UNIVERSIDADE DE SÃO PAULO

INSTITUTO DE BIOSCIÊNCIAS

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

FRANCISCO D'ALBERTAS GOMES DE CARVALHO

Caminhos para a intensificação ecológica através da restauração e da certificação agrícola

Paths for an ecological intensification of agriculture through restoration and agriculture certification

São Paulo

2022

FRANCISCO D'ALBERTAS GOMES DE CARVALHO

Caminhos para a intensificação ecológica através da restauração e da certificação agrícola

Paths for an ecological intensification of agriculture through restoration and agriculture certification

tese submetida ao Programa de Pós-Graduação em Ecologia da Universidade de São Paulo para a obtenção do título de Doutor em Ecologia.
Orientador: Jean Paul Meztger

São Paulo

2022

Ficha Catalográfica

d'Albertas Gomes de Carvalho, Francisco
Caminhos para a intensificação ecológica através da restauração e da certificação agrícola
Número de páginas

Tese (Doutorado) - Instituto de Biociências da Universidade de São Paulo. Departamento de Ecologia.

1. Conservação 2. Políticas Ambientais 3. Paisagens Agrícolas I. Universidade de São Paulo. Instituto de Biociências. Departamento de Ecologia.

Comissão Julgadora:

Prof(a). Dr(a).

Prof(a). Dr(a).

Prof(a). Dr(a).

Prof(a). Dr(a).

Prof(a). Dr(a). Jean Paul Walter Metzger

Orientador(a)

para Julia, pela paciência

AGRADECIMENTOS

Gostaria de agradecer em primeiro lugar ao Jean, meu orientador. Aprendi muito – e espero continuar aprendendo – nos últimos oito anos (!) em que trabalhamos juntos.

Agradeço também ao lugar que foi minha casa nesses anos, o LEPaC, e a todos os membros atuais e passados desse laboratório incrível. Foi realmente inspirador conviver com tantas pessoas talentosas e dedicadas em fazer ciência. Nele, além de me formar como pesquisador, fiz amigos que carrego pra toda vida. Não me arrisco a esgotar nomes, afinal, o LEPaC é uma casa bem grande. Mas deixo aqui registrado quem me acompanhou ao longo do doutorado: Isa, Ju, Mila, Clarice, Carito, Pat, Doug, Artur, Adrian, Karla, Naty, Vitor, Duda, Mari, Ma Fê (se esqueci de alguém, me desculpem). As trocas acadêmicas e pessoais, impossíveis de serem separadas, com certeza me fizeram um Ecólogo melhor. Obrigado também ao Wellington por todo o suporte.

Não menos importante, especialmente em tempos tão sombrios, o meu trabalho só foi possível graças ao financiamento que me foi concedido pela CAPES e pela FAPESP. Espero estar à altura do voto de confiança que me foi dado, e que a minha pesquisa seja um pequeno tijolo na construção de um futuro possível.

Tive o privilégio — mais um — de visitar a Universidade de Cambridge, no Reino Unido, durante 12 meses. Foram meses muito ricos e de muito trabalho. Fui muito bem recebido e queria registrar aqui minha gratidão ao Andrew Balmford, meu supervisor e ao Charles, Gianlucca e Fernando, que fizeram com que eu me sentisse em casa.

Obrigado também ao Departamento de Ecologia da USP. Sinto um orgulho danado de ter feito parte desse lugar. Por trás dele estão pessoas incríveis como a Vera e a Shirlene, espinhas dorsais do programa. Além, é claro, dos discentes, que se tornam amigos, companhias de cafés, conversas, viagens e planos.

O doutorado é um processo cheio de rituais. Um deles é a formação de um comitê de acompanhamento, para nos socorrer de vez em quando. Agradeço ao

Gerd Sparovek e ao Luis Fernando Guedes Pinto por toparem ser parte dele. Outro é a banca de qualificação. Obrigado à Rozely Ferreira, Carla Morsello e ao Paulo Guilherme Mollin pelas contribuições.

Ao longo do meu treinamento como pesquisador eu aprendi que uma introdução deve ser estruturada como uma pirâmide invertida; começa-se com as teorias e fatos mais gerais, e vai-se afunilando até se chegar ao problema a ser atacado. Aqui eu fiz o processo inverso. Estou chegando então à base da pirâmide imaginária que me constitui.

Obrigado a minha família, por me proporcionar tantas vivências. E pelo apoio incondicional em (não) fazer escolhas que culminaram em quem eu sou. Obrigado ao meu pai, Gilberto, a minha mãe, Christina e a minha irmã, Manuela.

Recentemente li um agradecimento que dizia mais ou menos assim (tradução minha): “agradeço ao meu amor, sem a qual eu teria terminado esse livro muito mais rápido.” Acho que em um primeiro momento, a frase pode soar ofensiva, mas em seguida, penso que o real sentido é reconhecer nossas prioridades na vida. Agradeço imensamente a Julia, minha companheira. Que na realidade nunca fez meu trabalho ir mais devagar. Ao contrário, sempre me apoiou e incentivou. Mas que também me lembra de que isso, o doutorado, a pesquisa, é apenas uma parte bem pequenininha de mim, de nós. Amo você Juquinha.

“Talvez tenha chegado a hora de superar a esperança.[. . .]Talvez tenha chegado o momento de compreender que, diante de tal conjuntura, é preciso fazer o muito mais difícil: criar/lutar mesmos sem esperança. O que vai costurar os rasgos do Brasil não é a esperança, mas a nossa capacidade de enfrentar os conflitos mesmo quando sabemos que vamos perder.”

(Eliane Brum, Banzeiro Òkòtó)

RESUMO

Criar resumo direto no arquivo principal. Acentos não funcionam usando arquivo externo.

Palavras-chave: Palavra-chave 1. Palavra-chave 2.

ABSTRACT

This will work in english

Keywords: Keyword 1. Keyword 2.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

1 INTRODUÇÃO

A expansão e a intensificação agrícolas promovidas pela revolução verde permitiram dobrar a produtividade agrícola (TILMAN, David, 1999), particularmente por meio da adoção de monoculturas em larga escala e do uso de insumos externos (TILMAN, D., 2001) — como fertilizantes e agroquímicos. Porém, uma série de impactos negativos decorreu desse processo, como a conversão de habitats naturais em áreas cultivadas e a redução da heterogeneidade das paisagens antrópicas (MATSON, 1997; TSCHARNTKE; KLEIN *et al.*, 2005), a poluição decorrente do uso excessivo de fertilizantes e pesticidas (CARPENTER et al., 1998; MATSON, 1997) e a intensificação do efeito estufa (PACHAURI; IPCC, 2008). Não por acaso, projeta-se que a agricultura seja responsável por até 70% da perda de biodiversidade terrestre no futuro (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY; UNITED NATIONS ENVIRONMENT PROGRAMME, 2014).

Esta situação cria um paradoxo uma vez que o impacto da agricultura convencional sobre os ecossistemas compromete a própria agricultura e a manutenção de serviços ecossistêmicos vitais ao bem-estar humano (FOLEY, 2005; (PROGRAM), 2005). De fato, mesmo cultivos manejados de forma intensiva também dependem, em maior ou menor grau, de serviços de regulação e provisão (BOMMARCO; KLEIJN; POTTS, 2013). Por exemplo, em 1997, a economia gerada pelos inimigos naturais de pragas agrícolas foi estimada em 100 bilhões de dólares anuais. A contribuição da polinização animal aos cultivos foi estimada em valores ainda mais altos: 200 bilhões de dólares (PIMENTEL *et al.*, 1997). Entretanto, o controle biológico de pragas e a polinização são prejudicados pela intensificação agrícola (GEIGER *et al.*, 2010).

A situação atual poderá se agravar ainda mais, pois a demanda por produtos agrícolas deve crescer intensamente nas próximas décadas para abastecer uma população crescente (GODFRAY *et al.*, 2010). Um dos grandes desafios da humanidade será aumentar a produtividade da agricultura, reduzindo as externalidades negativas (FOLEY, 2005). É improvável que este objetivo seja alcançado com uma expansão da fronteira agrícola ou exclusivamente por meio da agricultura convencional (GODFRAY *et al.*, 2010). Portanto, é vital que a agricultura se torne mais sustentável por meio de um processo de intensificação ecológica, baseada no manejo e favorecimento dos organismos provedores de serviços ecossistêmicos que contribuem para uma maior produtividade (BOMMARCO; KLEIJN; POTTS, 2013).

Ações de restauração de áreas naturais ou seminaturais podem ser usadas como uma forma de intensificação ecológica e têm o potencial de frear a perda de biodiversidade global, aumentar a resiliência de serviços ecossistêmicos vitais (ARONSON; ALEXANDER, 2013; BENAYAS *et al.*, 2009; TEEB, 2012, 2010) e incrementar a produtividade agrícola (BULLOCK; PYWELL; WALKER, 2007; WADE; GURR; WRATTEN, 2008). De fato, é possível haver um aumento na produtividade, especialmente em países em desenvolvimento onde a produtividade ainda está distante de atingir seu potencial máximo (NEUMANN *et al.*, 2010), através de um adequado arranjo espacial de áreas restauradas, que favoreça polinizadores e animais que se alimentam das pragas agrícolas (BOESING, Andrea L.; NICHOLS; METZGER, Jean P., 2017; GARIBALDI; STEFFAN-DEWENTER *et al.*, 2011). Além disso, florestas tropicais restauradas tem o potencial de retirar em média 3,05 toneladas de carbono ha^{-1} ano^{-1} da atmosfera nos primeiros 20 anos (POORTER *et al.*, 2016). Esse é um serviço ecossistêmico de regulação climática crítico, que pode ser comercializado em mercados de crédito de carbono.

Felizmente, a restauração ecológica foi incluída em compromissos globais, como é o caso das metas de Aichi e do desafio de Bonn, em que diversos países, entre eles o Brasil, se comprometem a restaurar milhões de hectares de áreas degradadas (CHAZDON *et al.*, 2017). O ano de 2021 marcou o início da década da restauração da ONU, em que se espera que essas metas sejam cumpridas. Iniciativas como estas são de extrema importância, porém, projetos de restauração têm custos elevados (DE GROOT *et al.*, 2013; NEWTON *et al.*, 2012) e requerem décadas para mostrarem resultados (CROUZEILLES; CURRAN *et al.*, 2016). Logo, é fundamental conhecer os custos e benefícios envolvidos para o melhor planejamento da restauração (@ DE GROOT *et al.*, 2013; METZGER; ESLER *et al.*, 2017; SABOGAL, 2015). No caso da agricultura, cenários analisando a relação de custo-benefício podem favorecer ações de restauração caso os custos sejam diluídos com ganhos em produtividade em médio e longo prazo. No entanto, atualmente, a grande maioria das publicações com restauração não considera adequadamente uma análise de custo-benefício (ACOSTA *et al.*, 2018; ARONSON; BLIGNAUT *et* *al.*, 2010; DE GROOT *et al.*, 2013; NEWTON *et al.*, 2012).

O cumprimento da Lei de Proteção da Vegetação Nativa *12.651 de 2012*, que dispõe sobre a conservação da vegetação nativa no Brasil - popularmente conhecida como Novo Código Florestal - implicará em uma das maiores ações de restauração em propriedades privadas no mundo, com cerca de 21 milhões de hectares de passivo ambiental a serem restaurados ou compensados (SOARES-FILHO *et al.*, 2014). A lei exige a toda propriedade rural no país uma área mínima de vegetação nativa que varia de 20 a 80%, a depender do bioma e da região. Esta área representa a soma de áreas de preservação permanente (**APP**), cuja localização é prevista na lei (e.g. entorno de corpos d'água e áreas declivosas), e da reserva legal (**RL**), definida pelo proprietário. Os produtores de médio e grande porte que não tinham RL suficiente em Julho de 2008, ou aqueles que suprimiram essa vegetação após essa data, têm um passivo ambiental e a obrigação legal de se adequar, restaurando ou compensando a área de vegetação faltante. No caso da RL, cabe ao proprietário optar por realizar um projeto de restauração dentro de sua propriedade ou por uma das quatro opções de compensação (definidas pelo artigo 66 da lei 12.651: cota de reserva ambiental (CRA); arrendamento de área sobre regime de servidão ambiental ou RL; doação ao poder público de área localizada no interior de Unidade de Conservação; cadastramento de outra área equivalente e excedente à RL, em imóvel de mesma titularidade ou adquirida em imóvel de terceiro), desde que no mesmo bioma. Adicionalmente, a lei condiciona a disponibilidade de crédito rural e a anistia de desmatamentos ilegais anteriores a 2008 ao cadastro dos imóveis rurais no Sistema Nacional de Cadastro Ambiental Rural (**SICAR**), que é de acesso público. O SICAR disponibiliza, assim, uma quantidade ímpar de informações espacialmente explícitas, o que representa uma oportunidade excepcional para avaliar os efeitos de diferentes cenários de restauração para a produção agrícola, que poderão servir de modelo para políticas públicas a serem implantadas no Brasil e em outras partes do mundo.

Além da restauração, formas alternativas de manejo agrícola podem levar a uma produção mais sustentável [eg. manejo integrado de pragas e nutrientes; Garibaldi, Gemmill-Herren *et al.* (2017); Pretty *et al.* (2006)]. Neste contexto, em resposta aos desafios impostos pela agricultura convencional, foram desenvolvidas as certificações agrícolas, que se caracterizam por padrões de práticas sustentáveis de adesão voluntária (MILDER *et al.*, 2015; POTTS; BIESMEIJER *et al.*, 2010). Estes padrões definem práticas de agricultura e recomendam ações que os produtores devem seguir para serem reconhecidos como responsáveis social e ecologicamente, e com isso, terem acesso a um mercado consumidor sensível a esta temática (MILDER *et al.*, 2015; MOLENAAR; KESSLER, 2017; PINTO; HAJJAR *et al.*, 2016).

Porém, mesmo que a adoção de certificações venha crescendo globalmente, ainda existem poucas evidências de seu impacto para a conservação (MILDER *et al.*, 2015; POTTS; BIESMEIJER *et al.*, 2010; TSCHARNTKE; MILDER *et al.*, 2015), bem como sobre o impacto de práticas agroecológicas em geral (GARIBALDI; GEMMILL-HERREN *et al.*, 2017). Dentre os principais problemas dos estudos existentes está a dificuldade em dissociar os efeitos da certificação de mudanças que já aconteceriam de forma independente (**meemken_sustainability_2021**; PINTO; GONÇALVES, 2017; TSCHARNTKE; MILDER *et al.*, 2015). Por exemplo, fazendas certificadas podem já ter práticas mais sustentáveis antes de serem certificadas, portanto, potenciais diferenças com fazendas não certificadas seriam erroneamente atribuídas à certificação. Para que iniciativas como a certificação se consolidem e potencializem os seus benefícios para a conservação e a produção agrícola, é fundamental desenvolver estudos robustos que levantem evidências sobre os efeitos destas iniciativas (MILDER *et al.*, 2015). Desse modo, essas pesquisas devem usar procedimentos metodológicos robustos, que considerem áreas contrafatuais (isto é, áreas controle para o tratamento em consideração, no caso a certificação, mas que sejam similares às áreas em tratamento nas demais características), para diferenciar quais padrões encontrados em propriedades com tratamento (no caso, certificadas) se devem ao tratamento ou estão apenas associados a ele (TSCHARNTKE; MILDER *et al.*, 2015).

De uma forma geral, esse trabalho visa contribuir no entendimento de caminhos para uma intensificação ecológica em paisagens agrícolas, seja através de um planejamento adequado das ações de restauração para atendimento aos requerimentos da lei 12.651 de 2012, ou então, pela avaliação rigorosa da efetividade de ações de certificação. Mais especificamente, buscamos cumprir três objetivos principais, organizados em três capítulos em que nos propomos a responder as seguintes perguntas:

Quais são os principais fatores determinantes na quantidade e localização de RL alocadas por proprietários rurais no SICAR?

No primeiro capítulo utilizamos modelos hierárquicos e o banco de dados do SICAR de uma das regiões mais tradicionais para a produção cafeeira no Brasil para buscar responder a essa pergunta.

É possível e se sim, em que condições, os custos com restauração em propriedades rurais pode ser compensado por aumentos na produtividade e com a geração de créditos de carbono?

No segundo capítulo, desenvolvemos cenários de restauração para propriedades rurais na mesma região cafeeira e calculamos uma estimativa detalhada do balanço financeiro destes cenários. Nos cenários, consideramos os custos, mas também os potenciais benefícios para a produtividade derivados do aumento potencial da provisão de serviços ecossistêmicos.

A certificação agrícola tem efeitos quantificáveis para a conservação?

No terceiro capítulo, utilizamos o banco de dados de uma das principais certificadoras do Brasil e do SICAR para elaborar uma análise robusta dos impactos da certificação para a conservação e cumprimento da legislação ambiental. Por meio do pareamento das propriedades certificadas com propriedades contrafactuais, fizemos uma análise temporal das tendências de desmatamento, regeneração e cumprimento da legislação ambiental das propriedades antes e depois da certificação. Para isso, utilizamos uma técnica estatística de regressão em painel calculando a diferença das diferenças entre propriedades tratamento e controle.

2 PRIVATE RESERVES SUFFERS FROM THE SAME LOCATION BIASES OF PUBLIC PROTECTED AREAS

Francisco d'Albertas, Adrian González-Chaves, Clarice Borges-Matosa, Vitor Zago de Almeida Paciello, Martine Maron, Jean Paul Metzger

This chapter was published as:

d'ALBERTAS, F. et al. Private reserves suffer from the same location biases of public protected areas. Biological Conservation, v. 261, p. 109283, 1 set. 2021. 10.1016/j.biocon.2021.109283

2.1 ABSTRACT

Setting aside areas for conservation on private properties is an essential component of the response to the biodiversity crisis. Often this is voluntary, but in Brazil, landowners are required to set aside between 20%-80% of their property for native vegetation, in what are called Legal Reserves. If degraded, they need to be restored. Alternatively, landowners can compensate for a Legal Reserve deficit on their own property by purchasing surplus credits from another property. Each landowner can define the location and spatial arrangement of their Legal Reserves within their properties, affecting the ability of the reserves to maintain biodiversity and provide ecosystem services. To identify the drivers determining the amount and location of those Legal Reserves, we accessed data for 3,622 rural properties in southeastern Brazil. We found that the likelihood of a landowner setting aside part of their farm as Legal Reserve (avoiding off-farm compensation) increased with farm size and extent of native vegetation cover, particularly where this vegetation is along rivers and steep slopes, where conserving vegetation is also mandated in what are called Areas of Permanent Protection. Properties with these characteristics located in areas of higher transportation costs and lower agricultural suitability were more likely to have the full Legal Reserve requirement within their areas. Within properties, the location of Legal Reserves was mostly in areas of the property with low agricultural suitability, high transportation cost and close to Areas of Permanent Protection. These two results suggest landowners' decisions are made to maximize property income and to reduce restoration costs. Conservation on private land in Brazil thus follows similar patterns to public protected areas, being mostly located on marginal land for agriculture. These areas do not necessarily provide the greatest potential biodiversity and ecosystem services benefits, suggesting that specific government interventions may be needed to encourage landowners to set aside native vegetation in ways that maximise conservation and ecosystem service outcomes.

Keywords: private-land conservation,land-regulation,environmental policy, Forest Code, Natural Vegetation Protection Law, Atlantic Forest

2.2 INTRODUCTION

One of the main policies in response to the biodiversity crisis (CARDINALE *et al.*, 2012; IPBES, 2019) is the creation of new protected areas worldwide (UNEP-WCMC IUCN, 2018). However, the location of public protected areas show a strong bias towards lands with high elevation, steeper slopes, low agricultural productivity, and low human density, not always considering biodiversity hotspots or ecological representativeness (VENTER *et al.*, 2018; WATSON *et al.*, 2014). Thus, there is a clear need to reduce these biases.

One way to reduce bias is to increase protected areas on private land (CORTÉS CAPANO *et al.*, 2019; DRESCHER; BRENNER, 2018). Agriculture cover > 30% of the Earth's ice-free surface (ELLIS *et al.*, 2010), mostly on private property. In turn, private properties shelter vasts amounts of native vegetation, for instance, 56% of the United States forests (SASS; BUTLER; MARKOWSKI-LINDSAY, 2017), 28% of Europe's forests (PULLA *et al.*, 2013) and 53% of the native vegetation in Brazil (FREITAS; ENGLUND *et al.*, 2017). Protecting or enhancing natural vegetation on private properties also has benefits to private landholders beyond conservation itself. Native vegetation within farms can help increase agricultural production through the provision of ecosystem services (DAINESE *et al.*, 2019). Natural pest control and pollination provided by native vegetation (BOESING, Andrea L.; NICHOLS; METZGER, Jean P., 2017; POTTS; IMPERATRIZ-FONSECA *et al.*, 2016; RAND; TYLIANAKIS; TSCHARNTKE, 2006) make economic contributions between US$ 10-1500 per hectare globally (LAUTENBACH *et al.*, 2012; NARANJO; ELLSWORTH; FRISVOLD, 2015; PIMENTEL *et al.*, 1997).

Some countries are implementing policies to set aside private areas for conservation in voluntary or mandatory schemes (GARIBALDI; PÉREZ-MÉNDEZ, 2019). Brazil, in particular, has an environmental regulation, the Native Vegetation Protection Law (Federal Law 12.651/2012), which establishes that all rural properties must have natural vegetation set aside as mandatory Areas of Permanent Protection (APP; sensitive areas such as riparian vegetation, hilltops, and steep slopes) and Legal Reserves. Legal Reserves should cover from 20% to 80% of the total property area, depending on the Country's biome and physiognomy, and can include APP. Farmers that do not have the full area of Legal Reserves vegetated must restore it, or opt for a compensation scheme outside their property (for example, trading with landowners with Legal Reserves surplus). The latter strategy aims to allow properties with high opportunity costs to conserve or restore less valuable areas outside their limits (MAY *et al.*, 2015). Legal Reserves are designed for the sustainable management of ecosystem services provided by natural vegetation and can combine native and non-native species (up to 50% of Legal Reserves area). They are of vital importance for biodiversity protection, water and energy security, climate regulation, and ecosystem service provision (METZGER; BUSTAMANTE *et al.*, 2019).

At present, Legal Reserves cover 167 million ha (METZGER; BUSTAMANTE *et al.*, 2019), representing nearly half of the remaining native vegetation areas in Brazil (SOARES-FILHO *et al.*, 2014), highlighting the importance of their maintenance. The proportion of vegetation in Legal Reserves is highest for the Atlantic Forest biome (70% of remnant vegetation), where most of the Brazilian population lives (REZENDE *et al.*, 2018). Nevertheless, to achieve the objectives of Legal Reserves, their location should be adequately planned to support species survival in fragmented landscape (FAHRIG, 2017; TAMBOSI *et al.*, 2014) while favoring ecosystem services that can increase agricultural productivity (BOESING, Andrea L.; NICHOLS; METZGER, Jean P., 2017; GARIBALDI; STEFFAN-DEWENTER *et al.*, 2011).

To enforce the implementation of the Native Vegetation Protection Law, in 2012 the Brazilian Government created a self-declaratory public-access database, named CAR (Portuguese acronym for environmental rural register), in which each landowner delimits the size and location of their Legal Reserves. This extensive CAR database, gathering more than 5.6 million properties and nearly 550 million ha of land (in July 2020), offers a unique opportunity to evaluate landowner's management choices in response to a land-regulation policy.

Here we use CAR data to shed light on which drivers affect farmer's decisions about the amount and spatial location of Legal Reserves within their properties and consider the implications of their choices for biodiversity conservation and ecosystem services provision. We address two important questions: (1) which drivers predict the proportion of Legal Reserves the landowners declare inside their properties versus outside their land? (2) For landowners that decided to allocate Legal Reserves inside their properties, which drivers can predict where those Legal Reserves are located? Following the pattern already described for public protected areas (Venter et al., 2018; Watson et al., 2014), we expected that land management decisions concerning Legal Reserves are made to maximize farm income. Farms located in marginal areas for agriculture production or less profitable were thus expected to set aside larger proportions of Legal Reserves inside their properties. We also expected that larger properties will declare higher proportions of Legal Reserves on-property. Considering the same reasoning, we also expected landowners will tend to locate their Legal Reserves within marginal lands. Additionally, we evaluated whether farmers are choosing to allocate Legal Reserves near existing native vegetation patches, which would increase patch size and could contribute to biodiversity conservation and ecosystem services provision.

2.3 METHODS

2.3.1 Study Region

To test which drivers are affecting choices about the amount and spatial location of Legal Reserves, our sample included 164 municipalities of southeastern Brazil, in one of the most important and traditional regions for coffee production (Figure 1). This region was predominantly covered by the Atlantic Rainforest, a highly biodiverse tropical forest, which suffered a long history of deforestation and fragmentation (JOLY; METZGER; TABARELLI, 2014). Yet, despite past human interference, the Atlantic Forest still shelter a highly diverse set of tropical species (MITTERMEIER *et al.*, 2011). For that reason, conservation policies to protect the remaining vegetation are fundamental to prevent further biodiversity losses. The study region has more than 500 thousand hectares of coffee plantations (Supplementary Figure A2), with an annual harvest of 900 thousand tons, representing 15% of the country's coffee production, and an income value of ca. 2 billion dollars (IBGE, 2016). Several studies have demonstrated the importance of Atlantic Forest remnants in providing key ecosystem services for coffee production, such as in modulating the flows of pollinators [Saturni, Jaffé e Metzger (2016);gonzalez-chaves_forest_2020] or natural enemies of coffee pests (ARISTIZÁBAL; METZGER, 2019; LIBRÁN-EMBID; DE COSTER; METZGER, 2017).

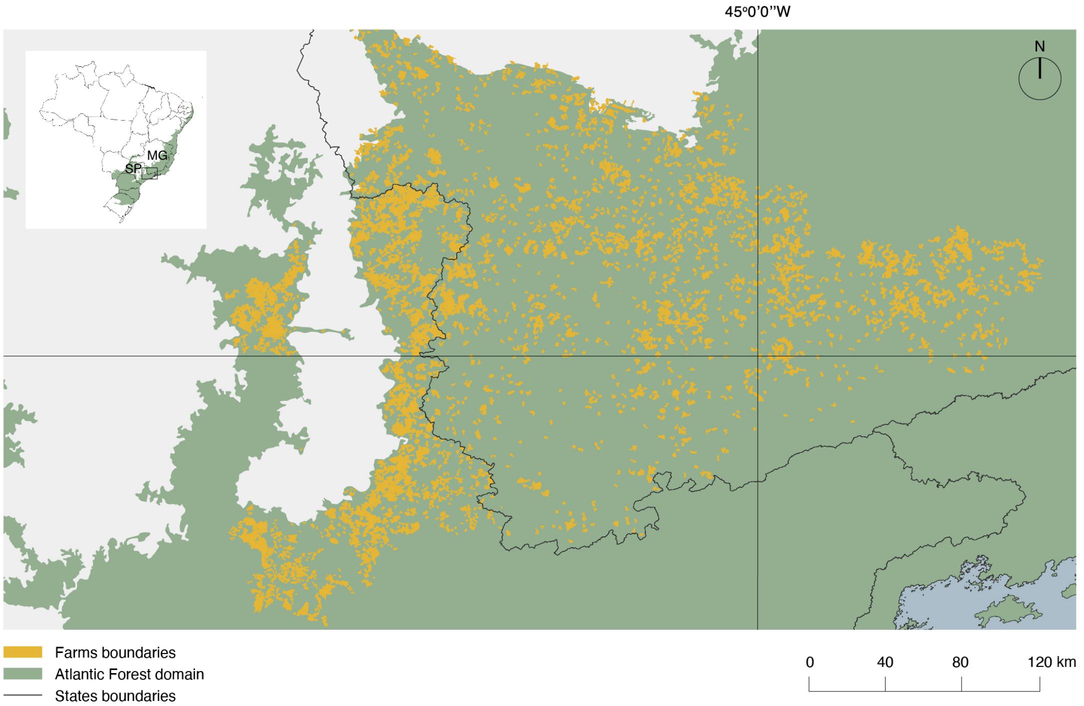


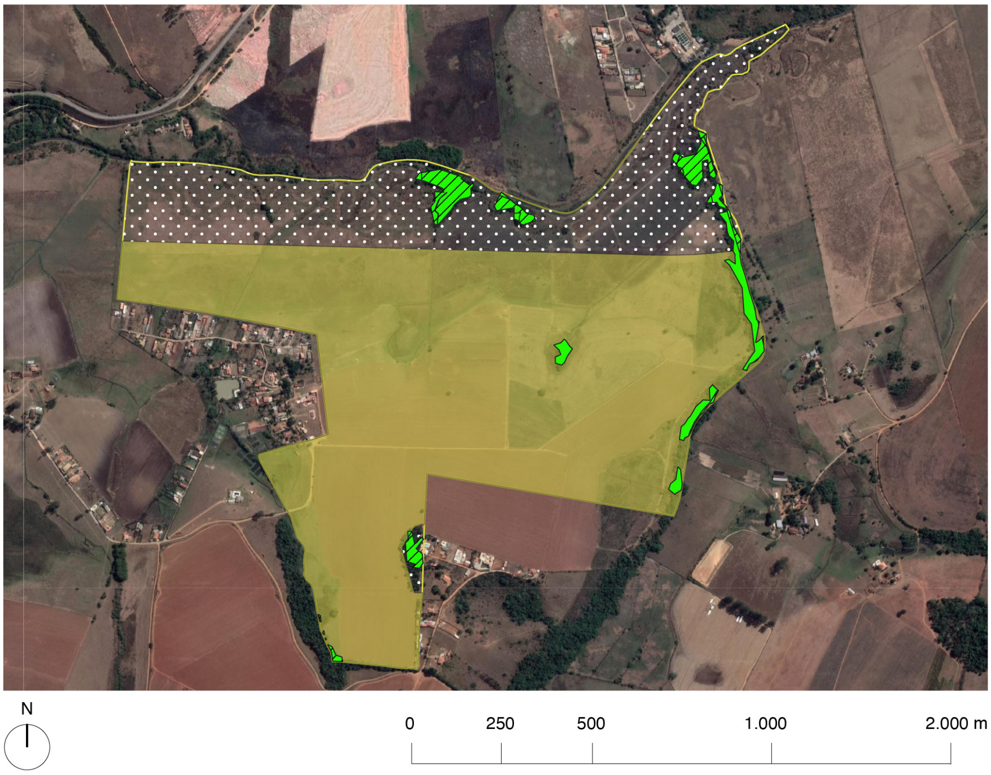
Figure 1 – Location of the farms included in our dataset (N= 3,622) in Southeastern Brazil, between the borders of Minas Gerais (MG) and São Paulo (SP) Estates.

