0004	0.342	0.031
	Extension transition of agriculture	0	0	0.0787	0.474