2.3.2 Rural property database (CAR)

We accessed information on property limits, Legal Reserves, and APP locations through the CAR database. Properties that do not register are susceptible to restrictions in their economic activities, particularly by preventing access to financial credit for agricultural activity. This measure has been designed to reduce the historically low level of compliance with previous versions of environmental regulations. According to the Native Vegetation Protection Law, all rural properties within the Atlantic Forest must conserve an area with forest equivalent to 20% of the area of the property as Legal Reserves. It can be located inside the property, including APPs, or it can also be compensated by protecting/or restoring forests on another property within the Atlantic Forest domain.

APP are mandatory for all rural properties and their location is predefined, including riparian zones, hilltops, high elevations and steep slopes. Legal Reserve requirements depend on the property size and their location can be decided by the landowner. Rural properties in Brazil are classified on fiscal modules (minimum size of an economically viable area) which varies from five to 110 ha, depending on the municipality (BRANCALION; GARCIA *et al.*, 2016). Small properties (≤ four modules, 20 – 440 ha) have to maintain and/or restore their APP but are not obliged to restore or compensate their Legal Reserves in case of past deforestation. For medium (4 - 15 modules, 20 – 1650 ha) and large properties (above 15 modules, usually ≥ 75 ha), conserving an area equivalent to 20% of the property is mandatory.

We downloaded the spatial data from all properties within our study region (`http://www.car.gov.br/publico/imoveis/index`), totalling nearly 170,000 records covering 4,540,860 ha. Small properties represented 95% of the data and 58% of the area. However, since only medium and large farms (25.39 – 6438.24 ha for our region) are obliged to restore Legal Reserves, we excluded small properties from further analyses. As the database is self-declaratory, data are imprecise and there is some overlap between properties due to differences in land demarcation. We retained in our dataset properties with less than 10% overlap, resulting in data from 3,622 rural properties. For these properties, we calculated the proportion of area that was declared Legal Reserve. With this, we assessed the amount of Legal Reserve declared inside each property and when it did not fulfill the 20% property size, we assumed the remaining amount will be compensated outside the property (*Question 1*). To understand what drivers influenced Legal Reserve location in-farm (*Question 2*) we considered only the 2,960 properties that have declared at least some extent of Legal Reserve in-farm, disregarding properties that did not have Legal Reserve declared in the CAR system. We have created a categorical map with two land-use and land-cover classes: vegetation and agricultural area. When allocating Legal Reserves, farmers can choose vegetated areas or a fraction of their agricultural area, which will require restoration. We have considered then two classes of Legal Reserve: vegetated Legal Reserve and non-vegetated Legal Reserve (Box 1). All GIS data was handled in ArcGIS 10.6.1 ®.



Description of the categories considered

Agricultural area: The productive area of the farms;

Farm boundary

Vegetation: The area of the farm covered with natural vegetation. Part of the vegetation can be allocated as Legal Reserve for compliance with the Native Vegetation Protection Law;

Vegetated LR: Standing natural vegetation within the farms that was allocated as Legal Reserve by the farmers at the CAR platform;

Non-vegetated LR: Productive areas of the farm that were allocated as LR by farmers at the CAR database. Those areas will have to be restored with natural vegetation in order to be accounted as LR, in a time horizon of twenty years.

Figure 2 – Box 1: Example of a property considered in the study showing land-use and land-cover classes used as dependent variables to evaluate factors influencing Legal Reserve (LR) location.

2.3.3 Drivers in Legal Reserve allocation

We tested whether the following drivers were related to the proportion of Legal Reserve declared within the property (*question 1*): opportunity cost (net present value in dollars ha^{-1} of the agricultural production over a time horizon of 20 years; details on Table 1 and in Supplementary Material); APP proportion; property size; native vegetation proportion; pasture proportion; land-use diversity; agricultural suitability; the presence of central pivot irrigation and transportation costs (Table 1). Further, to understand what influences Legal Reserve location within farms (question 2) we considered the following potential drivers: opportunity cost; agricultural suitability, and transportation costs (Table 1). We have also considered the distance to any native vegetation and APP within the property as two additional drivers potentially influencing the location of non-vegetated Legal Reserves.

Table 1 – Independent variables considered as drivers of Legal Reserve (LR) in-farm amount (question 1) and location (question 2) declared by farmers. APP – areas of permanent protection; Sup. Mat - Supplementary Material.

Variable	Data generation	Question
Agricultural suitability index	Values extracted from a agricultural suitability map (30m) with soil, climate, and relief data aggregated in an index ranging from 0 (no suitability) to 1 (very high suitability) (Sparovek et al., 2015) . For question 1 we used mean values per property while for question 2 we extracted the pixel value	1,2
Diversity of land-uses (D)	Using a 30m resolution land-use map (Freitas et al. 2018) with crops, forestry, and pasture cover, we calculated a diversity index according to the formula: D = sum (proportion land-use * the number of land-uses)	1

Table 1 – Independent variables considered as drivers of Legal Reserve (LR) in-farm amount (question 1) and location (question 2) declared by farmers. APP – areas of permanent protection; Sup. Mat - Supplementary Material. *(continued)*

Variable	Data generation	Question
Irrigation	Presence/ absence of central pivot irrigation for each farm (National Water Agency)	1
Opportunity cost	We crossed the spatial location of pastures and crops – from the same land-use map used on the diversity of land-uses calculation – with the weighted mean municipality income (CONAB, 2017) from the main crops (IBGE, 2017) and cattle farming (CEPEA, 2017). Then, we calculated the net present value (USD/ha) per pixel (30m) using a time horizon of 20 years and a discount rate of 8%. The final result was a spatial cost surface with 30m resolution. For question 1 we have used total value per property and in question 2, the pixel value (details on Sup.Mat.)	1,2
Property size (hectares)	We calculated the size in hectares for each property using the vector data available at the CAR*	1

Table 1 – Independent variables considered as drivers of Legal Reserve (LR) in-farm amount (question 1) and location (question 2) declared by farmers. APP – areas of permanent protection; Sup. Mat - Supplementary Material. *(continued)*

Variable	Data generation	Question
Proportion of vegetation	We used a high-resolution vegetation map (FBDS**, 5m resolution) to calculate the proportion of natural vegetation covering each property. We did not use it for land-uses because it does not differentiate cropland and pastureland. We have accessed the correlation of the vegetation cover with the coarser resolution land-use map to make sure the two data-sets were comparable (cor> 0.9)	1
Proportion of pasture	Proportion of pasture per property according to the land-use map	1
Proportion of APP	Proportion of APP per property according to the information available at the CAR*	1
Transportation cost	We extracted values from a 30m resolution transportation cost map for Brazil (Freitas et al.,2018), in which each cell contains the cost in minutes to runoff agricultural production to the destination of dominant commodities in the country. For question 1 we have used mean values per property and in question 2, we used pixel values.	1,2

Table 1 – Independent variables considered as drivers of Legal Reserve (LR) in-farm amount (question 1) and location (question 2) declared by farmers. APP – areas of permanent protection; Sup. Mat - Supplementary Material. *(continued)*

Variable	Data generation	Question
Distance to APP	We have calculated an Euclidean distance map in which each pixel contains the distance, in meters, from the nearest pixel of APP	2
Distance to vegetation	We have calculated an Euclidean distance map in which each pixel contains the distance, in meters, from the nearest pixel of vegetation	2

Note:
* The CAR database (Portuguese acronym for environmental rural registry) is available at http://www.car.gov.br/publico/imoveis/index
** The Brazilian Foundation for Sustainable Development (in Portuguese Fundação Brasileira parao Desenvolvimento Sustentável - FBDS) produced a land-use and land-cover mapwith supervised RapidEye image classification, for the year 2013 (http://geo.fbds.org.br/)

2.3.4 Statistical analysis

2.3.4.1 Question 1 (declared amount of in-farm Legal Reserve)

Due to a high proportion of values of 0% and 20% in the distribution of Legal Reserve proportion per property (Supplementary Figure A3), we categorized properties into four classes: *no Legal Reserve declared*, *Legal Reserve deficit*, *Legal Reserve compliance*, *Legal Reserve surplus* (Box 2). As a consequence of categorizing our response variable in more than two levels, we split the analysis for Legal Reserve proportion into three parts. In each part, we have adjusted a Bayesian hierarchical additive linear model with a binomial distribution and uninformative priors, using the package *rstanarm* [Gabry *et al.* (2018); see the Supplementary Material for details on construction and priors] from the R environment (TEAM, 2018). In the first part of the analysis, we compared properties without vs. those with Legal Reserve declared (which combined Legal Reserve deficit, Legal Reserve compliance, and Legal Reserve surplus classes), to test if there are particular drivers distinguishing properties not declaring any Legal Reserve. In the second part, we combined properties with Legal Reserve compliance and Legal Reserve surplus and compared them with properties with Legal Reserve deficit. We were interested in evaluating what drivers distinguish landowners that declare Legal Reserve with some deficit from those declaring the full legal requirement inside their land. In the third part, we compared properties with Legal Reserve compliance and properties with Legal Reserve surplus, to determine what particular characteristics make landowners decide to strictly follow Legal Reserve requirements or to go further and indicate a Legal Reserve surplus. For all analyses, the identity of the State (Minas Gerais or Sao Paulo) was modeled as a random effect.

The importance of the independent variables included in the models was measured based on the effect size: variables with 95% confidence intervals around estimates including zero were considered as non-informative. To validate the models, we split properties data using the R package *caTools* (JAREK, 2019) in training datasets (75% of the data), used to build the binomial models and test datasets (25%), used to evaluate the performance of the models. We used the values of the independent variables from the testing dataset to generate response values predicted by the models. Next, we compared the predicted values of the response variable generated by the model with the real values contained in the test dataset. The comparison relied on the calculation of the area under the curve (AUC) of the receiver operating characteristic curve (ROBIN *et al.*, 2011). The curve was obtained with the R package pROC (ROBIN *et al.*, 2011).

no LR (proportion = 0)

Properties included in the database in which landowners did not indicate any LR. In this case, they will have to entirely compensate the LR outside their properties.

LR deficit (0 ≤ proportion < 0.18)

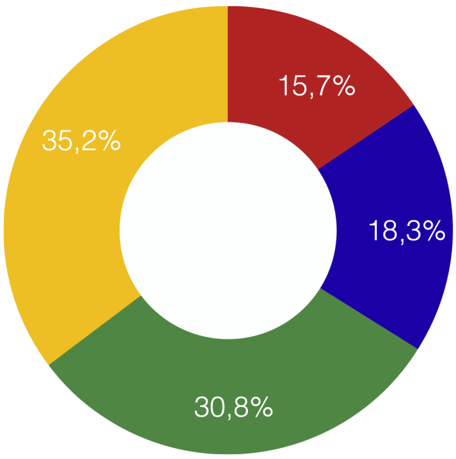
Properties in which landowners indicated part of the land as LR, but below the legal requiremente. In that case, instead of using 0.2 as threshold (the legal requirement), we considered an error of 0.02, to account for imprecisions in the process vectoring the information in the CAR database. The difference between the proportion of LR allocated and the legal requirement will have to be compensated outside the property.

LR compliance (0.18 ≤ proportion ≤ 0.22)

Properties in which landowners have indicated their full legal requirement. We have considered in that case a margin of error of ± 0.02 instead of usign a threshold of 0.2. No compensation is needed for farms in that category.

LR surplus (> 0.22)

Properties in which landowners have indicated more than LR requirement. Following the same margin of error of 0.02, we are considering all properties which extra LR probably signaling the intention of receiving compensation from others properties that indicated LR below legal requirement. No compensation needed in that case as well.



Nearly half of the properties (49%) have less than 18% of LR, while the majority of the properties (51%) are signaling the full LR inside the farm or even declaring surplus areas (n = 3,622).

Figure 3 – Box2: Farms were divided into categories based on the proportion of Legal Reserve (LR) indicated at the environmental rural registry (CAR).

2.3.4.2 Question 2 (declared in-farm Legal Reserve location)

To extract the values of all drivers inside each property, we randomly generated a large cloud of points within all properties limits, with a minimum distance of 50 m. Subsequently, we sampled 2000 points within each Legal Reserve class and land-use and land-cover category. Our analyses were divided into two parts, in which we performed paired comparisons between vegetated Legal Reserves and agricultural areas (part 1) and non-vegetated Legal Reserves and agricultural areas (part 2), using hierarchical binomial additive models, including property identity as a random factor. We have also done an additional analysis, comparing characteristics of vegetated areas with those of agricultural areas to test if particular drivers could be influencing the allocation of vegetated Legal Reserve that are distinct from the drivers that acted on present remnant vegetation distribution within the farms.

2.4 RESULTS

The 3,622 studied properties cover 766,592.9 ha, from which 13.7% (105,265 ha) is natural vegetation. The agricultural area is composed of pasture (54%), crops (42%) and a small presence of forestry (4%). Nearly half of the sampled properties (49%) allocated less than 18% of Legal Reserve, while the majority (51%) signaled the full Legal Reserve inside the farm or even a surplus (Box 2). Except for properties with no Legal Reserve declared, vegetation cover increases with compliance level (Figure 4). The area declared as Legal Reserve sum 108,750.4 ha, which corresponds to 14.2% of the area covered by private properties. From the total Legal Reserve declared, 33% (36,496.41 ha) are non-vegetated Legal Reserve and will require restoration. On the contrary, 36,011.81 ha of Legal Reserve declared are areas of surplus. The deficit of Legal Reserves areas which will have to be compensated is equivalent to 45,040.82 ha (25% more than the total area of surplus Legal Reserve declared by the farms).

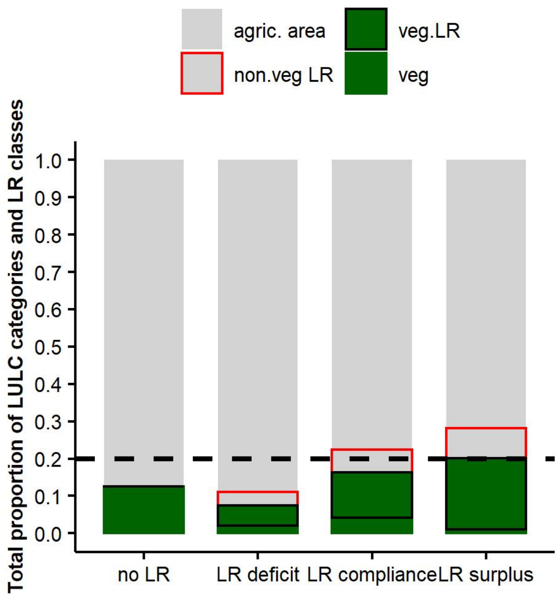


Figure 4 – Proportion of the properties covered by agricultural area (agric.) and vegetation (veg) for properties with no Legal Reserve (LR) declared (n= 663), properties with Legal Reserve deficit (n= 1,115), properties with Legal Reserve compliance (n= 1,275), and properties with Legal Reserve surplus (569). A fraction of the land-use and land-cover (LULC) categories are overlayed by non-vegetated Legal Reserve (non.veg LR) and vegetated Legal Reserve (veg. LR). The black dotted line represents the legal requirement of 20%.

2.4.1 Drivers affecting the proportion of Legal Reserve declared

Landowners of larger properties with a higher proportion of APP and lower proportion of pasture are more likely to allocate full or at least part of the Legal Reserve within their property, according to our predictions (AUC = 0.70; Figure 5; Supplementary Figure A4). Further, larger properties with a higher proportion of vegetation and APP, higher transportation cost, and lower agricultural suitability were more likely to have set aside the full Legal Reserve requirement or even with a surplus, dispensing the need for compensation schemes (AUC = 0.78; 5; Supplementary Figure A5). These farms also had lower land-use diversity. Farms with more Legal Reserve than required by law, generating a surplus, had a higher proportion of vegetation in the property and were smaller (AUC = 0.62; 5; Supplementary Figure A6). The presence of central pivot irrigation and opportunity cost were not important drivers modulating farmer's intentions in any comparison.

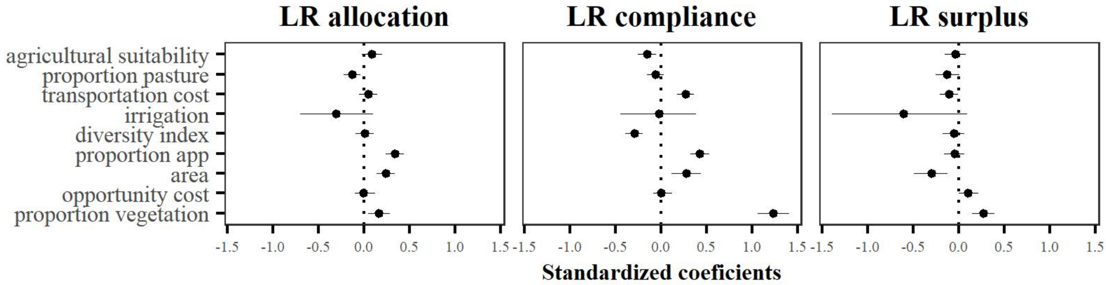


Figure 5 – Parameters estimates with mean (black dot) and credible 95% intervals of the predictors of the amount of Legal Reserve (LR) declared by landowners (N= 3,622), considering the three different contrasting situations defined for answering question 1. We have modeled the predictors concerning properties having: LR allocated inside the property; LR compliance or surplus when compared with a LR deficit situation; and LR surplus in contrast to a compliance situation.

2.4.2 Drivers affecting Legal Reserve location

Remnant forest fragments are located in areas with lower agricultural suitability and closer to APP (AUC = 0.71; Figure 4; Supplementary Figure A7). The areas where Legal Reserves were allocated follow very similar patterns, for both vegetated (AUC = 0.69; 6; Supplementary Figure A8) and non-vegetated Legal Reserves (AUC = 0.74; 6; Supplementary Figure A9). For vegetated Legal Reserves, in particular, there seems to be an additional positive effect of transportation cost on their location.

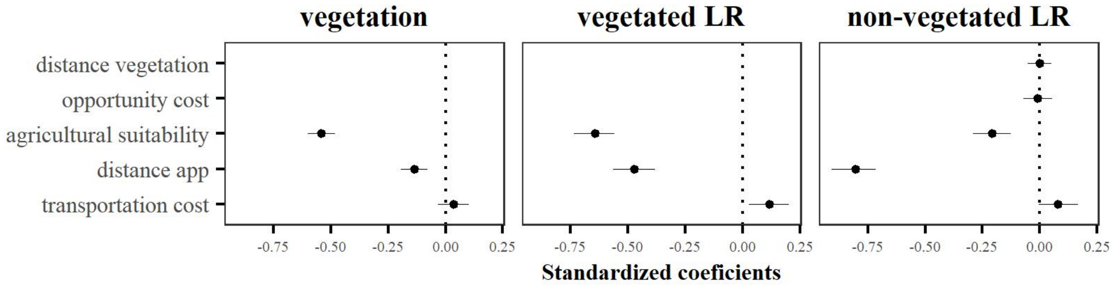


Figure 6 – Parameters estimates with mean (black dot) and credible 95% intervals of the predictors of the location of natural vegetation and Legal Reserve (LR) declared by landowners (N= 2,960), considering three different contrasting situations. We modeled the influence of drivers on the probability of: an area to be covered with vegetation instead of being converted to agriculture; choosing a vegetation patch as vegetated LR; and setting aside an agricultural area as non-vegetated LR.

2.5 DISCUSSION

The major drivers influencing Legal Reserve allocation are vegetation in-farm, property size, transportation costs, and agricultural suitability. Landownders with larger properties that have lower agricultural suitability, higher transportation costs and more vegetation in farm are more likely to invest in Legal reserves. This suggests that economic processes are the primary driver determining landowner decisions around investment in Legal Reserves. We also show that farmers owning properties with low vegetation cover are unlikely to invest in in-farm restoration to achieve Legal Reserve compliance, instead opting for compensation schemes such as purchase credits to compensate their vegetation deficit on other properties. Decisions based on these criteria will result in the concentration of Legal Reserves and native vegetation in private properties of lower agricultural value in the future, while leaving a large number of properties with few areas of forest under protection. This replicates biases in the spatial distribution of public protected areas (VENTER *et al.*, 2018) where areas of marginal agricultural value are disproportionately protected.

This pattern is likely to have significant consequences for biodiversity conservation since marginal agricultural areas very often do not have higher conservation value, i.e. are not places with a large concentration of threatened species (VENTER *et al.*, 2018). Besides, they might fail to preserve species distinct from areas with greater agricultural potential (ROUGET; RICHARDSON; COWLING, 2003). It will also have consequences for the provision of ecosystem services that are affected by the loss of biodiversity (TSCHARNTKE; TYLIANAKIS *et al.*, 2012). Our results suggests a future scenario where areas with lower vegetation cover are much less likely to undergo restoration interventions to restablish Legal Reserves, despite the disproportionate benefits that these actions could yield for biodiversity or provisioning services on these lands (DAINESE *et al.*, 2019). Policies aiming to promote biodiversity and ecosystem services across landscapes will need to provide incentives for landowners to allocate Legal Reserve in ways that provide the largest benefits (Brancalion et al., 2019). In the following sections, we discuss the potential consequences of the current pattern of Legal Reserve allocation and options to improve the implementation of the Native Vegetation Protection Law.

2.5.1 Main drivers modulating Legal Reserve allocation

Reserves being set aside for present and future native vegetation conservation inside private properties were much more likely to be established in areas of low agricultural value and in areas with high transportat costs. The agricultural sector is the most important driver of landscape changes in Brazil, whose economy relies heavily on agriculture (CALABONI *et al.*, 2018; MARTINELLI *et al.*, 2010). Crops occupy areas of high suitability while maintenance of natural vegetation is relegated to areas of marginal suitability. Transportation costs affect input costs and farm profitability (FLIEHR; ZIMMER; SMITH, 2019; TAMM; VÕSA; LOKO, 2010), so a reduction in transportation costs can increase land-value (MIRANDA *et al.*, 2019).

Landowners with larger areas of existing native vegetetation were also more likely to invest in in-farm conservation activities rather than opting for a compensation scheme, a pattern that mirrors that in other regions of Brazil (JUNG *et al.*, 2017). Setting aside remnant forests as Legal Reserve in-farm instead of opting for compensation schemes is an attractive option for farmers for two reasons. First, a restrictive law (Law n. 11.428/2006) forbids deforestation in most situations in the Atlantic forest biome, even on private land, meaning that remnant forests are unlikely to be converted to different uses legally at present. Second, in cases where farmers are allocating Legal Reserve surpluses, the surplus can be traded as Legal Reserve credits with landowners with Legal Reserve deficit, adding monetary value to forests or even to restored forests (SOARES-FILHO *et al.*, 2014).

Further, landowners with more Areas of Permanent Protection (APP) were more likely to allocate areas of their farms as Legal Reserves. This is a consequence of the legislation design since APP are mandatory and must be in-farm. Moreover, they can be deducted from the total Legal Reserve area, reducing restoration requirements, and thus avoiding the conversion of productive areas to forests. In cases where non-vegetated Legal Reserves are being allocated near to APP (but are not overlapping them), farmers may be seeking to avoid subdivisions of the agricultural area by increasing forest patches instead of creating new patches. More fragmented farmland could imply changes in farm's management activities, for instance, difficulting mechanization, and potentially increasing costs. This could favor the formation of more connected vegetation patches and potentially decrease restoration costs through natural regeneration (CROUZEILLES; CURRAN *et al.*, 2016).

In addition to the effect of remnant vegetation and APP, larger properties are more likely to fulfill their Legal Reserve requirements in-farm. As demonstrated for other regions in Brazil, larger properties are more likely to retain natural vegetation (MICHALSKI; METZGER; PERES, 2010; STEFANES *et al.*, 2018), making it easier for them to fulfill the requisites of their Legal Reserve in-farm. Besides, their owners might be more likely to comply with the legislation because of higher profitability (MICHALSKI; METZGER; PERES, 2010) as they tend to own more suitable agricultural land (CASTRO; TEIXEIRA, 2012; RADA; HELFAND; MAGALHÃES, 2019), which require compliance with the law. This and exposure to higher environmental exigencies from international markets can be an important incentive for higher compliance levels among larger landholders (RAJÃO *et al.*, 2020). Using land on the property is a more direct way of complying with the legislation than compensation mechanisms since the latter still lacks proper regulation (MELLO; FENDRICH; BORGES-MATOS; BRITES; TAVARES; ROCHA; MATSUMOTTO *et al.*, s.d.). However, smaller farms with full Legal Reserve within their area are also more likely to set aside surplus areas, probably as an alternative source for future income trading Legal Reserve credits.

The proportion of pasture was negatively related to Legal Reserve allocation. We raise the following potential explanations. First, pastures in the study region, as well as in most pasturelands in Brazil (STRASSBURG; LATAWIEC *et al.*, 2014) are predominantly extensive low productivity land, not driven by markets with high environmental exigencies, such as beef exporting (STRASSBURG; LATAWIEC *et al.*, 2014). They require more area than crops, which could generate resistance from farmers to convert agricultural land into forests. Secondly, financial benefits from ecosystem services provided by natural areas are less evident for cattle breeding (for instance nutrient cycling) than for crops, in which pollination or pest control, for example, are fundamental to many cultivars (BOESING, Andrea Larissa; NICHOLS; METZGER, Jean Paul, 2018). Interviews with cattle farmers in Brazil showed that most of them did not have the minimum Legal Reserve requirement and, while they recognized that having vegetation in the farm might contribute to water provision, they do not believe it can bring financial gains (LATAWIEC *et al.*, 2017). Considering that valuing ecosystem services is determinant in shaping landowner's attitudes towards forest conservation (TISOVEC-DUFNER *et al.*, 2019), this seems to be a plausible explanation to relate pasture to low Legal Reserve allocation. Additionally, land conversion to pasture is associated with land speculation in Brazil (STRASSBURG; LATAWIEC *et al.*, 2014) and pasture areas could be a low-cost management decision to consolidate anthropic areas and avoid vegetation regeneration while awaiting for the increase in land valuation by the market.

Finally, there seems to be a negative effect of land-uses diversity on landowner's decision to declare all Legal Reserve in-farm. The development of modern conventional agriculture is strongly related to farm specialization, mostly due to economy of scale, regional specialization, use of synthetic fertilizers disentangling crop need for livestock waste, and consumer demand for cheap products year-round (BOWMAN; ZILBERMAN, 2013). Given this situation, higher valued farms are generally more specialized and more focused on growing crops or livestock than, for example, combining the two practices. Therefore, specialized farms are probably more sensitive to market pressure and environmental compliance, and consequently, more likely to set-aside Legal Reserves.

2.5.2 Recurrent bias in native vegetation distribution

The conservation in private lands follows similar patterns of those extensively described for public protected areas, mostly allocated in marginal lands for agriculture. Unfortunately, this bias disregards the local and regional importance of forest patches for biodiversity conservation and ecosystem service provision and the benefits that come from restoration in high priority degraded areas (BRANCALION; NIAMIR *et al.*, 2019; METZGER; BUSTAMANTE *et al.*, 2019). There is plenty of evidence in the literature that habitat size and the physical and functional connectivity among patches are fundamental attributes to maintain biodiversity (BOSCOLO; METZGER, 2011; MARTENSEN *et al.*, 2012; UROY; ERNOULT; MONY, 2019), especially in regions that suffered drastic habitat loss and fragmentation, as in the case of the Atlantic forest (JOLY; METZGER; TABARELLI, 2014). On a positive note, our findings suggest that farms already containing natural vegetation are likely to increase their natural patches or at least increase their level of protection. On the other hand, farms with current low vegetation cover are less likely to improve that condition.

The uneven distribution of protected forests in private land will have a direct impact on biodiversity conservation. Tropical priority areas for biodiversity conservation often have unfavorable economic conditions for restoration (BRANCALION; NIAMIR *et al.*, 2019). Forest dependent species that could pottentially occurr on highly productive land might be different from the ones in marginal areas, in particular for a biome with a high level of regional and local endemism such as the Atlantic Forest (MITTERMEIER *et al.*, 2011), and will not be adequately protected (e.g. with habitat amount above minimum required for viable populations) facing the risk of extinction. Furthermore, monocultures within landscapes with low vegetation cover have a deficit in ecosystem services provision (DAINESE *et al.*, 2019), which can negatively impact yields through dilution effects (demand higher than service supply) or insufficient spillover (TSCHARNTKE; TYLIANAKIS *et al.*, 2012). Taking the example of coffee, the most important crop in our study region, pollination has the potential to increase fruit-set between 15-50% (RICKETTS *et al.*, 2004; SATURNI; JAFFÉ; METZGER, 2016), while natural pest control by has also been shown to contribute to fruit-set (ARISTIZÁBAL; METZGER, 2019; CLASSEN *et al.*, 2014) and to substantially reduce herbivory in fruits and leaves (ref. felipe!). Indeed, coffee yields tend to be twice as high in municipalities with 20% or more forest cover than in those with lower forest cover (González-Chaves et al. in prep). This suggests that trend for low-vegetatation areas to become less vegetated into the future could carry significant yield penalties, that could be even further exacerbated by climate change.

Unfortunately, while there is a clear incentive to join the CAR system, the economic incentive of complying with the legislation and in particular to invest in restoration is low (AZEVEDO *et al.*, 2017). As a consequence, the existing uneven pattern of native vegetation distribution tends to be maintained, or even exacerbated, leading to an unbalanced representation of biodiversity, and low ecosystem service provision in the most productive areas.

2.5.3 Securing the role of Legal Reserves

For Legal Reserves to fulfill their roles contributing to private land conservation and agricultural production, the first step is to regulate and fully implement the Native Vegetation Protection Law. In particular, for the Atlantic Rain Forest, this means restoring the 6.8 Mha (4.1 Mha as APP, and 2.7 Mha as Legal Reserve) that were converted to land uses in the past (GUIDOTTI *et al.*, 2017). If the environmental deficit is restored in the Atlantic forest, the biome would surpass the biodiversity threshold of 30% of landscape vegetation cover (Rezende et al., 2018), below which most biodiversity is doomed to extinction (BANKS-LEITE *et al.*, 2014).

Better configuration and spatial allocation of forest patches and Legal Reserve restoration must be also pursued, so that functional distance between forest fragments are reduced (TAMBOSI *et al.*, 2014) and biodiversity flows between crops and natural vegetation are enhanced (González-Chaves et al. 2020). Policies prioritizing this could enhance biodiversity and the provision of ecosystem services such as pollination and natural pest control (ARROYO-RODRÍGUEZ *et al.*, 2020; BENAYAS *et al.*, 2009; BOESING, Andrea L.; NICHOLS; METZGER, Jean P., 2017; DAINESE *et al.*, 2019; GARIBALDI; STEFFAN-DEWENTER *et al.*, 2011), contributing to agriculture yield (BULLOCK; PYWELL; WALKER, 2007; WADE; GURR; WRATTEN, 2008).

To stimulate the adoption of more effective set-aside policies and to increase the number of farmers that are willing to set aside the full Legal Reserve obligation, there is a need for policies that incentivize restoration inside the properties and reduce the demand for compensation, which tends to maintain or accentuate the contrasts in the distribution of native vegetation cover. Market mechanisms like payment for ecosystem services (PES) have already been shown to increase forest cover in private properties in the Atlantic forest through restoration (RUGGIERO *et al.*, 2019) and could be used to achieve this goal (BRANCALION; GARCIA *et al.*, 2016). Besides, to increase PES effectivity with clear targets (WUNDER *et al.*, 2020), landowners who prioritize restoring their legal deficit within their land and are selected for a PES contract could have the value adjusted through ecological criteria. For example, promoting a higher payment for properties located in areas previously identified as a priority for biodiversity conservation (favoring larger and more connected patches of natural vegetation) or for ecosystem service provision (favoring greater interface with productive areas).

To help to reduce the costs of allocating Legal Reserves, some economic activities can also be sustainably developed inside Legal Reserve. Interesting results showed that a consortium of commercial eucalyptus trees for wood production mixed with native species is highly viable (AMAZONAS *et al.*, 2018) and can reduce restoration costs by 44-75% at the Atlantic Forest (BRANCALION; AMAZONAS *et al.*, 2020). Government agencies must assist farmers to develop sustainable Legal Reserve management plans, helping them to diversify their income and turn the cost-benefit of setting aside land more favorable. Non-governmental agencies, which have a central role in providing technical assistance to farms adhering to CAR (JUNG *et al.*, 2017), can also contribute to this matter.

Additional incentives can come from the private sector. The possibility of market restrictions was crucial for the adherence to the CAR database (AZEVEDO *et al.*, 2017) and will likely be the main incentive for landowners to further comply with the legislation. Companies whose supply-chain relies on agricultural products could use compliance adherence to set-aside as criteria for choosing their suppliers, monitoring deforestation at the property level with agricultural exportation (RAJÃO *et al.*, 2020). As a benefit, companies adopting such measurement would reduce their reputational risks.

In conclusion, by using a publicly available centralized database, we were able to visualize private forest conservation trends in Brazil. Our data points to a future scenario in which without government incentives, in-farm forest ditribution will mimic that of protected areas, overwelmingly concentrated in marginal land for agriculture. This situation could be a missing opportunity for farmers to benefit from ecosystem service provision and for biodiversity conservation. The Native

Vegetation Protection Law is a great opportunity for Brazil to adopt a broad scale land-use regulation policy and reverse the negative impacts of land conversion for agriculture. With adequate tools, the compliance with the law can foster synergies between biodiversity conservation and food production. However, it must involve broad sectors of society, such as farmers, industry and the third sector. If well succeeded, such regulation could be a benchmark for other countries adopting ambitious restoration targets to deal with one of the greatest challenges of our times: feed the world, halve biodiversity loss and divert from the most catastrophic scenarios of climate change.

3 WHEN DO BENEFITS FROM ECOSYSTEM RESTORATION OFFSET COSTS?

Francisco d’Albertas, Gerd Sparovek, Luis Fernando Guedes Pinto, Camila Hohlenwerger, Jean Paul Metzger

This chapter was submited to Nature Sustainability and is currently under consideration by the editor. **Date: include date on the latest status!**

3.1 ABSTRACT

Restoration is a critical tool for reversing biodiversity declines and mitigating climate change. However, it is a costly intervention. Where restoration provides significant financial benefits, such as by increasing crop yield or providing carbon credits, these costs may be offset. Focusing on a restoration hotspot in the Brazilian Atlantic Forest, we develop restoration scenarios and calculate estimations of their financial balance to understand conditions where restoration costs might be compensated by yield and carbon credit-derived benefits. Our study suggests that restoration costs can be offset by yield increases when farms already have >10% forest cover and restoration targets are below 25% forest cover. Current CO_2 price is not sufficient in offsetting net costs for higher restoration targets. A carbon value of 35-124 USD/ton would be required to promote restoration. The identification of balanced financial conditions, that create landscapes suitable for biodiversity conservation, climate mitigation, and agricultural production, has broader implications and is strategic to scale up restoration.

3.2 INTRODUCTION

Habitat loss (TILMAN *et al.*, 2017) and climate change (FODEN *et al.*, 2013) threaten biodiversity globally, but clear restoration targets can greatly reduce species extinction risk (LECLÈRE *et al.*, 2020; STRASSBURG; IRIBARREM *et al.*, 2020) and simultaneously improve biodiversity conservation and human wellbeing(BARRAL *et al.*, 2015; BENAYAS *et al.*, 2009; BULLOCK; PYWELL; WALKER, 2007; REY BENAYAS; BULLOCK, 2012; SHIMAMOTO; BOTOSSO; MARQUES, 2014; WADE; GURR; WRATTEN, 2008). Many countries have made ambitious restoration commitments for the current UN decade on restoration, including to restore 350 Mha of degraded land by 2030 under the Bonn Challenge (ERBAUGH *et al.*, 2020). However, these actions face important difficulties to be implemented given the high costs involved. These include direct restoration costs, fencing and opportunity cost of forgone production. Recent work has highlighted that these costs can act as a major financial barrier to the wide-scale adoption of restoration [Brancalion, Meli *et al.* (2019); groot_benefits_2013].

However as well as costs, farmland restoration can also deliver ecosystem service and yield benefits, e.g. via crop pollination and pest control. In some cases, these benefits can be substantial, such as for coffee production. Several studies have demonstrated the importance of landscape native vegetation cover and the proximity between coffee fields and natural areas in modulating the flows of pollinators and natural pest controllers, which can increase coffee yield by 10 to 30% (ARISTIZÁBAL; METZGER, 2019; GONZÁLEZ-CHAVES; JAFFÉ *et al.*, 2020; LIBRÁN-EMBID; DE COSTER; METZGER, 2017; RICKETTS *et al.*, 2004; ROUBIK, 2002; SATURNI; JAFFÉ; METZGER, 2016; MOREAUX *et al.*, 2022). Restoration also can deliver large carbon benefits. Restored tropical secondary forests have the potential to sequester an average of 3.05 tons of carbon ha-1 year-1 from the atmosphere throughout 20 years (POORTER *et al.*, 2016). Carbon stock is a critical regulation service that benefits people globally and can be traded in carbon markets, helping to compensate restoration costs. Yet, from our knowledge, few studies (BRADBURY *et al.*, 2021) have incorporated the benefits of restoration in farmlands to the cost analyses, nor have they explored the situations under which these benefits may prove substantial enough to overcome costs. Once the effects of restoration on yield and in farm income can offset at least partially restoration costs, understanding the factors that play a role in this cost/benefit balance is key to inform landowners and support decision making and agri-environmental policies.

Here, we explore how much, and under which conditions, benefits from ecosystem restoration can offset costs. We do so in the Brazilian Atlantic Forest, a globally iconic biome (LAURANCE, 2009), a restoration hotspot (BRANCALION; NIAMIR *et al.*, 2019), and one of the leading coffee regions of Brazil. Coffee is among the top 20 commodities traded globally (FAO, 2019) and Brazil is its major producer and exporter. We developed a set of scenarios with different on-farm restoration targets and calculated a detailed estimation of their financial consequences to understand how and when the costs of ecological restoration might be compensated by restoration-derived yield benefits, carbon credits, and agricultural credit lines. We have combined ecological data on how restoring natural habitats can improve ecosystem service provision with economic assessments on the balance of restoration costs and benefits. Our work can provide a framework for identifying circumstances where restoration benefits can outstrip costs, helping meet global restoration commitments and to promote restoration within agricultural landscapes.

3.3 STUDY SYSTEM AND SCENARIO CONSTRUCTION

Restoration commitments in Brazil are guided by a legal obligation dictated by the Native Vegetation Protection Law (Law 12.651/2012), which drives and enforces how, where and how much native vegetation should be conserved, managed, or restored within farms (MELLO; FENDRICH; SPAROVEK *et al.*, 2021; MELLO; FENDRICH; BORGES-MATOS; BRITES; TAVARES; ROCHA; MATSUMOTO *et al.*, 2021). All rural properties within the Atlantic Forest must have a minimum of 20% of the area set aside as natural vegetation. This is composed of Areas of Permanent Protection (APP), whose location is defined by the legislation (environmentally sensitive areas, such as riparian areas, hilltops, and steep slopes) and Legal Reserves allocated by landowners to achieve the minimum set-aside target of 20%. Farmers who do not have the mandatory area covered with natural vegetation must restore it within 20 years, or in the case of Legal Reserves, opt for a compensation scheme outside their property – e.g. trading with landowners with Legal Reserves surplus (MELLO; FENDRICH; SPAROVEK *et al.*, 2021; MELLO; FENDRICH; BORGES-MATOS; BRITES; TAVARES; ROCHA; MATSUMOTO *et al.*, 2021). The spatial information concerning farm boundaries and set-aside areas is uploaded to an environmental rural register platform named CAR (Portuguese acronym), a public access database.

To analyze the cost-benefit relationship incurred by restoration actions, we designed 8 scenarios with a time window of 20 years, based on the Native Vegetation Protection Law, and more ambitious commitments (Methods). Our **baseline scenario** represents the 2017 land-use and land-cover situation. In four additional scenarios, we set forest cover targets at the farm-level, ranging from 10-40% with 10% increment, including targets above the 20% required by the law (**farm-level restoration scenarios**). Finally, to test the performance of designating restorations at a regional instead of farm-scale, we simulated three **regional-level restoration scenarios** where we combined the area of all focal farms and set three targets (20, 30, and 40%) so that the combined farms-area would have achieved the defined target at the regional scale. This regional approach favors restoration within farms with lower restoration costs in the region, while high-cost farms compensate for their forest deficit. For the farm and regional level scenarios, we used a prioritization algorithm (HANSON *et al.*, 2020) that applies linear programming to find optimal solutions to achieve the targets, whilst minimizing restoration costs incurred by farmers.

The scenarios were applied to 507 farms from 58 municipalities selected in one of the most traditional areas for coffee production in the country (Figure 7), responsible for 22% of the national production and ~7% of the global production (2019 data from the International Coffee Organization and the Brazilian Institute of Geography and Statistics-IBGE). This region is within the Atlantic Rainforest biome, recognized as one of the world's largest biodiversity hotspots. Our focused farms ranged from 7-2,000 ha in size (mean= 233 ha).

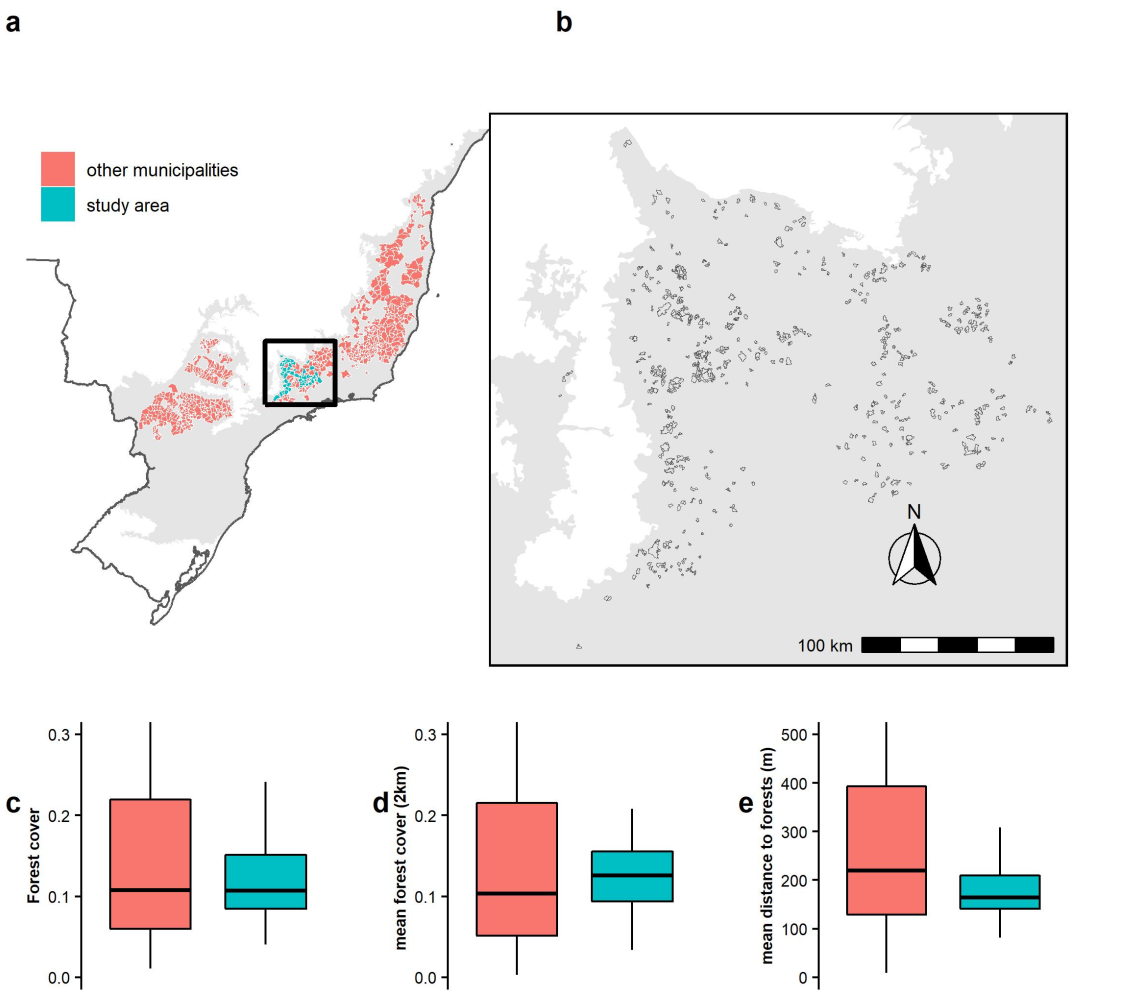


Figure 7 – Study system map showing the municipalities where coffee is produced in the Atlantic Forest, the spatial distribution of our focused farms, and the distribution of forests within the municipalities. Municipalities (n=622) within the Atlantic Forest (gray shade) that grow coffee (a); zoom on our study region (n=58 municipalities) and focal farms boundaries (hollow lines) (b). Although broadly similar to coffee-producing municipalities elsewhere in the Atlantic Forest, with nearly the same average forest cover (c), our focused municipalities have 21 % higher median forest cover surrounding coffee fields (0.10 vs. 0.12; d), and coffee fields are on average 33 % closer to forest patches (163.8 m vs. 219.3 m; e). The boxplots on figures c-e show the lower quartile, the median, and the upper quartile of the data distribution. Data from Gonzales-Chaves et al (2021).

We estimated the immediate cost of allocating areas for restoration as a sum of restoration costs and the opportunity cost of foregone production (Supplementary Figure B1), hereafter named total restoration costs. Restoration costs for the 20 years were estimated using a 30 m resolution raster containing the probability of natural regeneration or the necessity of actively planting seedlings (CROUZEILLES; BEYER *et al.*, 2019) and costs with restoration from projects within the Atlantic Rainforest (BRANCALION; MELI *et al.*, 2019) (Methods). The forgone production was calculated as a combination of the net present value over 20 years of the main crops grown in the region and the spatial distribution of crops and pasture (see Methods for details). We also explored consequences of restoration scenarios on coffee production, accounting for changes in area under production and changes in coffee yield, which we parameterized using a coffee-yield model relating landscape metrics to coffee productivity (Methods). This model, allowed us to realistically forecast restoration-derived changes in yield outcomes.

We also considered compensation payments, based on the Native Vegetation Protection Law, which established a market for Legal Reserves (Methods). Total restoration costs, opportunity cost based on our yield model, and compensation payments were combined and will hereafter be referred to as total intervention costs. For carbon sequestration calculation, we used literature data to estimate aboveground (POORTER *et al.*, 2016) and belowground (ZANINI *et al.*, 2021) carbon sequestered over 20 years in each scenario (Methods).

3.4 RESULTS

Opportunity cost and restoration cost increased substantially with the proportion of area targeted for restoration (Figure 8 a and b; Supplementary Figure B2a and B2b), mostly due to the increasing coffee area converted to forest (Figure 8c; Supplementary Figure B2c). Most scenarios had a marginal increase in yield in comparison with the baseline scenario (Figure 8d; Supplementary Figure B2d). However, for scenarios with restoration targets >20%, yield increases did not increase total production enough (Figure 8e; Supplementary Figure B2e) to compensate for the replacement of coffee-planted areas with forest. Scenarios rl30 and rl40 had an unexpected average decrease in yield. Those later scenarios resulted in concentrated forest patches, favoring situations of high forest cover (>50%) and very low coffee cover (<10%) (Supplementary Figure B3), even though the average distance from the nearest forest did not vary significantly among scenarios (Supplementary Figure B4). Farms in a similar situation used to build our predictive yield model had lower yield (Supplementary Figure B5), which can be a consequence of a lower productivity potential where they are located (see Supplementary Material), as described previously in the Atlantic Forest region (GONZÁLEZ-CHAVES; CARVALHEIRO *et al.*, 2021).

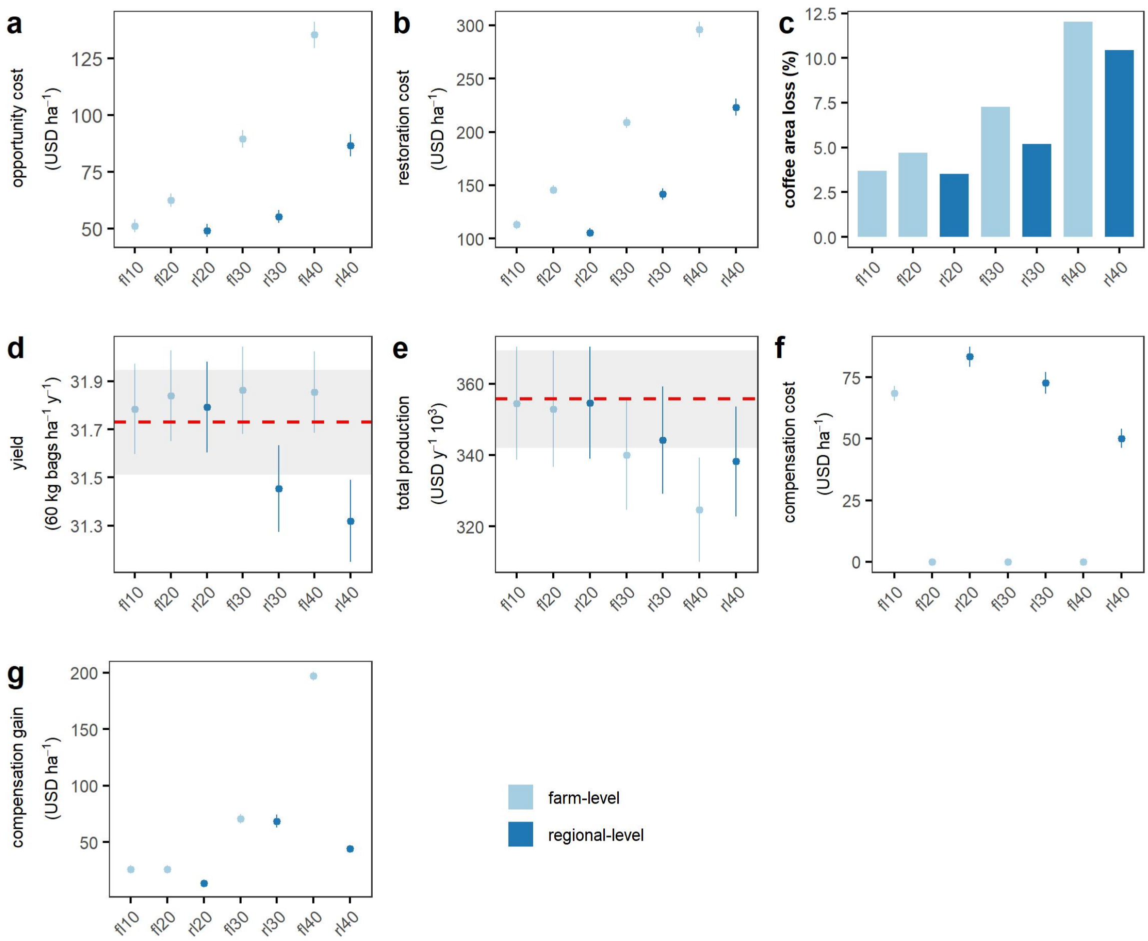


Figure 8 – Average cost and benefits used to calculate the final cash flow after the restoration interventions in each scenario. (a) Mean opportunity cost with forgone production of non-coffee products divided by farm area; (b) Mean restoration costs over 20 years divided by farm area; (c) Total coffee area loss in comparison with the baseline scenario; (d) Mean coffee field yield estimated with our spatial yield model; (e) Mean total coffee production estimated with the yield model; (f) Compensation costs divided by farm area for farms with forest cover < 20 % after the restoration intervention; (g) Compensation gains divided by farm area for farms with forest cover > 20 % after the restoration intervention. The mean values are presented with 95 % confidence interval. The red dotted line represents the baseline scenario and the gray shade is the 95 % confidence interval. Farm-level = fl; regional-level=rl.

There were three scenarios for which we did not find reductions in production after 20 years and where coffee yield showed a slight increase (Figure 8e; Supplementary Figure B2e): fl10, fl20, and rl20. Under these scenarios, restoration actions were more advantageous economically, and the relationship between costs and benefits was more balanced (Figure 9). In addition to the changes in production, we also computed forest compensation costs and gains – when farmers trade their Legal Reserve surplus and deficit to achieve legal compliance (Figure 8f-g; Supplementary Figure B2f-g). However, compensation schemes represented a small fraction of the cash flow associated with the interventions (Figure 9), which were predominantly a result of changes in production, suggesting that losing coffee areas was the main financial challenge posed by restoration in the region.

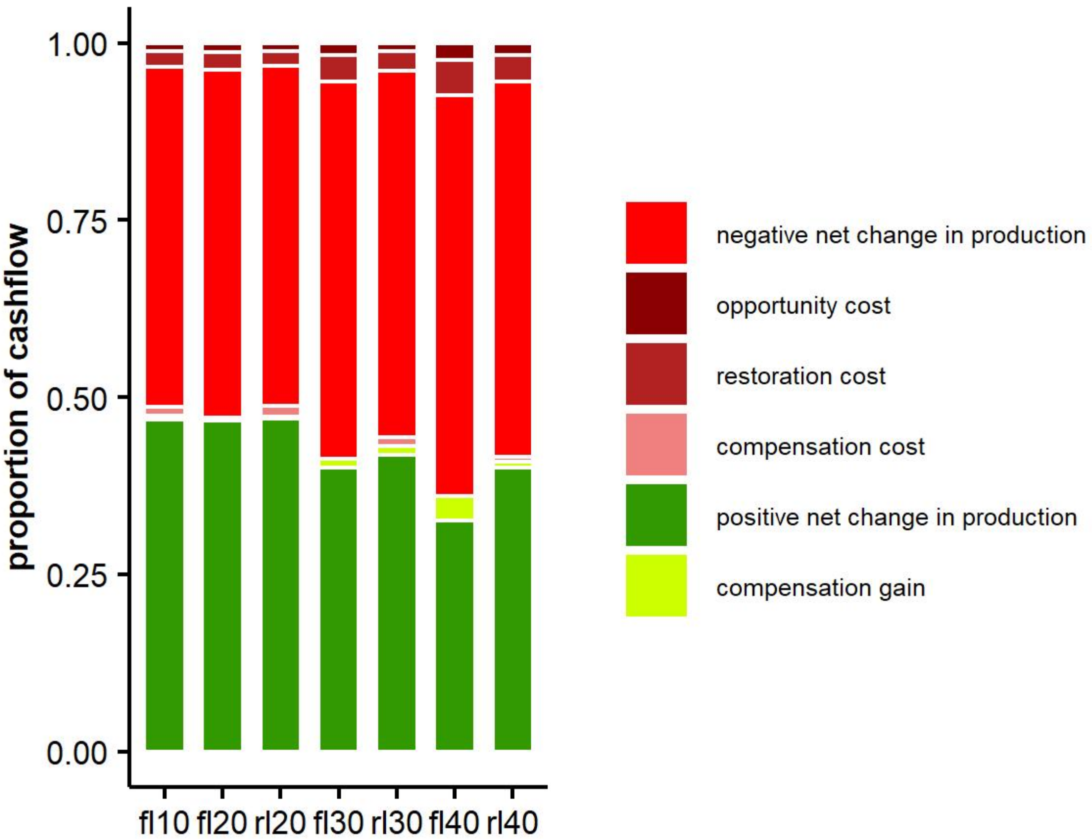


Figure 9 – Proportional of the cash flow represented by the intervention costs. The costs are shown in shades of red – opportunity cost, restoration costs, negative changes in production, and compensation costs – and the gains in green shades – compensation gains and positive net changes in production. Farm-level = fl; regional-level=rl.

The overall financial balance for all scenarios was negative. For example, achieving legal compliance enforcing farm-level forest cover (fl20) without offsite compensation would imply an average cost of USD 63,719 per farm, or around USD 32 million in total to add ~ 12 thousand ha of forest above the baseline (Figure 10a). However, when we considered the farm's forest cover at the baseline, we found that for farms that already had at least 10% forest cover, yield increase outweighed total intervention costs for some scenarios. As a result, there was an average increase of up to a 1.7% in net income in comparison with the baseline scenario for scenarios fl10 ,fl20, and rl20 (Figure 10b; Supplementary Figure B6). For farms with forest cover below 10%, total intervention costs outweighed potential benefits with yield increase (Figure 10c). These results suggest that for our study region, compliance with the Native Vegetation Protection Law would have net financial gains for farms with > 10% of forest cover. However, farms with <10% forest cover and scenarios with more ambitious restoration targets (>20%) had 3 to 16.6% decrease in farm income, reflecting the negative net change in production and the high restoration costs.

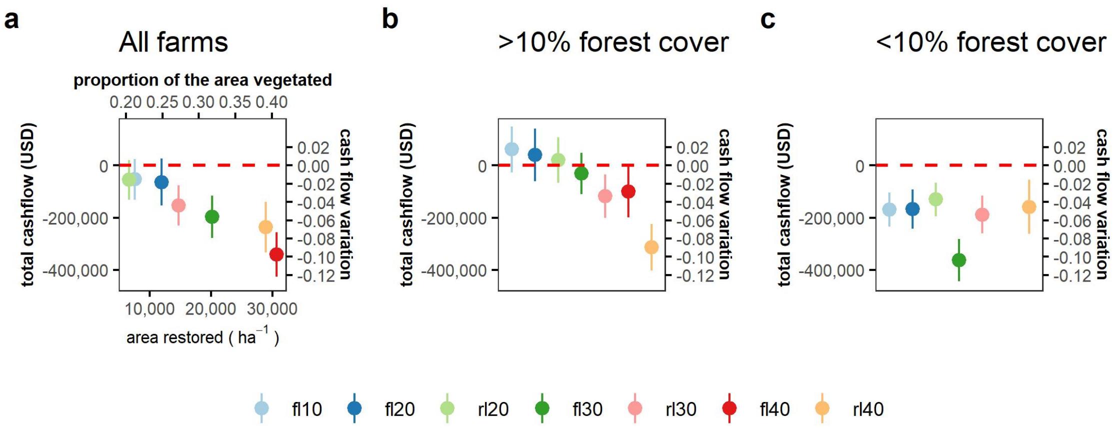


Figure 10 – Mean total cash flow estimates for each scenario. (a) Average farm cash flow and the ratio between mean cash flow and farm income in the baseline scenario (cashflow variation) ± 95 % confidence interval. The cash flow is plotted against the proportion of the farm's area vegetated after the interventions and the total area restored. The red dotted line represents the baseline scenario. Farm-level = fl; regional-level=rl. We split the farms in two groups: (b) farms with total vegetation cover >10% prior to the restoration (n=253) and (c) farms <= 10% vegetation cover (n= 254).

Regional-level scenarios on average led to lower net costs compared to farm-level scenarios, but with less area restored. Interestingly, the regional approach enables legal compliance with lower costs even with compensation schemes concentrated on the region ("local market"), while the farm-level approach favors a higher forest cover (around 25% of the region; Figure 10a and Supplementary Figure B6) and a lower degree of fragmentation (in total number of fragments), but with forest cover more concentrated in smaller forest patches (Figure 11). In farm-level scenarios, restoration tends to be done in small areas and as an extension of existing fragments. With a 20% target – which would guarantee legal compliance without compensation outside our study region – the regional approach had an average cash flow 14% higher than the farm-level approach but restored nearly half the area (6,600 ha vs. 11,940 ha; Figure 10a). This is because to meet a regional target, only 7% of additional forests were required, once remnant forest areas at the farms already summed 14% of the region at the baseline. On the contrary, for farms with >10% forest cover, the farm-level approach (fl20) had a higher cash flow (Figure 10b) and is the win-win scenario, in which both benefits and forest cover are maximized.

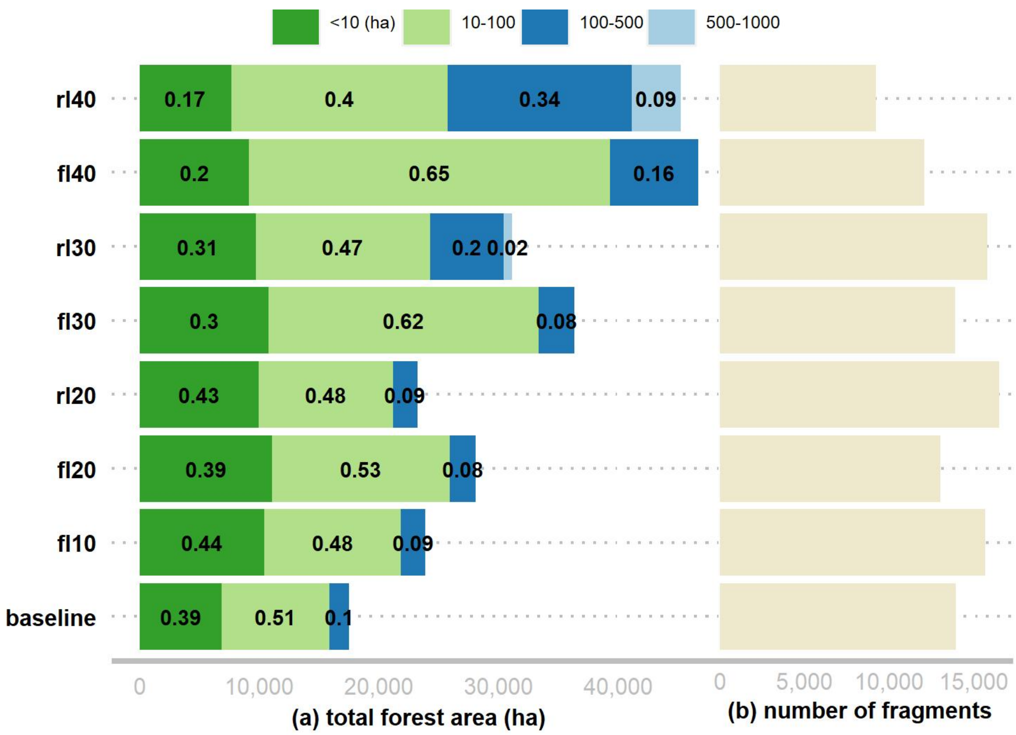


Figure 11 – Distribution of forests for each scenario. Total forest area (restored and remnant forest combined) within farms boundaries (a) and total number of forest fragments (b). Farm-level = fl; regional-level=rl. Fragments in figure (a) were grouped in five size classes based on their area, in hectares, as shown in the color legend.

Compliance with the Native Vegetation Protection law has the potential to remove 2,6-4,2 million tons of CO_2 from the atmosphere in our focal farms, which would require USD ~283-312 million investment to compensate net costs (Figure 12). If we assume a carbon value at current levels (~4 dollars/ton) (DONOFRIO *et al.*, 2020), our focal farms would have access to ~ USD 10 – 43 million of restoration compensation, depending on the scenario. This represents a small fraction (~3-11%) of net intervention costs. To offset net restoration costs with carbon markets, we estimate that the ton of CO_2 would have to be traded between USD 35-124, depending on the scenario. While the amount of carbon sequestered had a four-fold increase from lower (10%) to higher (40%) forest cover target scenarios, the total net costs increased only 1.36 fold. As a consequence, the estimated value of carbon to offset restoration costs turned out to be higher in low to intermediate forest cover scenarios (fl10 and, particularly, rl20).

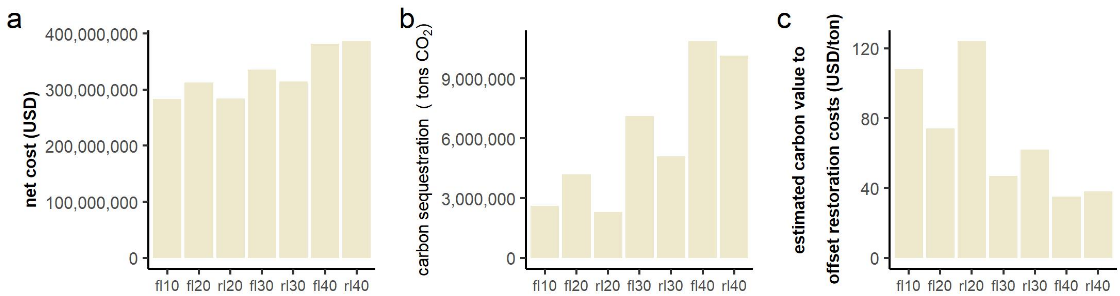


Figure 12 – Potential carbon sequestration and the estimated value of carbon to offset restoration costs in the different scenarios. We used literature data (see Methods) to estimate (a) the above and belowground carbon sequestered by restored forests after 20 years. The net intervention cost (b)was calculated as the sum of all farm's negative cash flows in each scenario. With net costs and carbon sequestered, we estimated the carbon value to offset restoration costs (c).

3.5 DISCUSSION

Our scenarios suggest that over 20 years, the costs of forest restoration within farms – including direct costs, opportunity costs, and changes in production – can be offset by ecosystem services benefits when restoration results in coffee yield increases. This offset condition occurs particularly when farms have >10% forest cover at the baseline. Those farmers who had historically deforested a smaller fraction of their land and had smaller legal forest cover deficits had a net financial benefit in complying with legal restoration mandates, whereas farmers who had deforested more land faced a financial burden. There is a clear threshold around 25% forest cover above which additional restoration substantially increases costs; more ambitious restoration targets (30% or more) resulted in a net financial loss for farmers up to 16% of farm's income. When comparing the cost-benefit of targeting restoration on the farm with a regional planning approach, we found that while a regional approach favored achieving restoration targets with smaller costs, targeting restoration at the farm level has led to disproportionally higher forest cover and even a higher net benefit (when farms had >10% forest cover on the baseline).

The 25% forest cover threshold is near the 30% biodiversity extinction threshold for the Atlantic Forest (BANKS-LEITE *et al.*, 2014), and within the required range of vegetation cover needed to maintain biodiversity in working landscapes [20-40%; Garibaldi, Oddi *et al.* (2020); Arroyo-Rodríguez *et al.* (2020)]. For more permeable matrices such as coffee, the threshold is estimated to be closer to 20% (BOESING, Andrea Larissa; NICHOLS; METZGER, Jean Paul, 2018). Our results support the feasibility of maintaining this minimal amount of native vegetation– around 25% (GARIBALDI; ODDI *et al.*, 2020; ARROYO-RODRÍGUEZ *et al.*, 2020) — suggesting the more economically advantageous restoration scenarios may be enough in reducing extinction debts for threatened biodiversity in those landscapes. The cost of reaching this target can be offset by the benefits of restoration, at least in some scenarios. The compliance with the Native Vegetation Protection Law could thus not only contribute to reducing extinction risk but also can provide economic benefits through productivity gains mediated by ecosystem services provision. Furthermore, the restoration-mediated benefits to yield we observed on our farms may be higher in other regions. Our focused municipalities already have high forest cover surrounding coffee fields, which were on average closer to forest patches in comparison to other areas (Supplementary Figure B7a). Coffee yield on local experiments was estimated to be 15-20.8 % higher on fields closer (< 800 m) [Ricketts *et al.* (2004); marco_services_2004] or in contact with forests (LATINI *et al.*, 2020). Some municipalities elsewhere also grow pollinator-dependent C. canephora, which is expected to be more sensitive to pollination supply increase mediated by forests González-Chaves, Carvalheiro *et al.* (2021). Thus, our results are likely to be conservative estimates of derivable restoration benefits.

Beyond coffee, several other crops are benefited by ecosystem services and are likely to have positive yield effects from an increase in forested areas within agricultural landscapes. Taking pollination as an example, for which the benefits for agriculture are more evident, crops such as soybean, rapeseed, apples, and many other fruits depend on this service (KLEIN *et al.*, 2007). Globally, pollination contributes to ~70% of the leading food crops, which account for ~35% of all production (KLEIN *et al.*, 2007). In Brazil, the economic contribution of pollination represents 30% of the total annual agricultural income with pollinator-dependent crops, half of it from soybean (GIANNINI *et al.*, 2015). This way, our findings have broader implications for other systems across the world.

3.5.1 Farm-level vs. regional approach

We found that a regional planning restoration governance tool was a useful restoration strategy for farms with low forest cover (<10%) to achieve the 20% target. In such a situation, the regional approach had a more advantageous cash flow in comparison with the farm-level approach for the same target. This was true even with compensation schemes – when landowners with farms below 20% forest cover pay to compensate their forest debt elsewhere – concentrated on the region. Regional planning also favored larger and more concentrated forest patches, which can be beneficial for biodiversity (CHASE *et al.*, 2020). Currently, there are no established mechanisms for regional planning (MELLO; FENDRICH; BORGES-MATOS; BRITES; TAVARES; ROCHA; MATSUMOTO *et al.*, 2021) — for instance, farmers are allowed to trade Legal Reserves across the entire Atlantic Forest. However, our results indicate that restoration planning would still be cost-effective if applied on a more regional scale. Moreover, whilst our prioritization approach only minimized costs, regional policies could also better design landscapes additionally increasing yield gains, creating landscapes to optimize service provision too.

On the other hand, we found the farm-level approach resulted in an overall larger forest amount, more evenly spread among the farms. For less sensitive species, habitat amount per se, even spread into a mosaic of forest patches, can be more important than fragment size (ARROYO-RODRÍGUEZ *et al.*, 2020). Similarly, for ecosystem services provided by mobile organisms, we expect this approach to be better by reducing the distance between natural areas towards crops (METZGER; VILLARREAL-ROSAS *et al.*, 2021; MITCHELL *et al.*, 2015). It would also reduce natural vegetation location bias exclusively on marginal areas for agriculture, which does not necessarily overlap with priority areas for conservation (BRANCALION; NIAMIR *et al.*, 2019; ALBERTAS; GONZÁLEZ-CHAVES *et al.*, 2021).

3.5.2 Carbon credit and additional governance actions

Although we estimate that there can be economic benefits with restoration, they are relatively long-term while the costs are immediate, which can discourage farmers from restoring their land. Carbon markets can be a complementary strategy to stimulate farmers to set aside land for conservation. However, current CO_2 prices averaging 4 USD per ton [@]1 would not be enough to offset intervention net costs. This value would have to rise to USD 72-124 per ton for legal compliance (around 20% forest cover), and USD 38-47 for more ambitious scenarios (>30% forest cover). This cost range is considerably higher than previous estimates about the value required to offset restoration projects within the Atlantic Forest (USD 18-20 per ton of CO2 removed) [@]47, reflecting the elevated opportunity cost of our study region. Nevertheless, they converge with estimates demonstrating that higher carbon prices (USD 20-50) will be needed to help make tropical forest restoration economically balanced in costs and benefits for landowners [Busch *et al.* (2019); strassburg_strategic_2019]. Another relevant aspect to consider is that the net cash balance is not homogeneously distributed among farms, making fixed carbon prices unfair. A better strategy would be to remunerate farmers proportionally to their restoration expenditures, though such policy would require a technical and socioeconomic challenge of paying neighbors different values according to their expected net expenditures with restoration.

It is also important to increase the offer of financial options for restoration, especially to account for other ecosystem services (BARRAL *et al.*, 2015; BENAYAS *et al.*, 2009; WADE; GURR; WRATTEN, 2008), such as increased soil quality [@]6 and water supply (TEIXEIRA *et al.*, 2021). Policies to account for multiple ecosystem services, such as payment for ecosystem services, must be considered, in which case restoration is expected to deliver net benefits (DE GROOT *et al.*, 2013; BRADBURY *et al.*, 2021). Additionally, a large portion of the costs incurred with the interventions was related to changes in production due to agricultural land being converted to forest, without any revenue. Our restoration simulation focused on native forests, but the expansion of coffee agroforestry systems (instead of restoring only native forests) can be profitable (GONCALVES *et al.*, 2021) and still host 65% more species richness than plantations(DE BEENHOUWER; AERTS; HONNAY, 2013). A mixed scheme, with forests and agroforestry, would help dilute restoration costs. A consortium of commercial eucalyptus trees for wood production mixed with native species is also a viable option (AMAZONAS *et al.*, 2018) and can reduce restoration costs by 44-75% (BRANCALION; AMAZONAS *et al.*, 2020).

3.5.3 Conclusion

Our results show that for a traditional coffee-producing region within the Brazilian Atlantic Forest, a command-and-control governance tool to enforce restoration within farms does not necessarily incur financial losses. Depending on the initial vegetation cover and the target to be reached, it can even provide marginal benefits for farmers besides contributing to the maintenance of biodiversity in working landscapes and helping to capture a relevant amount of carbon. However, additional policies such as carbon markets and financing restoration activities are vital to make restoration action broadly feasible and immediately attractive for farmers. This illustrative study case on how target restoration will impact agricultural production on working landscapes in tropical regions can be applied and expanded to other landscapes worldwide to understand how much and in which conditions benefit from ecosystem restoration can offset costs.

3.6 METHODS

3.6.1 Study area

Our study focused on the “Mogiana” and “Sul de Minas” region, one of the most traditional areas for coffee production in the country, responsible for 22% of the national production and ~7% of the global production (2019 data from the International Coffee Organization and the Brazilian Institute of Geography and Statistics-IBGE). We downloaded farm boundaries from a government self-declaratory public-access database, named CAR (Portuguese acronym for environmental rural register), in which each landowner delimits their property boundary and the size and location of their Legal Reserves and Areas of Permanent Protection. We filtered the properties excluding the ones with > 10% overlap, small properties – which are not required to restore their Legal Reserves – and properties outside the Atlantic Forest boundaries. Then, we crossed the remaining properties with vector files with the distribution of coffee fields compiled by Brazilian agronomic institutions (CONAB and EMATER) for the year 2016. We applied a coffee cover proportion threshold of at least 0.125 for the properties, which kept 90% of the coffee planted area but reduced by 48% the number of properties. After filtering the data, we ended up with 507 properties ranging from 31 –2,500 ha in size and covering a total area of nearly 120,000 ha.

For this region, we produced a land-use and land-cover map with 30 m resolution combining three sources: a 30 m resolution raster with the spatial distribution of crops and pastures from Freitas et al. (FREITAS; SPAROVEK *et al.*, 2018); a forest cover raster with 5 m resolution (FBDS, 2013); and the coffee cover vector data.

3.6.2 Restoration financial impacts

We estimated the immediate costs in the allocation of forests for our as a sum of restoration costs and the opportunity cost of foregone production combined in a spatial surface with 30 m resolution (Supplementary Figure B1), hereafter named total restoration costs. The forgone production was calculated as a combination of the net present value (NPV) over 20 years of the main crops grown in the region, according to IBGE 59and the spatial distribution of crops and pasture. The NPV is the sum of all cash flows within a determined period in the future, after applying a discount rate, and it is mainly used to determine if an investment will be profitable or will result in loss. It was calculated according to equation 1:

$$(1) NPV(i,N) = \sum_{t=0}^{N} = \frac{b-c}{(1+i)^t}$$

where the benefits (b) are the cash inflows and the costs (c) are the cash outflows of each activity, i is the discount rate and t is the time in the future, in years, for which the present value is being calculated. After accessing the yield per municipality (IBGE, 2017), we have calculated the cash flow using production costs and gains from the mains crops (CONAB, 2017) and beef and milk production (CEPEA, 2017) for each municipality for the year 2017. We have applied a discount rate of 8%, following interest rates practiced by agricultural credit financial institutes in Brazil and previously used in similar studies (NIEMEYER *et al.*, 2019a). We considered a time frame of 20 years, which is the time required by the Natural Vegetation Protection Law for restoration projects to be fully executed. The values were converted to USD using a conversion rate of 3.21.

Restoration costs for the 20 years were estimated considering the probability of natural regeneration and costs with active restoration. The probability of natural regeneration was based on Crouzeilles et al.(2019), who calculated pixel-level natural regeneration potential for the entire Atlantic Forest as a function of environmental and socioeconomic factors. Costs with restoration for the Atlantic Rainforest were assembled by Brancalion et al (BRANCALION; MELI *et al.*, 2019). In the present study, we considered total planting cost (planting of seedlings) as USD 2041.27 ha^{-1} and assisted regeneration costs (natural regeneration with fences) as USD 344.07 ha^{-1}. We integrated those costs on a spatial surface with 30m resolution following equation 2:

$$(2) r = (1 - p) * c + p * a$$

where p is the probability of natural regeneration, c is total planting cost per ha, a is assisted regeneration costs per ha and r is total restoration cost ha-1per 20 years.

We solved the prioritization problem using the *prioritzr* package (HANSON *et al.*, 2020) with Gurobi solver (GUROBI OPTIMIZATION; LLC, 2020). The problem was defined with a minimum set objective, here aiming to minimize costs and a relative target which defined our scenarios. The relative target was calculated as the difference between the farm (farm-level restoration scenarios) or region's (regional-level restoration scenarios) current forest cover and the final forest cover desired for the scenarios (10-40% range). Because APP locations are mandated by the legislation, we also included a constrain to the algorithm to convert first APP areas and then continue with the prioritization process (locked in constrain). After solving the prioritization problems and generating the different land-use and land cover associated with each scenario, we explored the consequences in terms of: combined extent and patch sizes of the resulting natural habitat; costs of restoration, and opportunity cost. For the costs of restoration, we applied an economy of scale factor related to the size of the restoration project within each farm, using parameters from Strassburg et al.(2019):

$$(3) d = 0.8068 + 0.3212 * log(x)$$

where d is a multiplicative factor ranging from 0-1 against the total restoration project area (x). The equation was fitted with a generalized linear model with a Gamma probability distribution. We applied this equation for each property in each scenario, using the area restored on-farm and multiplied restoration cost per property by d to obtain the final restoration cost with a discount.

To explore the restoration effect on coffee production, we developed a coffee yield model described in the next section, to calculate a more accurate change in yield. To avoid double-counting coffee forgone production, we subtracted the forgone cost for coffee patches converted to forest (which occur on some few occasions) in each scenario based on the static cost used to generate the scenarios and considered the coffee production values estimated with the yield model, which, at the property level, could be positive or negative.

To account for compensation schemes, for farmer's intentions and farm-level scenarios, we considered a value of USD 161 ha^{-1} $year^{-1}$, which was the average value for Legal Reserves from the States of São Paulo and Minas Gerais traded on an online platform(`https://www.bvrio.org`). Based on this value, we calculated the net present value over 20 years, considering the same discount rate applied for forgone land-uses. For our regional-level scenarios, we used the same value for standing forests at the region and the total restoration costs we calculated for restored forests surpluses (> 20% of the property with forests), which we considered for trading schemes – instead of allowing compensations to happen on standing forests outside our focus farms — to keep all compensation within the region.

3.6.3 Modeling yield

To generate a yield model that we could use to estimate the coffee yields associated with each of our scenarios we first visited 16 farms in the region and collected yield data (60 kg bags ha^{-}1per harvest) from 92 coffee fields (0.35- 48,3241 ha) for different years between 2004-2018 (Supplementary Table B1). Since coffee is bi-annual, with one large harvest followed by a low yield harvest, to make the data comparable, we selected the maximum yield value per coffee field as a proxy for the large harvest. Our dependent variable is the yield per field in the major season. As independent variables, we considered: landscape variables, using a multiscalar approach to detect the most suitable scales; and local variables (Supplementary Table B2). We did not include Climatic variables because a preliminary analysis revealed our focal farms are all within high suitable areas for coffee grown in terms of rain and temperature. For our final model, we fitted a hierarchical Bayesian model allowing the intercept to vary among year and coffee field, using a negative binomial probability distribution, using the r package *brms* (BÜRKNER, 2017) (R^2_c= 0.49,R^2_m=0.43; details on models construction and selection of the final model on Supplementary Material, Supplementary Figure B5, Supplementary Tables B3 and

B4):

$$yield/ha \sim \mathrm{NB}(\alpha_{Fl[i]} + \alpha_{Y[j]} + \beta C_{1km} + \beta F_{1km} + \beta C_{1km} : \beta F_{1km} + \beta F_{300m} + \beta PA)$$

where Fl is the field, Y is the year, C is the proportion of coffee on 1 km buffer, F_1km is the proportion of forest on 1 km buffer, F_300m is the proportion of forest on 300 m buffer, PA is the coffee field perimeter-area ratio (m/m2), and i and j are the identity of the field and the year from where yield data was collected.

3.6.4 Carbon

We obtained aboveground biomass (AGB) for restored forests using Poorter et al., equation (2016), which estimates secondary forests tree biomass accumulation on the Neotropics over 20 years in function of annual rainfall, rainfall seasonality, and the climatic water deficit (CWD):

$$(5) AGB = 135.17 – 103,950 * \frac{1}{rainfall} + 1.521983 * rainfallseasonality + 0.11448 * CWD$$

The climatic data was downloaded from an online database containing daily high-resolution (0.25 x 0.25 degrees) gridded meteorological data for Brasil from 1980-2016 (XAVIER; KING; SCANLON, 2016). We used the r package *ClimClass* (ECCEL; CORDANO; TOLLER, 2016)to calculate the CWD. Because of the biomass erosion reported for fragments in the Atlantic Forests due to high disturbance levels (LIMA *et al.*, 2020), we adopted a conservative approach and reduced the AGB estimates by a factor of 0.53 following the average AGB values found on a field inventory near our study region (ALBERTAS; COSTA *et al.*, 2018). After calculating the potential AGB, we converted it to carbon by multiplying values to 0.5 and subsequently to CO_2, using a conversion factor of 44/12. For belowground biomass, we considered that roots and soil carbon content increase (in comparison to a previous pasture land-use) represented an additional 18% CO2 sequestered 33. The values were taken from a remnant forest fragment, however, the rate of accumulation for soil biomass is higher in the first 20 years of regeneration and low variation was found for aging forests (BRANCALION; GUILLEMOT *et al.*, 2020;

JONES *et al.*, 2019). With total CO_2 estimated, we used the net intervention cost for farms with a negative balance in each scenario to calculate the price of the ton of CO_2 necessary to offset the intervention costs.

4 AGRICULTURAL CERTIFICATION AS A COMPLEMENTARY TOOL FOR GOVERNANCE: HOW TO DO BETTER?

Francisco d'Albertas, Patricia Ruggiero, Luís Fernando Guedes Pinto, Gerd Sparovek, Jean Paul Metzger

4.1 ABSTRACT

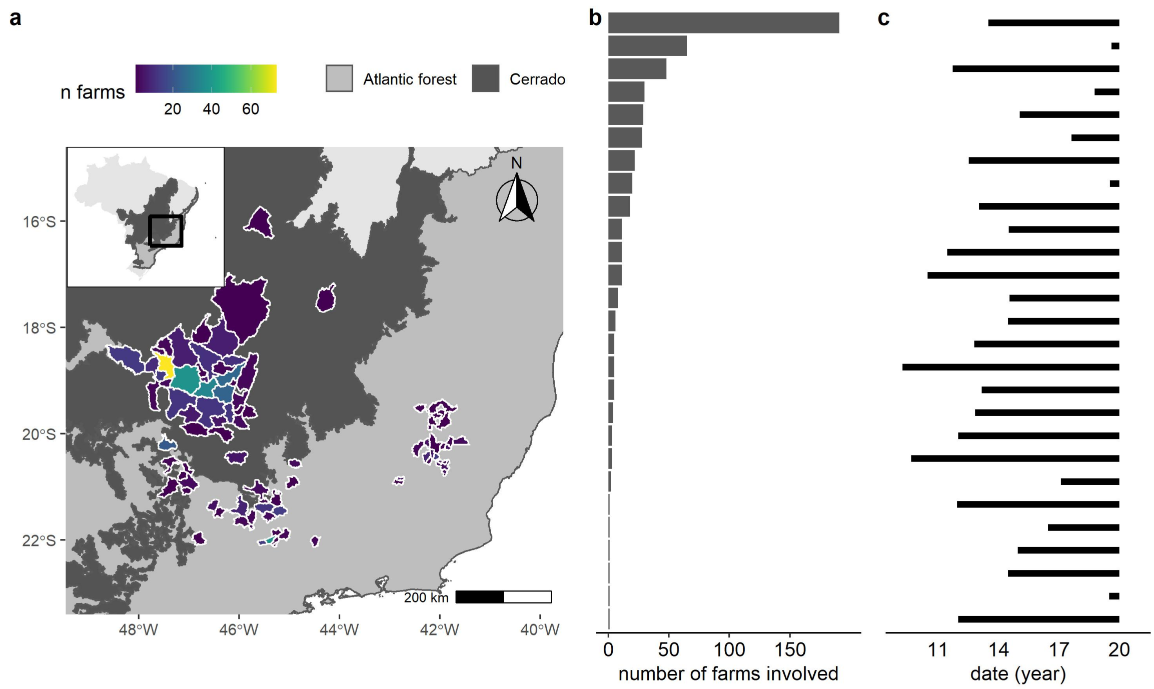
Placeholeder: Ainda vou trabalhar no texto

4.2 INTRODUCTION

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

4.3 METHODS

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.



(#fig:Figure3.1)

Figure 13 – Spatial and temporal distribution of certified farms. (a) Distribution of farms per municipality across southern Atlantic Forest and Cerrado biomes; (b) number of certified farms per contract; (c) period under certification per contract from 2009 to 2020.

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

4.3.1 Certification requirements

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

4.3.2 Constructing counterfactuals

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Table 2 – Set of covariates used in the matching procedure to identify control farms. The table contains the variable's name, how it was calculated, and the reason why it was induced in the model. APP – areas of permanent protection.

Variable	Calculation	Reasoning
Natural vegetation cover	Proportion of the farm's area covered with natural vegetation for the year 2009	The amount of natural vegetation at the beginning of the certification process has a direct implication for farm's compliance with environmental law and certification requirements
Pasture cover	Proportion of the farm's area covered with pasture for the year 2009 categorized: 0-0.25; 0.25-1.	The proportion of pasture at the beginning of the certification process allows for the distinction between cattle raising and agriculture farms, two different main economic regional activities

Table 2 – Set of covariates used in the matching procedure to identify control farms. The table contains the variable's name, how it was calculated, and the reason why it was induced in the model. APP – areas of permanent protection. *(continued)*

Variable	Calculation	Reasoning
Sum of deforestation rates	Sum of the deforestation rate (in years) before certification (ratio between the area deforested at a given year and the area covered with natural vegetated for the previous year) between the period 2003-2009	Zero deforestation is required for certification so farmers which have not deforested near the certification date are more likely to undergo a certification

Table 2 – Set of covariates used in the matching procedure to identify control farms. The table contains the variable's name, how it was calculated, and the reason why it was induced in the model. APP – areas of permanent protection. *(continued)*

Variable	Calculation	Reasoning
Sum of regeneration rates	Sum of the yearly regeneration rate (ratio between the area regenerated at a given year and the property's area) between the period 2003-2009	Farms increasing their amount of natural vegetation close to the certification date are more likely to achieve legal and certification demands
Presence/Absence of Legal Reserves	Binary variable indicating whether a property has a Legal Reserve area allocated at the SICAR platform.	Farms with Legal Reserves indicate a predisposition to accept land-use restrictions, added by the certification process, for conservation purposes. We adopted this as a dummy variable to improve model fitness.
Proportion of APP	Proportion of the farm's area covered with APP	APP must mandatorily be restored within-farm so the proportion of APP may influence the decision to engage in certification

Table 2 – Set of covariates used in the matching procedure to identify control farms. The table contains the variable's name, how it was calculated, and the reason why it was induced in the model. APP – areas of permanent protection. *(continued)*

Variable	Calculation	Reasoning
Property area*	We divided the property area into three size categories: small (0.5 ha – 260 ha), medium (64 ha–974 ha) and large (267 - 8761 ha)	The farm's size direct influence their production scale and the financial capacity to engage in certification schemes, which can be expensive
Mean slope	Mean farm's slope (degrees)	Soil relief is a direct indicator of agricultural suitability and farm's value

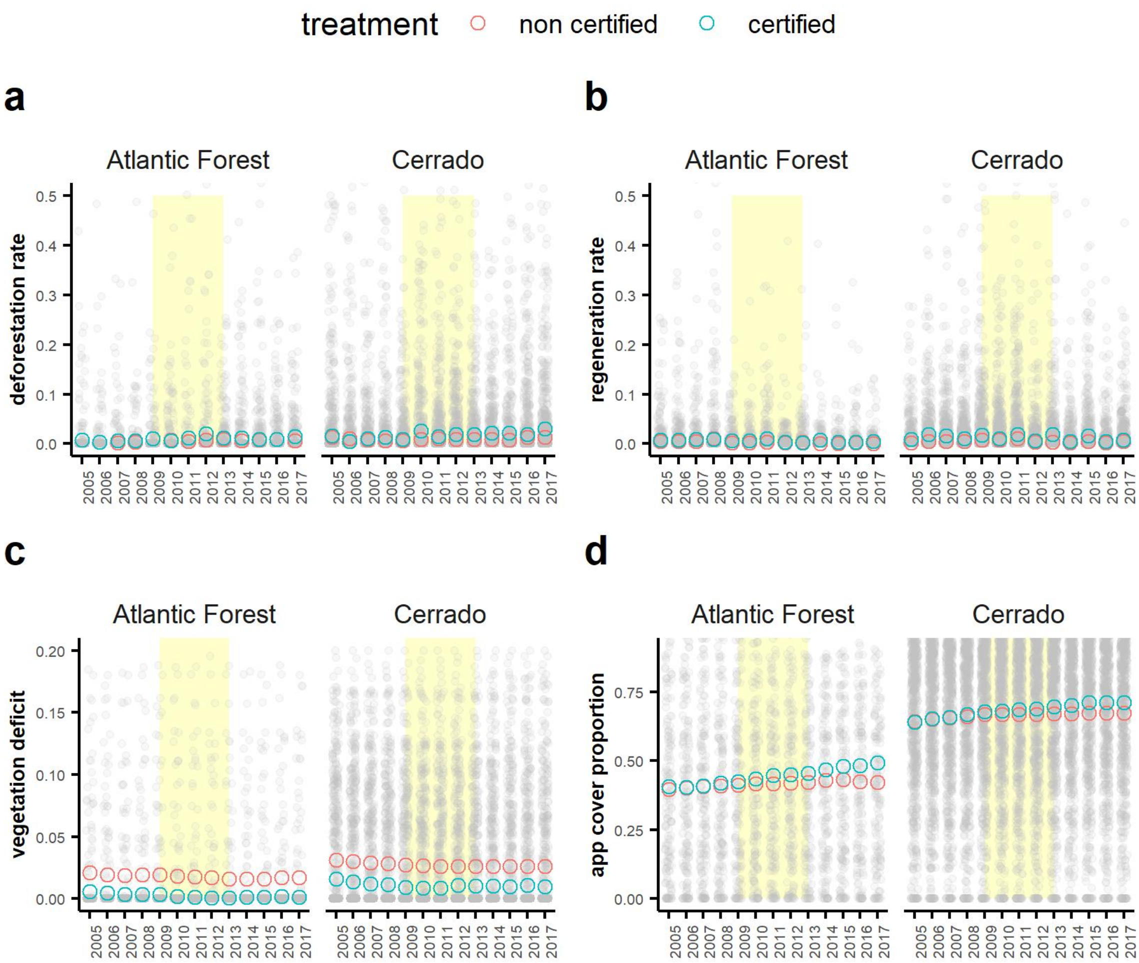
Note:
* Size ranges for small, medium or large properties are defined by the government at the municipal level,in accordance with intrinsic characteristics of the region . For this reason, there are overlaps between categories.

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

4.3.3 Panel data

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

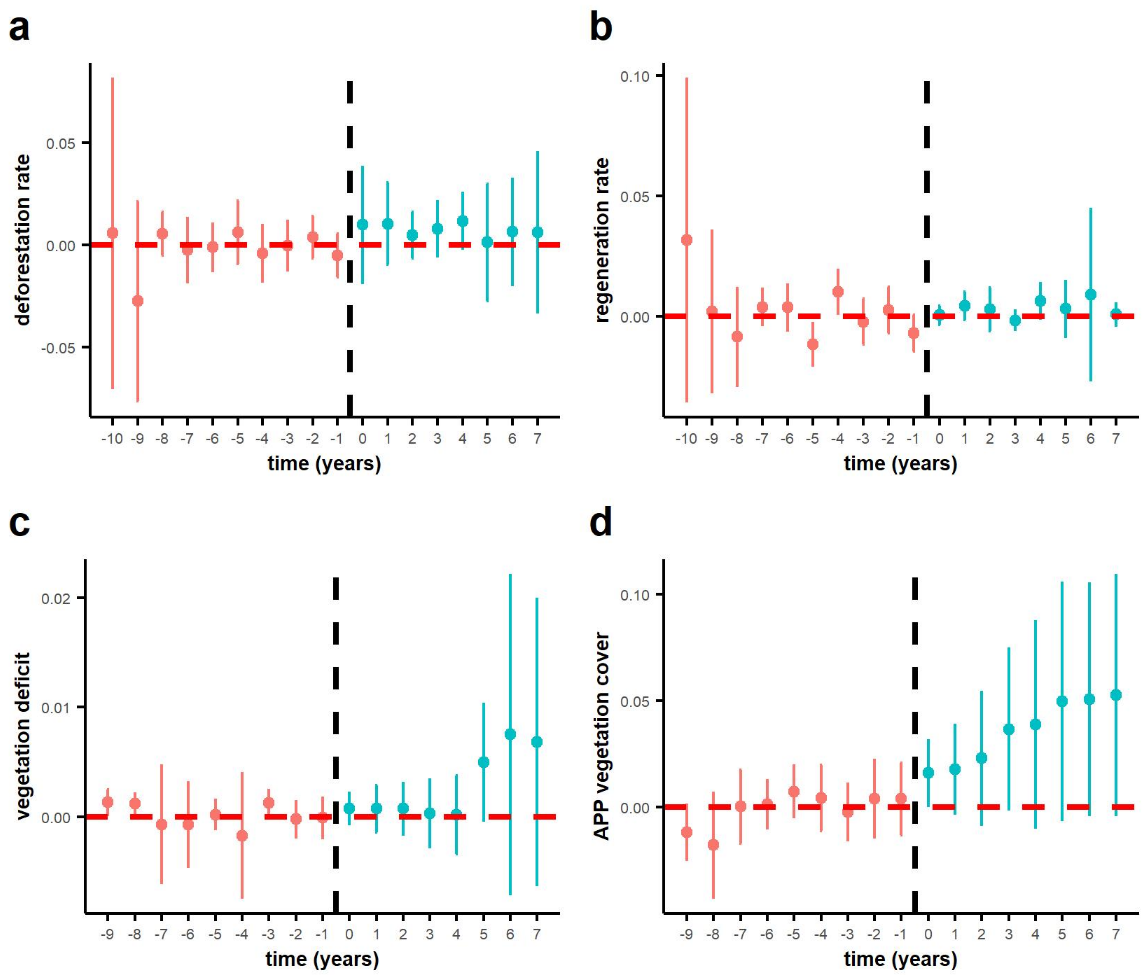
4.4 RESULTS



(#fig:Figure3.2)

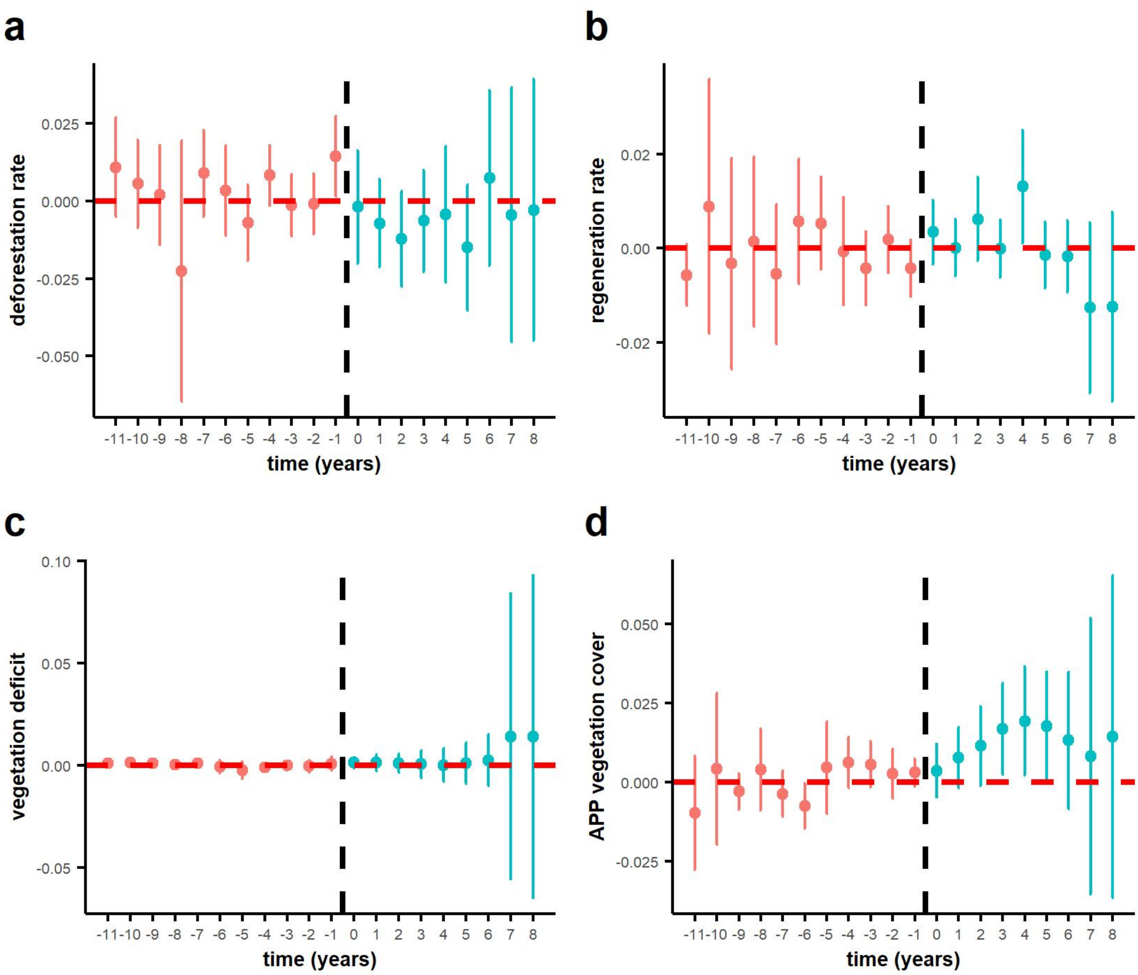
Figure 14 – Exploratory annual trends for certified and non-certified properties. Annual deforestation rate (a), regeneration rate (b), vegetation deficit outside APPs(c), and proportion of APP covered with natural vegetation. The distribution of values is illustrated by the gray dots and the average annual value by the red and blue dots, for non-certified and certified farms, respectively. The yellow shade is delimited by the minimum and median certification dates.

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.



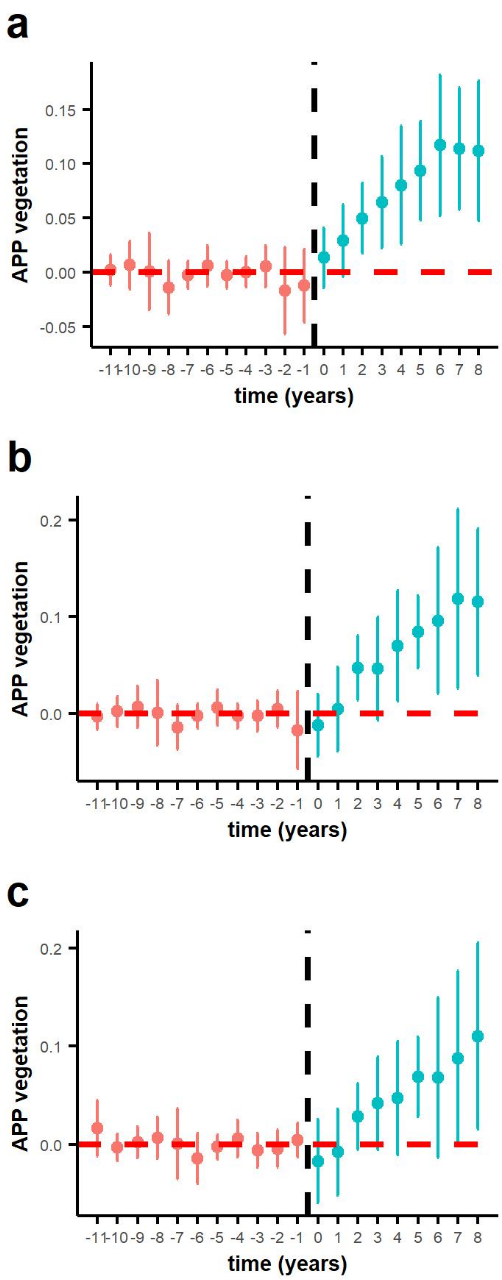
(#fig:Figure3.3)

Figure 15 – Average group-time treatment effect for properties within the Atlantic Forest. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), the vegetation deficit outside APPs (c), and the proportion of APP covered with natural vegetation between certified and non-certified farms (d). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.



(#fig:Figure3.4)

Figure 16 – Average group-time treatment effect for properties within the Cerrado. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), the vegetation deficit outside APPs (c), and the proportion of APP covered with natural vegetation between certified and non-certified farms (d). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.



(#fig:Figure3.5)

Figure 17 – APP vegetation average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. To account for an anticipation effect, instead of entering the real certification date on the model, we considered time zero as: certification date minus one year (a); certification date minus two years (b); and certification date minus three years (c). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

4.5 DISCUSSION

4.5.1 Certification in consolidated agricultural landscapes as a tool to achieve conservation targets: findings and limitations

4.5.2 Potential synergies between certification and environmental compliance

4.5.3 Extending certification benefits

4.5.4 Conclusion

5 CONCLUSÃO

As conclusões devem responder às questões da pesquisa, em relação aos objetivos e às hipóteses. Devem ser breves, podendo apresentar recomendações e sugestões para trabalhos futuros.

REFERÊNCIAS

(PROGRAM), Millennium Ecosystem Assessment (Ed.). **Ecosystems and human well-being: synthesis**. Washington, DC: Island Press, 2005. OCLC: ocm59279709. ISBN 978-1-59726-040-4 978-1-59726-039-8.

ACOSTA, Andre L. *et al.* Gaps and limitations in the use of restoration scenarios: a review. en. **Restoration Ecology**, v. 26, n. 6, p. 1108–1119, 2018. ISSN 1526-100X. DOI: 10.1111/rec.12882. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12882. Acesso em: 23 mai. 2019.

ALBERTAS, Francisco d'; COSTA, Karine *et al.* Lack of evidence of edge age and additive edge effects on carbon stocks in a tropical forest. **Forest Ecology and Management**, v. 407, p. 57–65, jan. 2018. ISSN 0378-1127. DOI: 10.1016/j.foreco.2017.09.042.

ALBERTAS, Francisco d'; GONZÁLEZ-CHAVES, Adrian *et al.* Private reserves suffer from the same location biases of public protected areas. en. **Biological Conservation**, v. 261, p. 109283, set. 2021. ISSN 0006-3207. DOI: 10.1016/j.biocon.2021.109283.

AMAZONAS, Nino Tavares *et al.* High diversity mixed plantations of Eucalyptus and native trees: An interface between production and restoration for the tropics. en. **Forest Ecology and Management**, v. 417, p. 247–256, 2018. ISSN 0378-1127. DOI: 10.1016/j.foreco.2018.03.015.

ARISTIZÁBAL, Natalia; METZGER, Jean Paul. Landscape structure regulates pest control provided by ants in sun coffee farms. en. **Journal of Applied Ecology**, v. 56, n. 1, p. 21–30, 2019. ISSN 1365-2664. DOI: 10.1111/1365-2664.13283.

ARONSON, James; ALEXANDER, Sasha. Ecosystem Restoration is Now a Global Priority: Time to Roll up our Sleeves. en. **Restoration Ecology**, v. 21, n. 3, p. 293–296, 2013. _eprint:

https://onlinelibrary.wiley.com/doi/pdf/10.1111/rec.12011. ISSN 1526-100X. DOI: 10.1111/rec.12011. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12011. Acesso em: 7 fev. 2022.

ARONSON, James; BLIGNAUT, James N. *et al.* Are Socioeconomic Benefits of Restoration Adequately Quantified? A Meta-analysis of Recent Papers (2000-2008) in *Restoration Ecology* and 12 Other Scientific Journals. en. **Restoration Ecology**, v. 18, n. 2, p. 143–154, mar. 2010. ISSN 10612971, 1526100X. DOI: 10.1111/j.1526-100X.2009.00638.x. Disponível em: https://onlinelibrary.wiley.com/doi/10.1111/j.1526-100X.2009.00638.x. Acesso em: 7 fev. 2022.

ARROYO-RODRÍGUEZ, Víctor *et al.* Designing optimal human-modified landscapes for forest biodiversity conservation. en. Edição: Ferenc Jordan. **Ecology Letters**, v. 23, n. 9, p. 1404–1420, 2020. ISSN 1461-023X, 1461-0248. DOI: 10.1111/ele.13535.

AZEVEDO, Andrea A. *et al.* Limits of Brazil's Forest Code as a means to end illegal deforestation. **Proceedings of the National Academy of Sciences of the United States of America**, v. 114, n. 29, p. 7653–7658, 2017. ISSN 0027-8424. DOI: 10.1073/pnas.1604768114.

BANKS-LEITE, Cristina *et al.* Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. en. **Science**, v. 345, n. 6200, p. 1041–1045, 2014. ISSN 0036-8075, 1095-9203. DOI: 10.1126/science.1255768.

BARRAL, María *et al.* Quantifying the impacts of ecological restoration on biodiversity and ecosystem services in agroecosystems: A global meta-analysis. **Agriculture Ecosystems & Environment**, jan. 2015. DOI: 10.1016/j.agee.2015.01.009.

BENAYAS, J. M. R. *et al.* Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. en. **Science**, v. 325, n. 5944,

p. 1121–1124, 2009. ISSN 0036-8075, 1095-9203. DOI: 10.1126/science.1172460.

BOESING, Andrea L.; NICHOLS, Elizabeth; METZGER, Jean P. Effects of landscape structure on avian-mediated insect pest control services: a review. en. **Landscape Ecology**, v. 32, n. 5, p. 931–944, 2017. ISSN 0921-2973, 1572-9761. DOI: 10.1007/s10980-017-0503-1.

BOESING, Andrea Larissa; NICHOLS, Elizabeth; METZGER, Jean Paul. Biodiversity extinction thresholds are modulated by matrix type. en. **Ecography**, v. 0, n. 0, 2018. ISSN 1600-0587. DOI: 10.1111/ecog.03365. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/ecog.03365.

BOMMARCO, Riccardo; KLEIJN, David; POTTS, Simon G. Ecological intensification: harnessing ecosystem services for food security. **Trends in Ecology & Evolution**, v. 28, n. 4, p. 230–238, abr. 2013. ISSN 0169-5347. DOI: 10.1016/j.tree.2012.10.012. Disponível em: http://www.sciencedirect.com/science/article/pii/S016953471200273X. Acesso em: 12 dez. 2017.

BOSCOLO, Danilo; METZGER, Jean Paul. Isolation determines patterns of species presence in highly fragmented landscapes. en. **Ecography**, v. 34, n. 6, p. 1018–1029, 2011. ISSN 1600-0587. DOI: 10.1111/j.1600-0587.2011.06763.x.

BOWMAN, Maria; ZILBERMAN, David. Economic Factors Affecting Diversified Farming Systems. en. **Ecology and Society**, v. 18, n. 1, mar. 2013. ISSN 1708-3087. DOI: 10.5751/ES-05574-180133. Disponível em: https://www.ecologyandsociety.org/vol18/iss1/art33/. Acesso em: 9 ago. 2019.

BRADBURY, Richard B. *et al.* The economic consequences of conserving or restoring sites for nature. en. **Nature Sustainability**, p. 1–7, mar. 2021. ISSN 2398-9629. DOI: 10.1038/s41893-021-00692-9.

BRANCALION, Pedro H. S.; AMAZONAS, Nino T. *et al.* Exotic eucalypts: From demonized trees to allies of tropical forest restoration? en. **Journal of Applied Ecology**, v. 57, n. 1, p. 55–66, 2020. ISSN 1365-2664. DOI: 10.1111/1365-2664.13513.

BRANCALION, Pedro H. S.; GARCIA, Letícia C. *et al.* A critical analysis of the Native Vegetation Protection Law of Brazil (2012): updates and ongoing initiatives. **Natureza & Conservação**, v. 14, p. 1–15, 2016. ISSN 1679-0073. DOI: 10.1016/j.ncon.2016.03.003.

BRANCALION, Pedro H. S.; GUILLEMOT, Joannès *et al.* The cost of restoring carbon stocks in Brazil's Atlantic Forest. en. **Land Degradation & Development**, n/a, n/a, 2020. ISSN 1099-145X. DOI: 10.1002/ldr.3764. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1002/ldr.3764. Acesso em: 20 nov. 2020.

BRANCALION, Pedro H. S.; MELI, Paula *et al.* What makes ecosystem restoration expensive? A systematic cost assessment of projects in Brazil. en. **Biological Conservation**, v. 240, p. 108274, dez. 2019. ISSN 0006-3207. DOI: 10.1016/j.biocon.2019.108274.

BRANCALION, Pedro H. S.; NIAMIR, Aidin *et al.* Global restoration opportunities in tropical rainforest landscapes. en. **Science Advances**, v. 5, n. 7, eaav3223, jul. 2019. ISSN 2375-2548. DOI: 10.1126/sciadv.aav3223. Disponível em: https://advances.sciencemag.org/content/5/7/eaav3223. Acesso em: 21 nov. 2019.

BULLOCK, James M.; PYWELL, Richard F.; WALKER, Kevin J. Long-term enhancement of agricultural production by restoration of biodiversity. en. **Journal of Applied Ecology**, v. 44, n. 1, p. 6–12, 2007. ISSN 1365-2664. DOI: 10.1111/j.1365-2664.2006.01252.x.

BÜRKNER, Paul-Christian. brms: An R Package for Bayesian Multilevel Models Using Stan. **Journal of Statistical Software**, v. 80, n. 1, p. 1–28, 2017. DOI: 10.18637/jss.v080.i01.

BUSCH, Jonah *et al.* Potential for low-cost carbon dioxide removal through tropical reforestation. en. **Nature Climate Change**, v. 9, n. 6, p. 463–466, jun. 2019. ISSN 1758-6798. DOI: 10.1038/s41558-019-0485-x.

CALABONI, Adriane *et al.* The forest transition in São Paulo, Brazil: historical patterns and potential drivers. en. **Ecology and Society**, v. 23, n. 4, 2018. ISSN 1708-3087. DOI: 10.5751/ES-10270-230407. Disponível em: https://www.ecologyandsociety.org/vol23/iss4/art7/.

CARDINALE, Bradley J. *et al.* Biodiversity loss and its impact on humanity. en. **Nature**, v. 486, n. 7401, p. 59–67, 2012. ISSN 1476-4687. DOI: 10.1038/nature11148.

CASTRO, de Eduardo Rodrigues; TEIXEIRA, Erly Cardoso. Rural credit and agricultural supply in Brazil. en. **Agricultural Economics**, v. 43, n. 3, p. 293–302, 2012. ISSN 1574-0862. DOI: 10.1111/j.1574-0862.2012.00583.x.

CEPEA. **Centro de Estudos Avançados em Economia Aplicada - CEPEA-Esalq/USP**. BR. [*S.l.*: *s.n.*], 2017. Publisher: Imagenet Tecnologia. Disponível em: https://www.cepea.esalq.usp.br/br. Acesso em: 14 ago. 2020.

CHASE, Jonathan M. *et al.* Ecosystem decay exacerbates biodiversity loss with habitat loss. en. **Nature**, v. 584, n. 7820, p. 238–243, ago. 2020. ISSN 1476-4687. DOI: 10.1038/s41586-020-2531-2.

CHAZDON, Robin L. *et al.* A Policy-Driven Knowledge Agenda for Global Forest and Landscape Restoration. en. **Conservation Letters**, v. 10, n. 1, p. 125–132, 2017. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/conl.12220. ISSN 1755-263X. DOI: 10.1111/conl.12220. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/conl.12220. Acesso em: 7 fev. 2022.

CLASSEN, Alice *et al.* Complementary ecosystem services provided by pest predators and pollinators increase quantity and quality of coffee yields. en. **Proceedings of the Royal Society of London B: Biological Sciences**, v. 281,

n. 1779, p. 20133148, 2014. ISSN 0962-8452, 1471-2954. DOI: 10.1098/rspb.2013.3148.

CONAB. **Companhia Nacional de Abastacimento**. [*S.l.*: *s.n.*], 2017. Disponível em: https://www.conab.gov.br/info-agro/custos-de-producao#_blank. Acesso em: 14 ago. 2020.

CORTÉS CAPANO, Gonzalo *et al.* The emergence of private land conservation in scientific literature: A review. **Biological Conservation**, v. 237, p. 191–199, 2019. ISSN 0006-3207. DOI: 10.1016/j.biocon.2019.07.010.

CROUZEILLES, Renato; BEYER, Hawthorne L. *et al.* Achieving cost-effective landscape-scale forest restoration through targeted natural regeneration. en. **Conservation Letters**, n/a, n/a, e12709, 2019. ISSN 1755-263X. DOI: 10.1111/conl.12709.

CROUZEILLES, Renato; CURRAN, Michael *et al.* A global meta-analysis on the ecological drivers of forest restoration success. **Nature Communications**, v. 7, p. 11666, mai. 2016. ISSN 2041-1723. DOI: 10.1038/ncomms11666. Disponível em: http://www.nature.com/doifinder/10.1038/ncomms11666. Acesso em: 21 out. 2017.

DAINESE, Matteo *et al.* A global synthesis reveals biodiversity-mediated benefits for crop production. en. **Science Advances**, v. 5, n. 10, eaax0121, 2019. ISSN 2375-2548. DOI: 10.1126/sciadv.aax0121.

DE BEENHOUWER, Matthias; AERTS, Raf; HONNAY, Olivier. A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. **Agriculture Ecosystems & Environment**, v. 175, p. 1–7, ago. 2013. DOI: 10.1016/j.agee.2013.05.003.

DE GROOT, Rudolf S. *et al.* Benefits of investing in ecosystem restoration. eng. **Conservation Biology: The Journal of the Society for Conservation Biology**, v. 27, n. 6, p. 1286–1293, dez. 2013. ISSN 1523-1739. DOI: 10.1111/cobi.12158.

DONOFRIO, Stephen *et al.* Voluntary Carbon and the Post-Pandemic Recovery. en, p. 16, 2020.

DRESCHER, Michael; BRENNER, Jacob C. The practice and promise of private land conservation. en. **Ecology and Society**, v. 23, n. 2, art3, 2018. ISSN 1708-3087. DOI: 10.5751/ES-10020-230203.

ECCEL, Emanuele; CORDANO, Emanuele; TOLLER, Giambattista. **ClimClass: Climate Classification According to Several Indices**. [*S.l.*: *s.n.*], 2016. Disponível em: https://CRAN.R-project.org/package=ClimClass.

ELLIS, Erle C. *et al.* Anthropogenic transformation of the biomes, 1700 to 2000. en. **Global Ecology and Biogeography**, v. 19, n. 5, p. 589–606, 2010. ISSN 1466-8238. DOI: 10.1111/j.1466-8238.2010.00540.x.

ERBAUGH, J. T. *et al.* Global forest restoration and the importance of prioritizing local communities. en. **Nature Ecology & Evolution**, v. 4, n. 11, p. 1472–1476, nov. 2020. ISSN 2397-334X. DOI: 10.1038/s41559-020-01282-2.

FAHRIG, Lenore. Ecological Responses to Habitat Fragmentation Per Se. **Annual Review of Ecology, Evolution, and Systematics**, v. 48, n. 1, p. 1–23, 2017. DOI: 10.1146/annurev-ecolsys-110316-022612.

FAO. Top 20 Commodities, Export Value by country, 2019. Disponível em: http://www.fao.org/faostat/en/#rankings/major_commodities_exports. Acesso em: 4 mai. 2021.

FBDS. Fundação Brasileira para o Desenvolvimento Sustentável, 2013. Disponível em: http://geo.fbds.org.br/. Acesso em: 2 jan. 2021.

FLIEHR, Olivia; ZIMMER, Yelto; SMITH, Linda H. Impacts of Transportation and Logistics on Brazilian Soybean Prices and Exports. **Transportation Journal**, v. 58, n. 1, p. 65–77, 2019. ISSN 0041-1612.

FODEN, Wendy B. *et al.* Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. en. **PLOS ONE**, v. 8, n. 6, e65427, jun. 2013. ISSN 1932-6203. DOI: 10.1371/journal.pone.0065427.

FOLEY, J. A. Global Consequences of Land Use. en. **Science**, v. 309, n. 5734, p. 570–574, jul. 2005. ISSN 0036-8075, 1095-9203. DOI: 10.1126/science.1111772. Disponível em: http://www.sciencemag.org/cgi/doi/10.1126/science.1111772. Acesso em: 15 mar. 2018.

FREITAS, Flavio L. M.; ENGLUND, Oskar *et al.* Who owns the Brazilian carbon? en. **Global Change Biology**, dez. 2017. ISSN 13541013. DOI: 10.1111/gcb.14011. Disponível em: http://doi.wiley.com/10.1111/gcb.14011. Acesso em: 22 dez. 2017.

FREITAS, Flavio L. M.; SPAROVEK, Gerd *et al.* Potential increase of legal deforestation in Brazilian Amazon after Forest Act revision. en. **Nature Sustainability**, v. 1, n. 11, p. 665–670, 2018. ISSN 2398-9629. DOI: 10.1038/s41893-018-0171-4.

GABRY, Jonah *et al.* **rstanarm: Bayesian Applied Regression Modeling via Stan**. [*S.l.*: *s.n.*], 2018. Disponível em: https://CRAN.R-project.org/package=rstanarm.

GARIBALDI, Lucas A.; GEMMILL-HERREN, Barbara *et al.* Farming Approaches for Greater Biodiversity, Livelihoods, and Food Security. eng. **Trends in Ecology & Evolution**, v. 32, n. 1, p. 68–80, jan. 2017. ISSN 1872-8383. DOI: 10.1016/j.tree.2016.10.001.

GARIBALDI, Lucas A.; ODDI, Facundo J. *et al.* Working landscapes need at least 20% native habitat. en. **Conservation Letters**, v. 14, n. 2, e12773, 2020. ISSN 1755-263X. DOI: 10.1111/conl.12773.

GARIBALDI, Lucas A.; PÉREZ-MÉNDEZ, Néstor. Positive outcomes between crop diversity and agricultural employment worldwide. **Ecological Economics**, v. 164, p. 106358, 2019. ISSN 0921-8009. DOI: 10.1016/j.ecolecon.2019.106358.

GARIBALDI, Lucas A.; STEFFAN-DEWENTER, Ingolf *et al.* Stability of pollination services decreases with isolation from natural areas despite honey bee visits. en. **Ecology Letters**, v. 14, n. 10, p. 1062–1072, 2011. ISSN 1461-0248. DOI: 10.1111/j.1461-0248.2011.01669.x.

GEIGER, Flavia *et al.* Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. en. **Basic and Applied Ecology**, v. 11, n. 2, p. 97–105, mar. 2010. ISSN 14391791. DOI: 10.1016/j.baae.2009.12.001. Disponível em: http://linkinghub.elsevier.com/retrieve/pii/S1439179109001388. Acesso em: 22 dez. 2017.

GIANNINI, T. C. *et al.* The Dependence of Crops for Pollinators and the Economic Value of Pollination in Brazil. **Journal of Economic Entomology**, v. 108, n. 3, p. 849–857, jun. 2015. ISSN 0022-0493. DOI: 10.1093/jee/tov093.

GODFRAY, H. Charles J. *et al.* Food Security: The Challenge of Feeding 9 Billion People. en. **Science**, v. 327, n. 5967, p. 812–818, fev. 2010. ISSN 0036-8075, 1095-9203. DOI: 10.1126/science.1185383. Disponível em: http://science.sciencemag.org/content/327/5967/812. Acesso em: 12 dez. 2017.

GONCALVES, Nicolas *et al.* Potential economic impact of carbon sequestration in coffee agroforestry systems. en. **Agroforestry Systems**, v. 95, n. 2, p. 419–430, fev. 2021. ISSN 1572-9680. DOI: 10.1007/s10457-020-00569-4.

GONZÁLEZ-CHAVES, Adrian; CARVALHEIRO, Luísa G. *et al.* Positive forest cover effects on coffee yields are consistent across regions. en. **Journal of Applied Ecology**, v. 59, n. 1, 2021. ISSN 1365-2664. DOI: 10.1111/1365-2664.14057. Disponível em:

https://onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.14057. Acesso em: 29 nov. 2021.

GONZÁLEZ-CHAVES, Adrian; JAFFÉ, Rodolfo *et al.* Forest proximity rather than local forest cover affects bee diversity and coffee pollination services. en. **Landscape Ecology**, jun. 2020. ISSN 1572-9761. DOI: 10.1007/s10980-020-01061-1. Disponível em: https://doi.org/10.1007/s10980-020-01061-1. Acesso em: 17 jul. 2020.

GUIDOTTI, Vinicius *et al.* NÚMEROS DETALHADOS DO NOVO CÓDIGO FLORESTAL E SUAS IMPLICAÇÕES PARA OS PRAs PRINCIPAIS RESULTADOS E CONSIDERAÇÕES. pt, 2017. DOI: 10.13140/rg.2.2.23229.87526. Disponível em: http://rgdoi.net/10.13140/RG.2.2.23229.87526.

GUO, Jiqiang *et al.* **rstan: R Interface to Stan**. [*S.l.*: *s.n.*], 2019. Disponível em: https://CRAN.R-project.org/package=rstan.

GUROBI OPTIMIZATION; LLC. **gurobi: Gurobi Optimizer 9.0 interface**. [*S.l.*: *s.n.*], 2020. Disponível em: https://www.gurobi.com.

HANSON, Jeffrey O. *et al.* **prioritizr: Systematic Conservation Prioritization in R**. 5.0.3. ed. [*S.l.*: *s.n.*], nov. 2020. Disponível em: https://CRAN.R-project.org/package=prioritizr. Acesso em: 26 nov. 2020.

IBGE. **Área plantada ou destinada à colheita, área colhida, quantidade produzida, rendimento médio e valor da produção das lavouras temporárias e permanentes**. [*S.l.*: *s.n.*], 2016. Disponível em: https://sidra.ibge.gov.br/tabela/5457.

IBGE. **Produção Agrícola Municipal**. [*S.l.*: *s.n.*], 2017. Disponível em: https://sidra.ibge.gov.br/pesquisa/pam/tabelas. Acesso em: 14 ago. 2020.

IPBES. Unedited draft chapter 2.2 Status and Trends – Nature. *In*: IPBES Global Assessment on Biodiversity and Ecosystem Services. Bonn, Germany: Kazuhito Ichii, Zsolt Molnár, David Obura, Andy Purvis, Katherine Willis (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity e Ecosystem Services, 2019. P. 171.

JAREK, Tuszynski. **caTools: Tools: moving window statistics, GIF, Base64, ROC AUC, etc..** [*S.l.*: *s.n.*], 2019. Disponível em: `https://CRAN.R-project.org/package=caTools`.

JOLY, Carlos A.; METZGER, J. P.; TABARELLI, Marcelo. Experiences from the Brazilian Atlantic Forest: ecological findings and conservation initiatives. **New Phytologist**, v. 204, p. 459–473, 2014. DOI: `10.1111/nph.12989`.

JONES, Isabel L. *et al.* Above- and belowground carbon stocks are decoupled in secondary tropical forests and are positively related to forest age and soil nutrients respectively. en. **Science of The Total Environment**, v. 697, p. 133987, dez. 2019. ISSN 0048-9697. DOI: `10.1016/j.scitotenv.2019.133987`.

JUNG, Suhyun *et al.* Brazil's National Environmental Registry of Rural Properties: Implications for Livelihoods. **Ecological Economics**, v. 136, p. 53–61, 2017. ISSN 0921-8009. DOI: `10.1016/j.ecolecon.2017.02.004`.

KARP, Daniel S. *et al.* Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. en. **Proceedings of the National Academy of Sciences**, v. 115, n. 33, e7863–e7870, ago. 2018. Publisher: National Academy of Sciences Section: PNAS Plus. ISSN 0027-8424, 1091-6490. DOI: `10.1073/pnas.1800042115`. Disponível em: `https://www.pnas.org/content/115/33/E7863`. Acesso em: 18 mar. 2021.

KLEIN, Alexandra-Maria *et al.* Importance of pollinators in changing landscapes for world crops. en. **Proceedings of the Royal Society B: Biological Sciences**, v. 274, n. 1608, p. 303–313, fev. 2007. ISSN 0962-8452, 1471-2954. DOI: `10.1098/rspb.2006.3721`.

LATAWIEC, Agnieszka E. *et al.* Improving land management in Brazil: A perspective from producers. en. **Agriculture, Ecosystems & Environment**, v. 240, p. 276–286, 2017. ISSN 0167-8809. DOI: `10.1016/j.agee.2017.01.043`.

LATINI, Anderson Oliveira *et al.* Reconciling coffee productivity and natural vegetation conservation in an agroecosystem landscape in Brazil. en. **Journal for Nature Conservation**, v. 57, p. 125902, out. 2020. ISSN 16171381. DOI: 10.1016/j.jnc.2020.125902.

LAURANCE, William F. Conserving the hottest of the hotspots. en. **Biological Conservation**, v. 142, n. 6, p. 1137, jun. 2009. ISSN 0006-3207. DOI: 10.1016/j.biocon.2008.10.011.

LAUTENBACH, Sven *et al.* Spatial and Temporal Trends of Global Pollination Benefit. en. **PLoS ONE**, v. 7, n. 4, p. 16, 2012.

LECLÈRE, David *et al.* Bending the curve of terrestrial biodiversity needs an integrated strategy. en. **Nature**, v. 585, n. 7826, p. 551–556, set. 2020. ISSN 1476-4687. DOI: 10.1038/s41586-020-2705-y.

LIBRÁN-EMBID, Felipe; DE COSTER, Greet; METZGER, Jean Paul. Effects of bird and bat exclusion on coffee pest control at multiple spatial scales. en. **Landscape Ecology**, v. 32, n. 9, p. 1907–1920, 2017. ISSN 0921-2973, 1572-9761. DOI: 10.1007/s10980-017-0555-2.

LIMA, Renato A. F. de *et al.* The erosion of biodiversity and biomass in the Atlantic Forest biodiversity hotspot. en. **Nature Communications**, v. 11, n. 1, p. 6347, dez. 2020. ISSN 2041-1723. DOI: 10.1038/s41467-020-20217-w.

MARTENSEN, Alexandre Camargo *et al.* Associations of Forest Cover, Fragment Area, and Connectivity with Neotropical Understory Bird Species Richness and Abundance. en. **Conservation Biology**, v. 26, n. 6, p. 1100–1111, 2012. ISSN 1523-1739. DOI: 10.1111/j.1523-1739.2012.01940.x.

MARTINELLI, Luiz A *et al.* Agriculture in Brazil: impacts, costs, and opportunities for a sustainable future. en. **Current Opinion in Environmental Sustainability**, v. 2, n. 5, p. 431–438, 2010. ISSN 1877-3435. DOI: 10.1016/j.cosust.2010.09.008.

MATSON, P. A. Agricultural Intensification and Ecosystem Properties. **Science**, v. 277, n. 5325, p. 504–509, jul. 1997. ISSN 00368075, 10959203. DOI: 10.1126/science.277.5325.504. Disponível em: http://www.sciencemag.org/cgi/doi/10.1126/science.277.5325.504. Acesso em: 22 dez. 2017.

MAY, P. H. *et al.* **Environmental reserve quotas in Brazil's new forest legislation: An ex ante appraisal**. [*S.l.*]: Center for International Forestry Research (CIFOR), Bogor, Indonesia, 2015. ISBN 978-602-387-004-2. Disponível em: https://www.cifor.org/library/5609/environmental-reserve-quotas-in-brazils-new-forest-legislation-an-ex-ante-appraisal/.

MELLO, de Kaline; FENDRICH, Arthur Nicolaus; BORGES-MATOS, Clarice; BRITES, Alice Dantas; TAVARES, Paulo André; ROCHA, Gustavo Casoni da; MATSUMOTO, Marcelo *et al.* Integrating ecological equivalence for native vegetation compensation: A methodological approach. en. **Land Use Policy**, v. 108, p. 105568, set. 2021. ISSN 0264-8377. DOI: 10.1016/j.landusepol.2021.105568.

MELLO, de Kaline; FENDRICH, Arthur Nicolaus; SPAROVEK, Gerd *et al.* Achieving private conservation targets in Brazil through restoration and compensation schemes without impairing productive lands. en. **Environmental Science & Policy**, v. 120, p. 1–10, jun. 2021. ISSN 1462-9011. DOI: 10.1016/j.envsci.2021.02.014.

MELLO, Kaline; FENDRICH, Arthur; BORGES-MATOS, Clarice; BRITES, Alice; TAVARES, Paulo André; ROCHA, Gustavo Casoni da; MATSUMOTTO, Marcelo *et al.* Integrating ecological equivalence for native vegetation compensation: a methodological approach. **Land Use Policy**.

METZGER, Jean Paul; BUSTAMANTE, Mercedes M. C. *et al.* Why Brazil needs its Legal Reserves. **Perspectives in Ecology and Conservation**, p. 91–103, 2019. ISSN 2530-0644. DOI: 10.1016/j.pecon.2019.07.002.

METZGER, Jean Paul; ESLER, Karen *et al.* Best practice for the use of scenarios for restoration planning. en. **Current Opinion in Environmental Sustainability**, v. 29, p. 14–25, dez. 2017. ISSN 1877-3435. DOI: 10.1016/j.cosust.2017.10.004. Disponível em: https://www.sciencedirect.com/science/article/pii/S187734351730146X. Acesso em: 30 nov. 2021.

METZGER, Jean Paul; VILLARREAL-ROSAS, Jaramar *et al.* Considering landscape-level processes in ecosystem service assessments. en. **Science of The Total Environment**, v. 796, p. 149028, nov. 2021. ISSN 0048-9697. DOI: 10.1016/j.scitotenv.2021.149028.

MICHALSKI, Fernanda; METZGER, Jean Paul; PERES, Carlos A. Rural property size drives patterns of upland and riparian forest retention in a tropical deforestation frontier. **Global Environmental Change**, v. 20, n. 4, p. 705–712, 2010. ISSN 0959-3780. DOI: 10.1016/j.gloenvcha.2010.04.010.

MILDER, Jeffrey C. *et al.* An agenda for assessing and improving conservation impacts of sustainability standards in tropical agriculture. en. **Conservation Biology**, v. 29, n. 2, p. 309–320, abr. 2015. ISSN 1523-1739. DOI: 10.1111/cobi.12411. Disponível em: http://onlinelibrary.wiley.com/doi/10.1111/cobi.12411/abstract.

MIRANDA, Javier *et al.* Land speculation and conservation policy leakage in Brazil. en. **Environmental Research Letters**, v. 14, n. 4, p. 045006, 2019. ISSN 1748-9326. DOI: 10.1088/1748-9326/ab003a.

MITCHELL, Matthew G.E. *et al.* Reframing landscape fragmentation's effects on ecosystem services. en. **Trends in Ecology & Evolution**, v. 30, n. 4, p. 190–198, abr. 2015. ISSN 01695347. DOI: 10.1016/j.tree.2015.01.011.

MITTERMEIER, Russell A. *et al.* Global Biodiversity Conservation: The Critical Role of Hotspots. *In*: ZACHOS, Frank E.; HABEL, Jan Christian (Ed.). **Biodiversity Hotspots: Distribution and Protection of Conservation Priority Areas**. Berlin, Heidelberg: Springer, 2011. P. 3–22. ISBN 978-3-642-20992-5. Disponível em: https://doi.org/10.1007/978-3-642-20992-5_1.

MOLENAAR, J.W.; KESSLER, J.J. **Aidenvironment report: Business benefits of using sustainability standards: A meta-review (2017)**. en. [*S.l.*: *s.n.*], mar. 2017. Disponível em: http://www.standardsimpacts.org/resources-reports/aidenvironment-report-business-benefits-using-sustainability-standards-meta-review. Acesso em: 17 abr. 2018.

MOREAUX, Céline *et al.* The value of biotic pollination and dense forest for fruit set of Arabica coffee: A global assessment. en. **Agriculture, Ecosystems & Environment**, v. 323, p. 107680, jan. 2022. ISSN 0167-8809. DOI: 10.1016/j.agee.2021.107680.

NARANJO, Steven E.; ELLSWORTH, Peter C.; FRISVOLD, George B. Economic Value of Biological Control in Integrated Pest Management of Managed Plant Systems. **Annual Review of Entomology**, v. 60, n. 1, p. 621–645, 2015. DOI: 10.1146/annurev-ento-010814-021005.

NEUMANN, Kathleen *et al.* The yield gap of global grain production: A spatial analysis. en. **Agricultural Systems**, v. 103, n. 5, p. 316–326, jun. 2010. ISSN 0308521X. DOI: 10.1016/j.agsy.2010.02.004. Disponível em: http://linkinghub.elsevier.com/retrieve/pii/S0308521X10000302. Acesso em: 22 dez. 2017.

NEWTON, Adrian C. *et al.* Cost–benefit analysis of ecological networks assessed through spatial analysis of ecosystem services. en. **Journal of Applied Ecology**, v. 49, n. 3, p. 571–580, 2012. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2664.2012.02140.x. ISSN 1365-2664. DOI: 10.1111/j.1365-2664.2012.02140.x. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2664.2012.02140.x. Acesso em: 7 fev. 2022.

NIEMEYER, Julia *et al.* Planning forest restoration within private land holdings with conservation co-benefits at the landscape scale. en. **Science of The Total Environment**, p. 135262, nov. 2019. ISSN 0048-9697. DOI: 10.1016/j.scitotenv.2019.135262. Disponível em: http://www.sciencedirect.com/science/article/pii/S0048969719352544. Acesso em: 4 fev. 2020.

NIEMEYER, Julia *et al.* Planning forest restoration within private land holdings with conservation co-benefits at the landscape scale. en. **Science of The Total Environment**, p. 135262, 2019. ISSN 0048-9697. DOI: 10.1016/j.scitotenv.2019.135262.

PACHAURI, Rajendra K.; IPCC (Ed.). **Climate change 2007: contribution of ... to the fourth assessment report of the Intergovernmental Panel on Climate Change. 4: Synthesis report: [a report of the Intergovernmental Panel on Climate Change]**. Geneva: IPCC, 2008. OCLC: 934551357. ISBN 978-92-9169-122-7.

PIMENTEL, David *et al.* Economic and environmental benefits of biodiversity. **BioScience**, v. 47, n. 11, p. 747–757, 1997.

PINTO, Luis Fernando Guedes; GONÇALVES, Eduardo Trevisan. Aprendizados da certificação socioambiental para a agricultura. **Perspectiva Imaflora**, n. 4, 2017. Disponível em: http://www.imaflora.org/download-form.php?id=647. Acesso em: 17 abr. 2018.

PINTO, Luis Fernando Guedes; HAJJAR, Reem *et al.* Transitioning to more sustainable, low emissions agriculture in Brazil. en, p. 7, 2016.

POORTER, Lourens *et al.* Biomass resilience of Neotropical secondary forests. **Nature**, v. 530, n. 7589, p. 211–214, fev. 2016. ISSN 0028-0836, 1476-4687. DOI: 10.1038/nature16512.

POTTS, Simon G.; BIESMEIJER, Jacobus C. *et al.* Global pollinator declines: trends, impacts and drivers. **Trends in Ecology & Evolution**, v. 25, n. 6,

p. 345–353, jun. 2010. ISSN 0169-5347. DOI: 10.1016/j.tree.2010.01.007. Disponível em: http://www.sciencedirect.com/science/article/pii/S0169534710000364.

POTTS, Simon G.; IMPERATRIZ-FONSECA, Vera *et al.* Safeguarding pollinators and their values to human well-being. en. **Nature**, v. 540, n. 7632, p. 220–229, 2016. ISSN 1476-4687. DOI: 10.1038/nature20588.

PRETTY, J. N. *et al.* Resource-Conserving Agriculture Increases Yields in Developing Countries. en. **Environmental Science & Technology**, v. 40, n. 4, p. 1114–1119, fev. 2006. ISSN 0013-936X, 1520-5851. DOI: 10.1021/es051670d. Disponível em: http://pubs.acs.org/doi/abs/10.1021/es051670d. Acesso em: 22 dez. 2017.

PULLA, Pamela *et al.* **Mapping the distribution of forest ownership in Europe**. en. [*S.l.*], 2013. P. 91.

RADA, Nicholas; HELFAND, Steven; MAGALHÃES, Marcelo. Agricultural productivity growth in Brazil: Large and small farms excel. **Food Policy**, v. 84, p. 176–185, 2019. ISSN 0306-9192. DOI: 10.1016/j.foodpol.2018.03.014.

RAJÃO, Raoni *et al.* The rotten apples of Brazil's agribusiness. en, p. 4, 2020.

RAND, Tatyana A.; TYLIANAKIS, Jason M.; TSCHARNTKE, Teja. Spillover edge effects: the dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats. en. **Ecology Letters**, v. 9, n. 5, p. 603–614, 2006. ISSN 1461-0248. DOI: 10.1111/j.1461-0248.2006.00911.x.

REY BENAYAS, José M.; BULLOCK, James M. Restoration of Biodiversity and Ecosystem Services on Agricultural Land. en. **Ecosystems**, v. 15, n. 6, p. 883–899, set. 2012. ISSN 1432-9840, 1435-0629. DOI: 10.1007/s10021-012-9552-0.

REZENDE, C. L. *et al.* From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. **Perspectives in Ecology and Conservation**, v. 16, n. 4, p. 208–214, 2018. ISSN 2530-0644. DOI: 10.1016/j.pecon.2018.10.002.

RICKETTS, Taylor H. *et al.* Economic value of tropical forest to coffee production. **Proceedings of the National Academy of Sciences of the United States of America**, v. 101, n. 34, p. 12579–12582, 2004.

ROBIN, Xavier *et al.* pROC: an open-source package for R and S+ to analyze and compare ROC curves. en. **BMC Bioinformatics**, v. 12, n. 1, p. 77, 2011. ISSN 1471-2105. DOI: `10.1186/1471-2105-12-77`.

ROUBIK, David W. The value of bees to the coffee harvest. en. **Nature**, v. 417, n. 6890, p. 708–708, jun. 2002. ISSN 1476-4687. DOI: `10.1038/417708a`.

ROUGET, Mathieu; RICHARDSON, David M; COWLING, Richard M. The current configuration of protected areas in the Cape Floristic Region, South Africa—reservation bias and representation of biodiversity patterns and processes. en. **Biological Conservation**, v. 112, n. 1, p. 129–145, jul. 2003. ISSN 0006-3207. DOI: `10.1016/S0006-3207(02)00396-8`. Disponível em: `http://www.sciencedirect.com/science/article/pii/S0006320702003968`. Acesso em: 4 dez. 2020.

RUGGIERO, Patricia G. C. *et al.* Payment for ecosystem services programs in the Brazilian Atlantic Forest: Effective but not enough. en. **Land Use Policy**, v. 82, p. 283–291, 2019. ISSN 0264-8377. DOI: `10.1016/j.landusepol.2018.11.054`.

SABOGAL. **Forest and landscape restoration: concepts, approaches and challenges for implementation**. [*S.l.*: *s.n.*], 2015. Disponível em: `http://www.fao.org/3/a-i5212e.pdf`. Acesso em: 20 abr. 2018.

SASS, Emma M.; BUTLER, Brett J.; MARKOWSKI-LINDSAY, Marla A. **Forest ownership in the conterminous United States circa 2017: distribution of eight ownership types - geospatial dataset**. en. [*S.l.*], 2017. type: dataset. DOI: `10.2737/RDS-2020-0044`. Disponível em: `https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0044`. Acesso em: 18 nov. 2020.

SATURNI, Fernanda Teixeira; JAFFÉ, Rodolfo; METZGER, Jean Paul. Landscape structure influences bee community and coffee pollination at different spatial scales. en. **Agriculture, Ecosystems & Environment**, v. 235, p. 1–12, 2016. ISSN 01678809. DOI: 10.1016/j.agee.2016.10.008.

SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY; UNITED NATIONS ENVIRONMENT PROGRAMME (Ed.). **Global biodiversity outlook 4: a mid-term assessment of progress towards the implementation of the strategic plan for biodiversity 2011-2020**. er: Secretariat for the Convention on Biological Diversity, 2014. ISBN 978-92-9225-539-8.

SHIMAMOTO, Carolina Y.; BOTOSSO, Paulo C.; MARQUES, Márcia C. M. How much carbon is sequestered during the restoration of tropical forests? Estimates from tree species in the Brazilian Atlantic forest. **Forest Ecology and Management**, v. 329, p. 1–9, 2014. ISSN 03781127. DOI: 10.1016/j.foreco.2014.06.002.

SOARES-FILHO, Britaldo *et al.* Cracking Brazil's forest code. **Science**, v. 344, n. 6182, p. 363–364, 2014.

SPAROVEK, Gerd *et al.* Effects of Governance on Availability of Land for Agriculture and Conservation in Brazil. en. **Environmental Science & Technology**, v. 49, n. 17, p. 10285–10293, 2015. ISSN 0013-936X, 1520-5851. DOI: 10.1021/acs.est.5b01300.

STEFANES, Mauricio *et al.* Property size drives differences in forest code compliance in the Brazilian Cerrado. **Land Use Policy**, v. 75, p. 43–49, 2018. ISSN 0264-8377. DOI: 10.1016/j.landusepol.2018.03.022.

STRASSBURG, Bernardo B. N.; BEYER, Hawthorne L. *et al.* Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. en. **Nature Ecology & Evolution**, v. 3, n. 1, p. 62–70, jan. 2019. ISSN 2397-334X. DOI: 10.1038/s41559-018-0743-8.

STRASSBURG, Bernardo B. N.; IRIBARREM, Alvaro *et al.* Global priority areas for ecosystem restoration. en. **Nature**, p. 1–6, out. 2020. ISSN 1476-4687. DOI: 10.1038/s41586-020-2784-9.

STRASSBURG, Bernardo B. N.; LATAWIEC, Agnieszka E. *et al.* When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. **Global Environmental Change**, v. 28, p. 84–97, 2014. ISSN 0959-3780. DOI: 10.1016/j.gloenvcha.2014.06.001.

TAMBOSI, Leandro R. *et al.* A Framework to Optimize Biodiversity Restoration Efforts Based on Habitat Amount and Landscape Connectivity: Optimizing Restoration Based on Landscape Resilience. en. **Restoration Ecology**, v. 22, n. 2, p. 169–177, 2014. ISSN 10612971. DOI: 10.1111/rec.12049.

TAMBURINI, Giovanni *et al.* Agricultural diversification promotes multiple ecosystem services without compromising yield. en. **Science Advances**, v. 6, n. 45, eaba1715, nov. 2020. ISSN 2375-2548. DOI: 10.1126/sciadv.aba1715. Disponível em: https://advances.sciencemag.org/lookup/doi/10.1126/sciadv.aba1715. Acesso em: 18 nov. 2020.

TAMM, K.; VÕSA, T.; LOKO, V. The impact of distance to the farm compound on the options for use of the cereal plot. en. **Agricultural and Food Science**, v. 19, n. 1, p. 43–56, 2010. ISSN 1795-1895. DOI: 10.2137/145960610791015087.

TEAM, R. Core. **R: A Language and Environment for Statistical Computing**. Vienna, Austria: R Foundation for Statistical Computing, 2018. Disponível em: https://www.R-project.org/.

TEEB. **The Economics of Ecosystems and Biodiversity in National and International Policy Making**. [*S.l.*]: Routledge, set. 2012. Google-Books-ID: hqTsgVmLpvcC. ISBN 978-1-136-53872-8.

TEEB. **The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations**. [*S.l.*]: Routledge, out. 2010. ISBN 978-1-84977-548-9 978-1-136-53880-3 978-1-84971-212-5. DOI: `10.4324/9781849775489`. Disponível em: `https://www.taylorfrancis.com/books/9781849775489`. Acesso em: 11 abr. 2018.

TEIXEIRA, Gabriela M. *et al.* Regeneration of tropical montane cloud forests increases water yield in the Brazilian Atlantic Forest. en. **Ecohydrology**, abr. 2021. ISSN 1936-0584, 1936-0592. DOI: `10.1002/eco.2298`. Disponível em: `https://onlinelibrary.wiley.com/doi/10.1002/eco.2298`. Acesso em: 29 abr. 2021.

TILMAN, D. Forecasting Agriculturally Driven Global Environmental Change. **Science**, v. 292, n. 5515, p. 281–284, abr. 2001. ISSN 00368075, 10959203. DOI: `10.1126/science.1057544`. Disponível em: `http://www.sciencemag.org/cgi/doi/10.1126/science.1057544`. Acesso em: 14 dez. 2017.

TILMAN, David. Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. en. **Proceedings of the National Academy of Sciences**, v. 96, n. 11, p. 5995–6000, mai. 1999. ISSN 0027-8424, 1091-6490. DOI: `10.1073/pnas.96.11.5995`. Disponível em: `http://www.pnas.org/content/96/11/5995`. Acesso em: 22 dez. 2017.

TILMAN, David *et al.* Future threats to biodiversity and pathways to their prevention. en. **Nature**, v. 546, n. 7656, p. 73–81, jun. 2017. ISSN 1476-4687. DOI: `10.1038/nature22900`.

TISOVEC-DUFNER, Karina Campos *et al.* Intention of preserving forest remnants among landowners in the Atlantic Forest: The role of the ecological context via ecosystem services. en. **People and Nature**, v. 0, n. 0, 2019. ISSN 2575-8314. DOI: `10.1002/pan3.10051`. Disponível em: `https://besjournals.pericles-prod.literatumonline.com/doi/abs/10.1002/pan3.10051`.

TSCHARNTKE, Teja; KLEIN, Alexandra M. *et al.* Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. en. **Ecology Letters**, v. 8, n. 8, p. 857–874, ago. 2005. ISSN 1461-0248. DOI: 10.1111/j.1461-0248.2005.00782.x. Disponível em: http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2005.00782.x/abstract.

TSCHARNTKE, Teja; MILDER, Jeffrey C. *et al.* Conserving Biodiversity Through Certification of Tropical Agroforestry Crops at Local and Landscape Scales. en. **Conservation Letters**, v. 8, n. 1, p. 14–23, jan. 2015. ISSN 1755-263X. DOI: 10.1111/conl.12110. Disponível em: http://onlinelibrary.wiley.com/doi/10.1111/conl.12110/abstract. Acesso em: 17 jan. 2018.

TSCHARNTKE, Teja; TYLIANAKIS, Jason M. *et al.* Landscape moderation of biodiversity patterns and processes - eight hypotheses. en. **Biological Reviews**, v. 87, n. 3, p. 661–685, 2012. ISSN 1469-185X. DOI: 10.1111/j.1469-185X.2011.00216.x.

UNEP-WCMC IUCN, NGS. **Protected Planet Report**. Cambridge UK; Gland, Switzerland; e Washington, D.C., USA., 2018.

UROY, L.; ERNOULT, A.; MONY, C. Effect of landscape connectivity on plant communities: a review of response patterns. en. **Landscape Ecology**, v. 34, n. 2, p. 203–225, 2019. ISSN 1572-9761. DOI: 10.1007/s10980-019-00771-5.

VENTER, Oscar *et al.* Bias in protected-area location and its effects on long-term aspirations of biodiversity conventions. en. **Conservation Biology**, v. 32, n. 1, p. 127–134, 2018. ISSN 1523-1739. DOI: 10.1111/cobi.12970.

WADE, Mark R; GURR, Geoff M; WRATTEN, Steve D. Ecological restoration of farmland: progress and prospects. **Philosophical Transactions of the Royal Society B: Biological Sciences**, v. 363, n. 1492, p. 831–847, 2008. ISSN 0962-8436. DOI: 10.1098/rstb.2007.2186.

WATSON, James E. M. *et al.* The performance and potential of protected areas. en. **Nature**, v. 515, n. 7525, p. 67–73, 2014. ISSN 1476-4687. DOI: 10.1038/nature13947.

WUNDER, Sven *et al.* Payments for Environmental Services: Past Performance and Pending Potentials. **Annual Review of Resource Economics**, v. 12, n. 1, null, 2020. DOI: 10.1146/annurev-resource-100518-094206.

XAVIER, Alexandre C.; KING, Carey W.; SCANLON, Bridget R. Daily gridded meteorological variables in Brazil (1980–2013). en. **International Journal of Climatology**, v. 36, n. 6, p. 2644–2659, 2016. ISSN 1097-0088. DOI: 10.1002/joc.4518.

ZANINI, Anani Morilha *et al.* The effect of ecological restoration methods on carbon stocks in the Brazilian Atlantic Forest. en. **Forest Ecology and Management**, v. 481, p. 118734, fev. 2021. ISSN 0378-1127. DOI: 10.1016/j.foreco.2020.118734.

APÊNDICE A – SUPPLEMENTARY MATERIAL - CHAPTER 2

A.1 CALCULATING OPPORTUNITY COST

To estimate land opportunity cost, we have calculated the Net Present Value (NPV) of the main agricultural activities on each municipality from our study region, according to the Brazilian Institute of Geography and Statistics (IBGE, 2017). The NPV is the sum of all cash flows within a determined period in the future, after applying a discount rate, and it is mainly used to determine if an investment will be profitable or will result in loss. It is calculated according to the following formula:

$$NPV(i,N) = \sum_{t=0}^{N} \frac{benefits - costs}{(1+i)^t}$$

where the benefits are the cash inflows and the costs are the cash outflows of each activity, i is the discount rate and t is the time in the future, in years, for which the present value is being calculated. After accessing the yield per municipality (IBGE, 2017), we have calculated the cash flow using production costs and gains from the mains crops (CONAB, 2017) and beef and milk production (CEPEA, 2017) for each municipality for the year 2017. We have applied a discount rate of 8%, following interest rates practiced by agricultural credit financial institutes in Brazil, and previously used in similar studies (NIEMEYER *et al.*, 2019b) and considered a time frame of 20 years, which is the time required by the Natural Vegetation Protection Law for restoration projects to be fully executed. The values were converted to US$ dollars using a convertion rate of 3.21414.

Following the calculation of the NPV, we have calculated the average NPV per municipality of crops and cattle farming weighted by the area of each activity. To spatialize this information, we have crossed the weighted average with the land-use map from 2017 (enfiar ref.!). Whenever the NPV assumed a negative value, we have adopted a conservative approach and transformed the value to 0. Because forestry only occupies 4% of the farms from our dataset, we have extended crops NPV for areas covered with forestry. We have also attributed a value of 0 for areas covered with natural vegetation. The resulting product is an opportunity cost map in dollars ha^{-1} with 30m resolution, covering the entire study region (Figure A1)

A.2 BAYESIAN MODELS DETAILS

The analysis was conducted using the R package rstanarm (GABRY *et al.*, 2018), an appendage of the rstan (GUO *et al.*, 2019) package to execute Markov Chain Monte Carlo. Each model was run with four independent Markov chains of 4000 iterations. The first 2000 was discarded as a warm-up. The model formulation and priors used in the models are presented below.

A.2.1 Question 1: Drivers affecting the proportion of Legal Reserve declared

The response variable (R) in question 1 is a binary categorical variable representing the amount of Legal Reserve (LR) declared in each property. We divided the analyses into three parts, in which we had the following categories adjusted to the same independent variables: a-) no LR declared vs. LR declared; b -) some LR allocated but below the legal requirement (LR proportion $>$0 and $<$0.18) vs. full LR requirement allocated (LR proportion ≥ 0.18); c-) full LR allocated with no surplus (LR proportion ≥ 0.18 and ≤ 0.22) vs. LR surplus allocated (LR proportion $>$0.22). We have considered a different random intercept for each State where the properties are located (Minas Gerais or São Paulo).

$$R \sim \text{Binomial}(1, p_i)$$

$$logit(p_i) = \alpha_{ESTATE}[i] + (\beta AS + \beta P + \beta Ir + \beta Div + \beta Tr + \beta OC + \beta APP + \beta A + \beta V) * p_i$$

$$\alpha_{ESTATE[i]} \sim \text{Normal}(0, 10)$$

$$\beta X_i \sim \text{Normal}(0, 2.5)$$

AS = agricultural suitability index (0-1); *P* = proportion of pasture at the farm; *Ir*= presence of central pivot irrigation; *Div*= diversity of land-uses index; *Tr*= transportation costs, in minutes; *OC*= opportunity cost, in dollars ha^{-1}; *APP*= proportion of Areas of Permanent Protection;*A*= farm area, in hectares; *V*= proportion of natural vegetation.

A.2.2 Question 2: Drivers affecting the location of LR

The response variable (R) in that case is a binary land-use (agriculture) or land-cover (natural vegetation) category or an LR (vegetated LR or non-vegetated LR). We randomly sampled 2000 points within each LR class and land-use and land-cover category from our properties database and extracted the values of all independent variables in the models. We have also considered a different random intercept for each property where the land-use or land-cover point was located. For all comparisons, we adopted the agricultural area as the reference variable.

A.2.2.1 *Vegetation vs. agricultural area*

$$R \sim \text{Binomial}(1, p_i)$$

$$logit(p_i) = \alpha_{property}[i] + (\beta AS + \beta Tr + \beta APP_d) * p_i$$

$$\alpha_{property[i]} \sim \text{Normal}(0, 10)$$

$$\beta X_i \sim \text{Normal}(0, 2.5)$$

A.2.2.2 *Vegetated LR vs agricultural area*

$$R \sim \text{Binomial}(1, p_i)$$

$$logit(p_i) = \alpha_{property}[i] + (\beta AS + \beta Tr + \beta APP_d) * p_i$$

$$\alpha_{property[i]} \sim \text{Normal}(0, 10)$$

$$\beta X_i \sim \text{Normal}(0, 2.5)$$

A.2.2.3 *Non-vegetated LR vs agricultural area*

$$R \sim \text{Binomial}(1, p_i)$$
$$logit(p_i) = \alpha_{property}[i] + (\beta AS + \beta Tr + \beta APP_d + \beta OC + \beta V_d) * p_i$$
$$\alpha_{property[i]} \sim \text{Normal}(0, 10)$$
$$\beta X_i \sim \text{Normal}(0, 2.5)$$

AS = agricultural suitability index (0-1); *Tr*= transportation costs, in minutes; *OC*= opportunity cost, in dollars ha^{-1}; APP_d= Euclidean distance to Areas of Permanent Protection;*A*= farm area, in hectares; V_d= Euclidean distance to natural vegetation.

A.3 SUPPLEMENTARY FIGURES

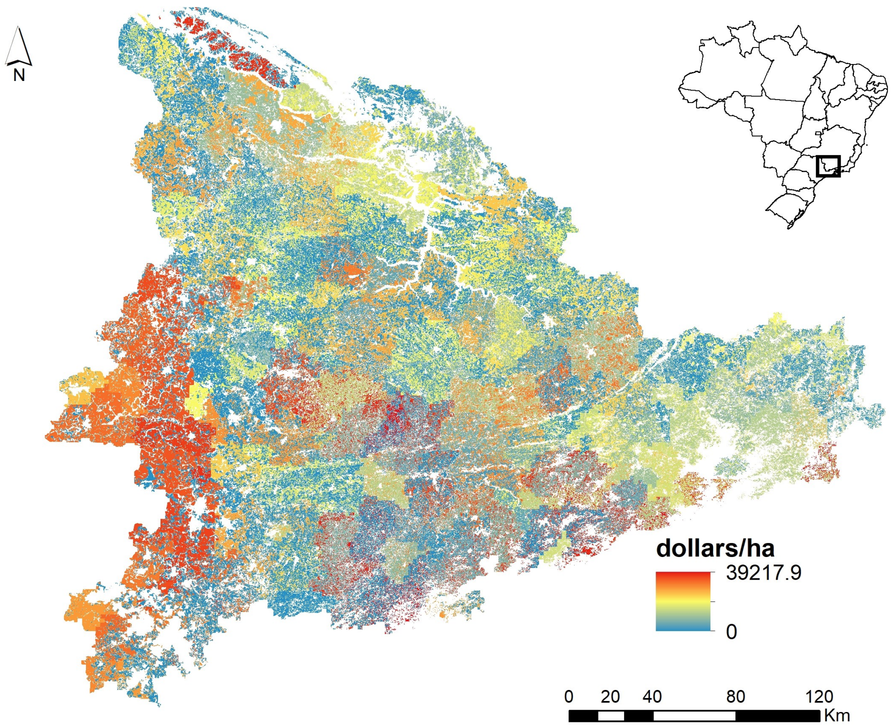


Figure A1 – Opportunity cost layer.

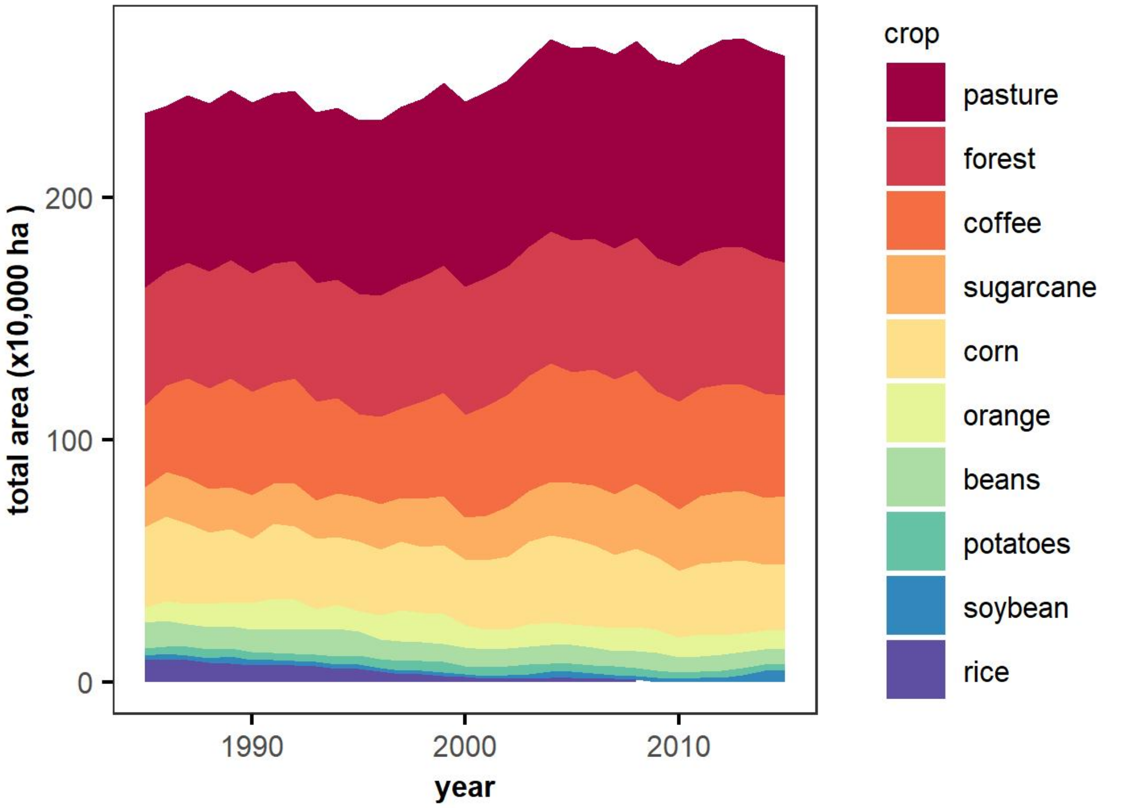


Figure A2 – Main land-uses-land-cover in the study region (>10.000 ha per municipality) from 1985 to 2015. The data on crops and forest cover was collected in march 2019 from IBGE (Brazilian Institute of Geography and Statistics) and the data on pastures was obtained from MapBiomas collection 2.3 (http://mapbiomas.org).

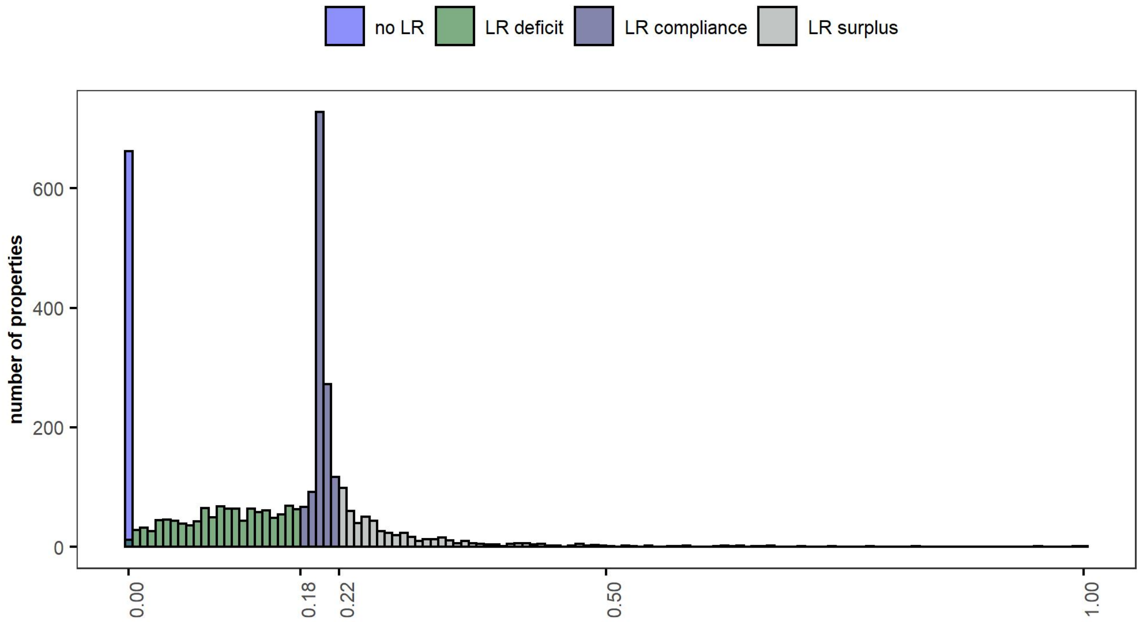


Figure A3 – Properties distributed among their Legal Reserve (LR) proportion for all 3,622 farms analyzed. There is an inflation on 0 and 0.2 values, so we have categorized LR proportion in four classes: no LR (proportion=0); LR deficit (0=proportion<0.18); LR compliance (0.18=proportion=0.22); LR surplus (proportion>0.22)

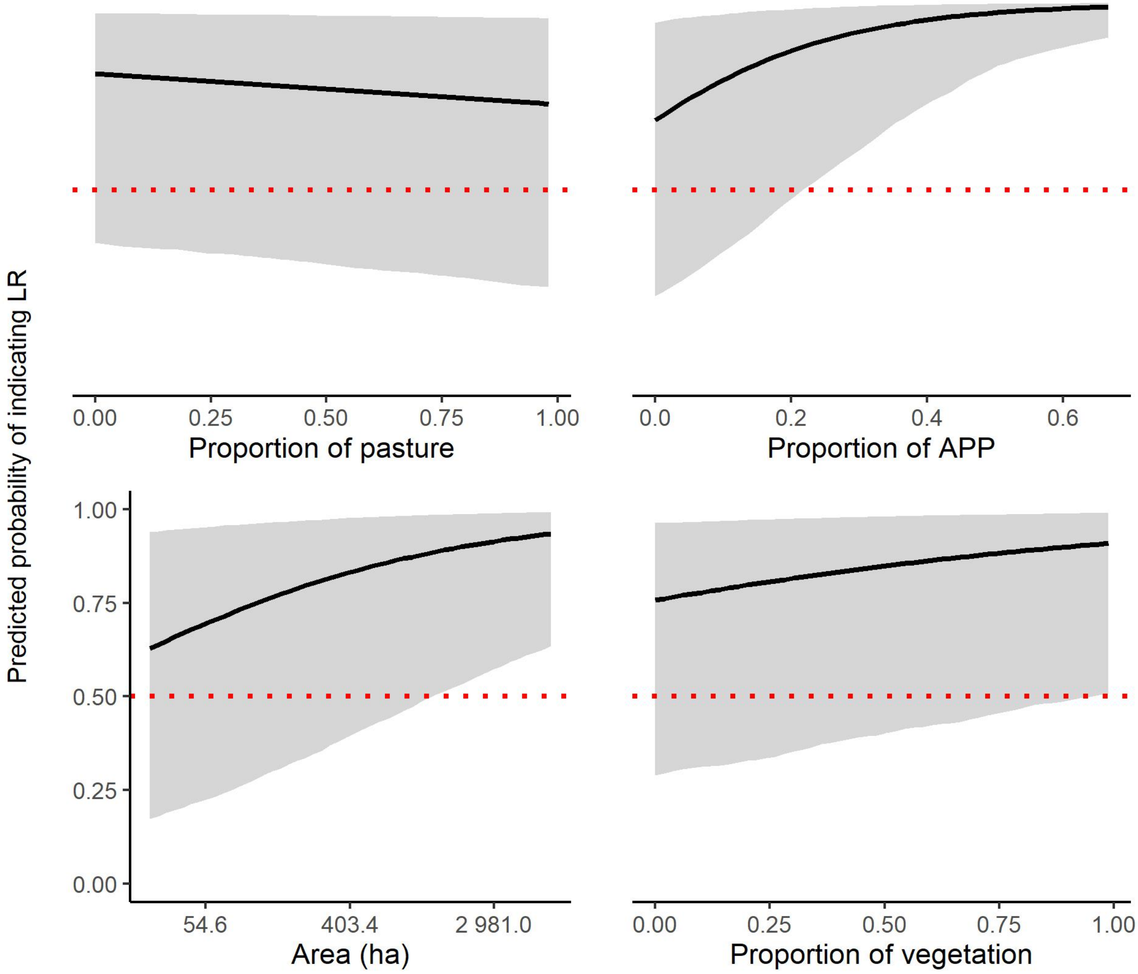


Figure A4 – Predicted probability of a farm to declare LR in contrast with farms that do not have any LR declared. The gray shade is the 95% confidence interval and the dotted red line represents a 50% probability.

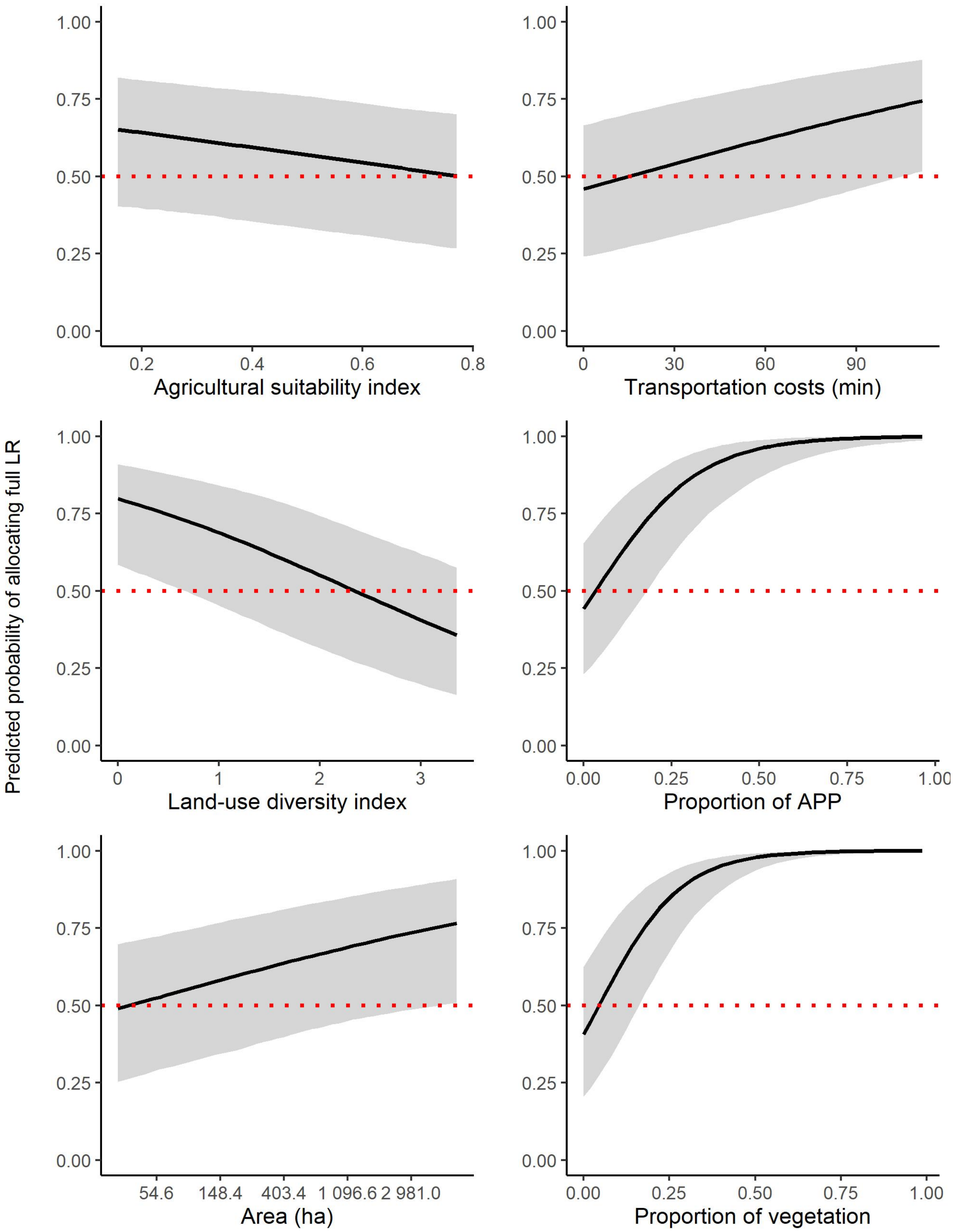


Figure A5 – Predicted probability of a farm to declare the full LR area in contrast with having a LR proportion below the legal requirement inside the farm. The gray shade is the 95% confidence interval and the dotted red line represents 50% probability.

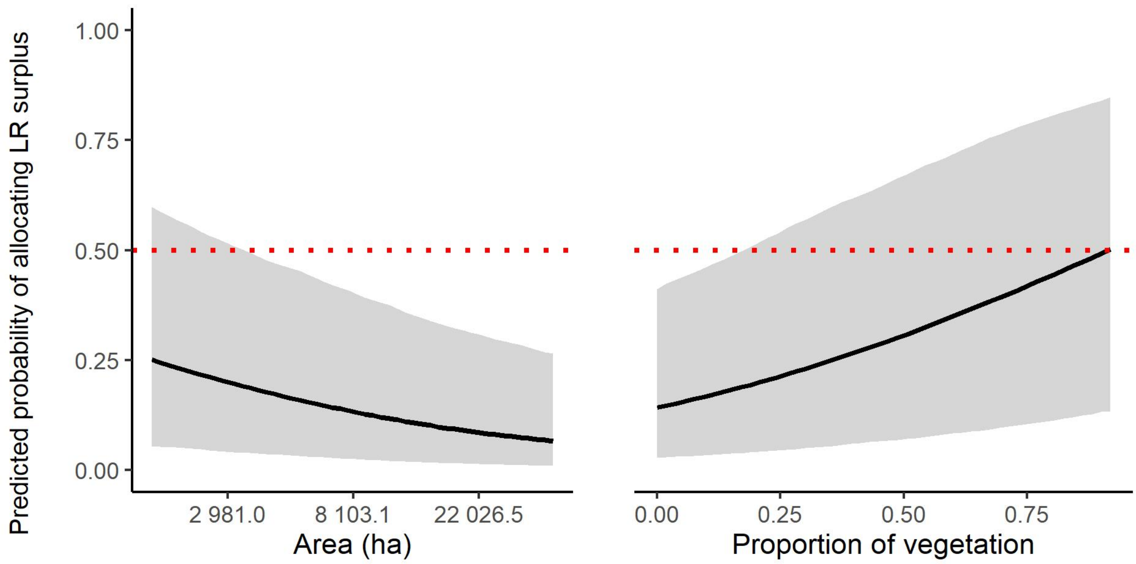


Figure A6 – Predicted probability of a farm area to allocate LR surplus in contrast with having LR compliance only. The gray shade is the 95% confidence interval and the dotted red line represents 50% probability.

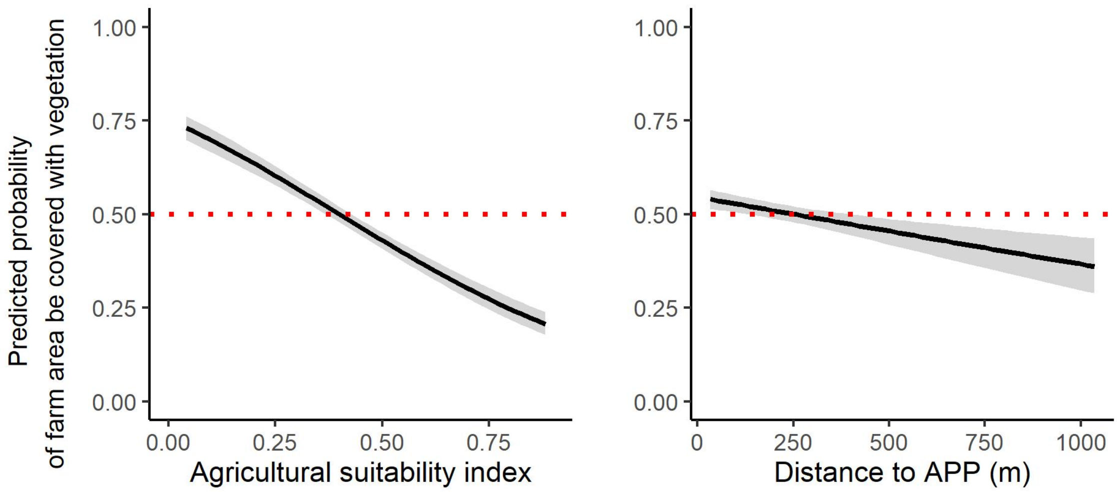


Figure A7 – Predicted probability of a farm area to be covered with natural vegetation in contrast of have being converted to agriculture. The gray shade is the 95% confidence interval and the dotted red line represent 50% probability

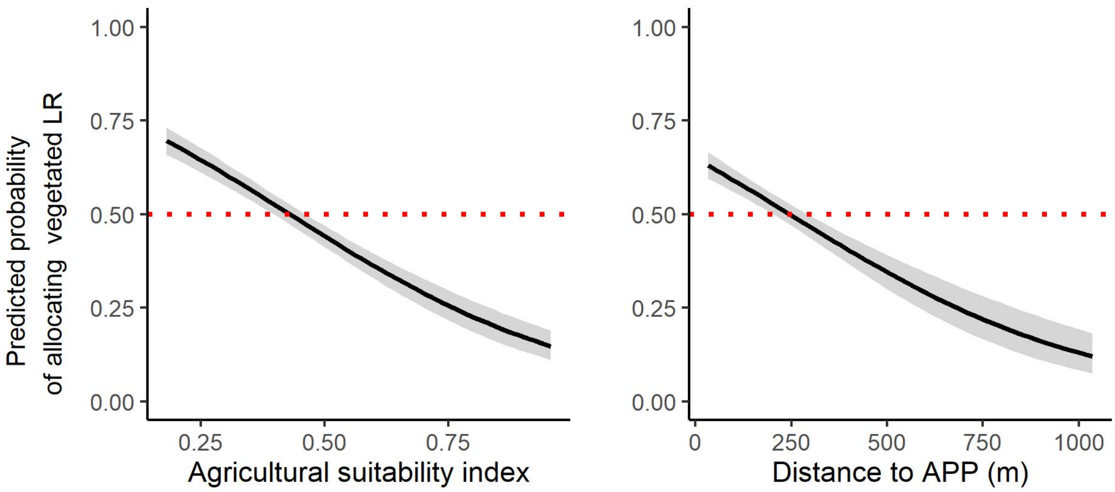


Figure A8 – Predicted probability of a farm area to be allocated as vegetated LRs in contrast with an agricultural area. The gray shade is the 95% confidence interval and the dotted red line represents 50% probability.

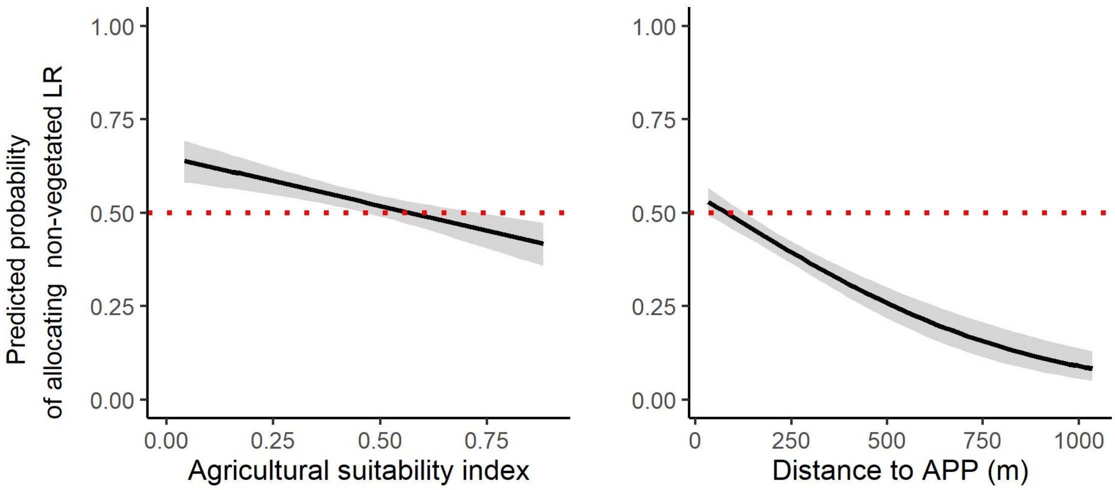


Figure A9 – Predicted probability of a farm area to be allocated as non-vegetated LRs in contrast with agricultural areas. The gray shade is the 95% confidence interval and the dotted red line represents 50% probability.

\newcommand{\beginsupplement2}{

}

\beginsupplement2

APÊNDICE B – SUPPLEMENTARY MATERIAL - CHAPTER 3

B.1 DETAILS ON MODELS CONSTRUCTION AND SELECTION

For the 16 farms which we collected yield data (60 kg bags $ha^(-1)$ per harvest) related to 92 coffee fields, we calculated a set of local and landscape metrics from different years between 2004-2018 (Supplementary Table B1): minimum distance to forest (in meters), coffee field area (ha), coffee field perimeter-area ratio (m/m2), mean agricultural suitability of each coffee field (based on the index developed by Sparovek et al. 2015), the coffee-forest edge density (m/mˆ2), the proportion of vegetation cover surrounding the coffee fields and the proportion of coffee surrounding the coffee fields.

We calculated the landscape metrics (coffee and vegetation cover and the coffee-forest-edge density) on a multiscale circular buffer ranging from 100-1000m radius. Then, for each variable, we fitted a simpler negative binomial regression model to select the scale with the highest likelihood (Supplementary Table B2). With the most suitable scales, we analyzed the colinearity among them to build the final models. The edge density was highly correlated with coffee cover and the property area was correlated with the perimeter-area ratio so we did not include those variables in the same model.

We fitted hierarchical Bayesian models allowing the intercept to vary among year and coffee fields using a negative binomial distribution and uninformative priors. Each model was run with four independent Markov chains of 4000 iterations. The first 2000 was discarded as a warm-up. The model formulation and priors used in the models are presented below.

$$yield/ha \sim \mathrm{NB}(\mu_i, \phi)$$

$$log(\mu_i) = \alpha_{Fl[i]} + \alpha_{Y[j]} + \beta C_{1km} + \beta F_{1km} + \beta C_{1km} : \beta F_{1km} + \beta F_{300m} + \beta PA + \beta S$$

$$\alpha_{Fl[i]\sim Nomral(\alpha,\sigma)}$$

$$\alpha_{Y[j]\sim Nomral(\alpha,\sigma)}$$

$$\alpha \sim Student = t(3, 3.7, 2.5)$$

$$\sigma \sim Student = t(3, 0, 2.5)$$

$$\beta(C_{1km}, F_{1km}, F_{300m}, CED_{1km}, PA, S) \sim flat$$

$$\phi \sim Gamma(0.01, 0.01)$$

where *Fl* is the field, *Y* is the year, *C* is the proportion of coffee on 1 km buffer, F_{1km} is the proportion of forest on 1 km buffer, F_{300m} is the proportion of forest on 300 m buffer, *PA* is the coffee field perimeter-area ratio (m/m_2), CED is the coffe-forest edge density (m/m^2), *S* is the agriculture suitability (0-1) and *i* and *j* are the identity of the field and the year from where yield data was collected.

We selected the final model by comparing the Leave-one-out cross-validation (LOO) of each of the above models. Model 1 had the lower estimated difference of expected leave-one-out prediction errors (Supplementary Table 3). We also tested whether the removal of the agriculture suitability would incur a worse performance, which did not happen so our final yield model is similar to model 1, without the agriculture suitability.

B.2 UNEXPECTED YIELD TRENDS FOR REGIONAL-LEVEL SCENARIOS

Contrary to our expectation, the regional-level approach led to a yield decrease when we target 30 and 40% forest cover. Meta-analyses on the effects of agricultural diversification have previously identified both positive and negative yield responses (**karp_crops_2018**; TAMBURINI *et al.*, 2020). Complex multitrophic interactions among natural enemies, pests, and crops might lead to more context-dependent situations [Karp *et al.* (2018); libran-embid_effects_2017], for instance, in which pests are benefited rather than decrease with more surrounding natural vegetation, negatively affecting coffee yield. With such levels of complexity, we might not be able to fully explain this pattern. Nevertheless, we raise two possible complementary explanations. Firstly, regional scenarios induced more concentrated forest patches, favouring situations of high forest cover (>50%) and low coffee cover (<10%) (Supplementary Figure B4). Farms in a similar situation used to build our predictive yield model had lower yields (Supplementary Figure B2a), which can be a consequence of a lower productivity potential where they are located, resulting in higher forest cover. A similar pattern was described for coffee production at the Atlantic Forest, where municipalities with higher forest cover have higher coffee production up to a limit of around 30-40%, above which yield drops (GONZÁLEZ-CHAVES; JAFFÉ *et al.*, 2020). Besides, a block-like configuration of forests reduces the flows of ecosystem services 6 if coffee and forests are distant. Secondly, those same farms used to build the model might have faced negative side-effects of increased pest damage associated with forests, affecting their yields. As a result, our model is penalizing coffee fields in situations of high forest cover and low coffee cover after the restoration.

B.3 SUPPLEMENTARY FIGURES

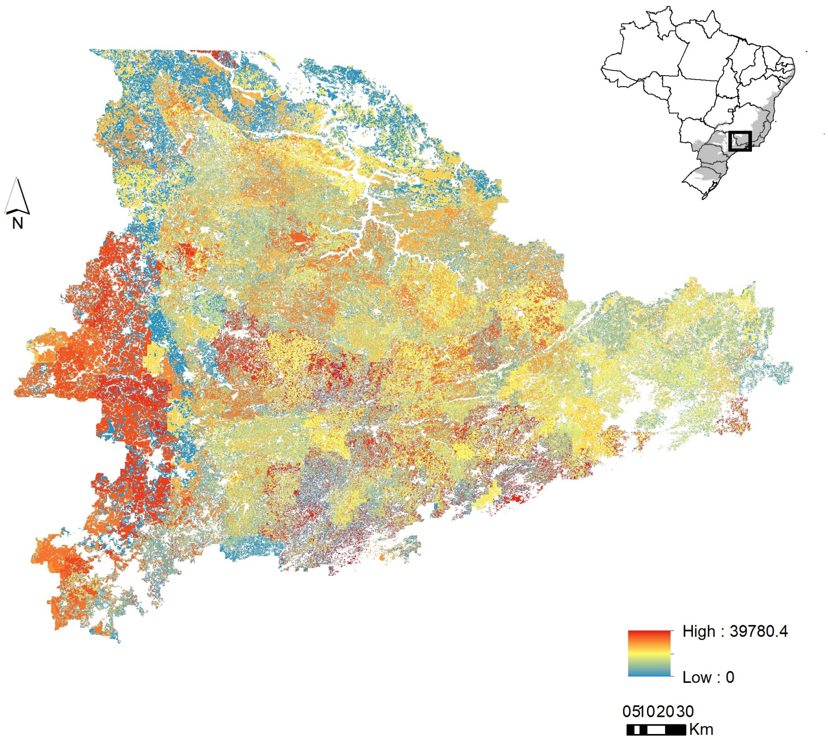


Figure B1 – Cost surface generated by the combination of opportunity cost and restoration cost. Restoration costs for the scenarios were estimated using a 30 m resolution raster containing the probability of natural regeneration or the necessity of actively planting seedlings7 and costs with restoration from projects within the Atlantic Rainforest8 .

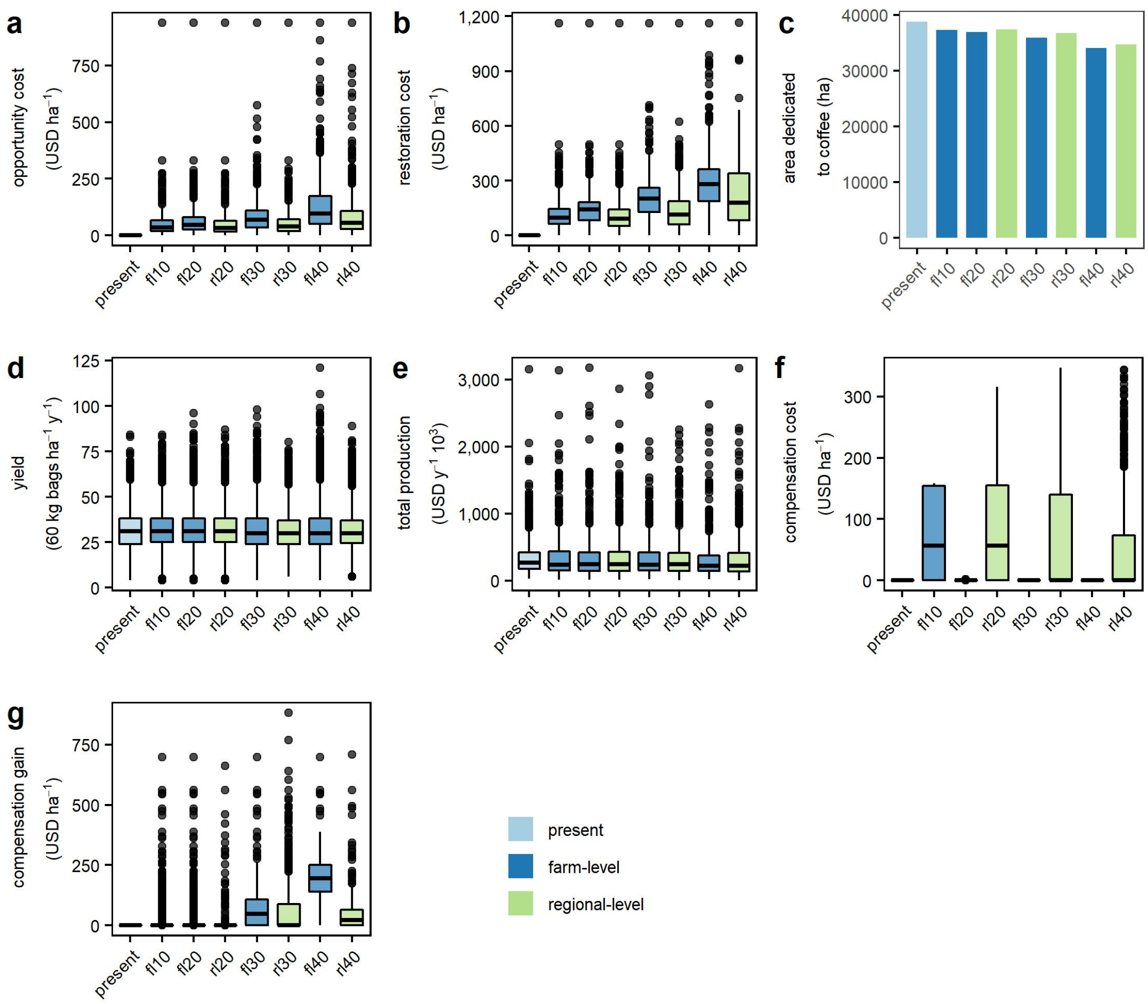


Figure B2 – Cost and benefits used to calculate the final cash flow after the restoration interventions in each scenario. Opportunity cost with forgone production of non-coffee products divided by farm area (a); restoration costs over 20 years divided by farm area; (b); total coffee area (c); coffee field yield estimated with our spatial yield model(d); total coffee production estimated with the yield model (e); net change in coffee production divided by farm area comparing the future scenarios with the baseline scenario (f); compensation costs divided by farm area for farms with forest cover < 20 % after the restoration intervention (g); compensation gains divided by farm area for farms with forest cover > 20 % after the restoration intervention (h). Cash values were converted to 2017 US dollars. Farm-level = fl; regional-level=rl.

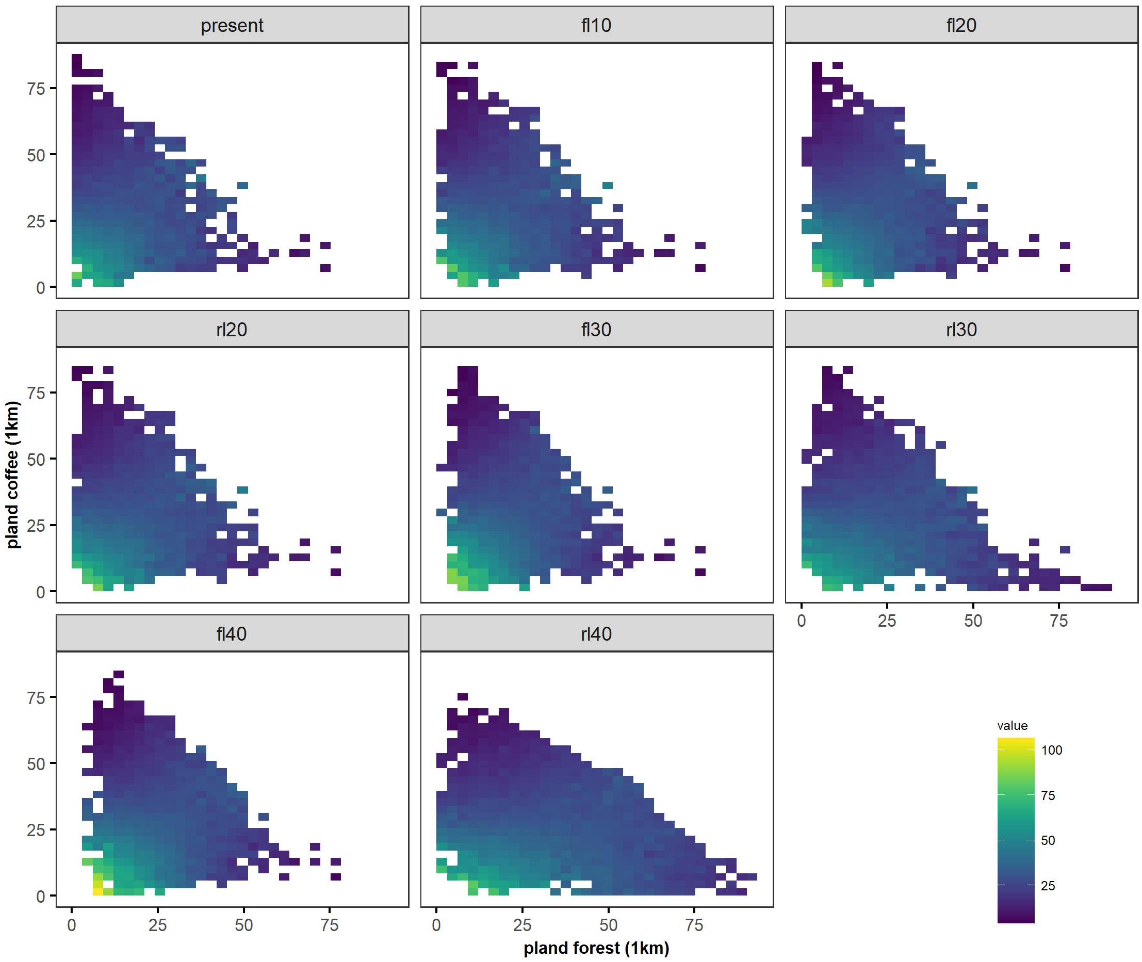


Figure B3 – Predicted yield values for the coffee fields in each scenario. Modelled Yield in function of the proportion of forest (x axis) and coffee (y axis) on a 1km circular buffer surrounding the coffee fields. Farm-level = fl; regional-level=rl.

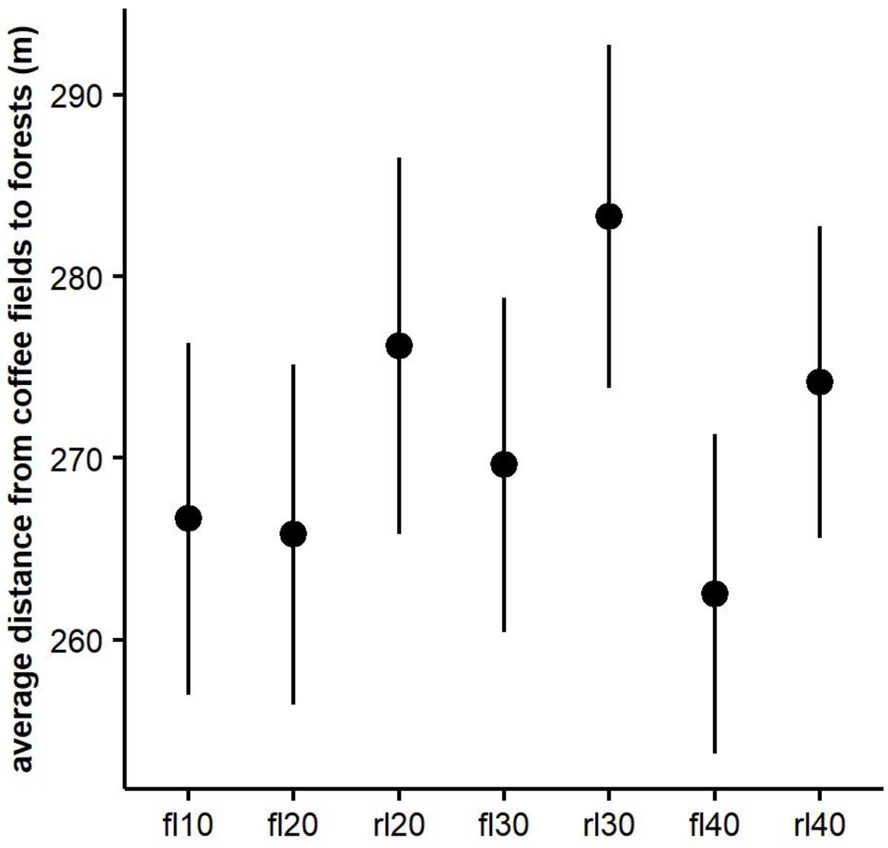


Figure B4 – Average distance from coffee fields to forests. After generating the land use cover for the scenarios, we calculated the mean distance to forest areas ±1 standard error. Farm-level = fl; regional-level=rl.

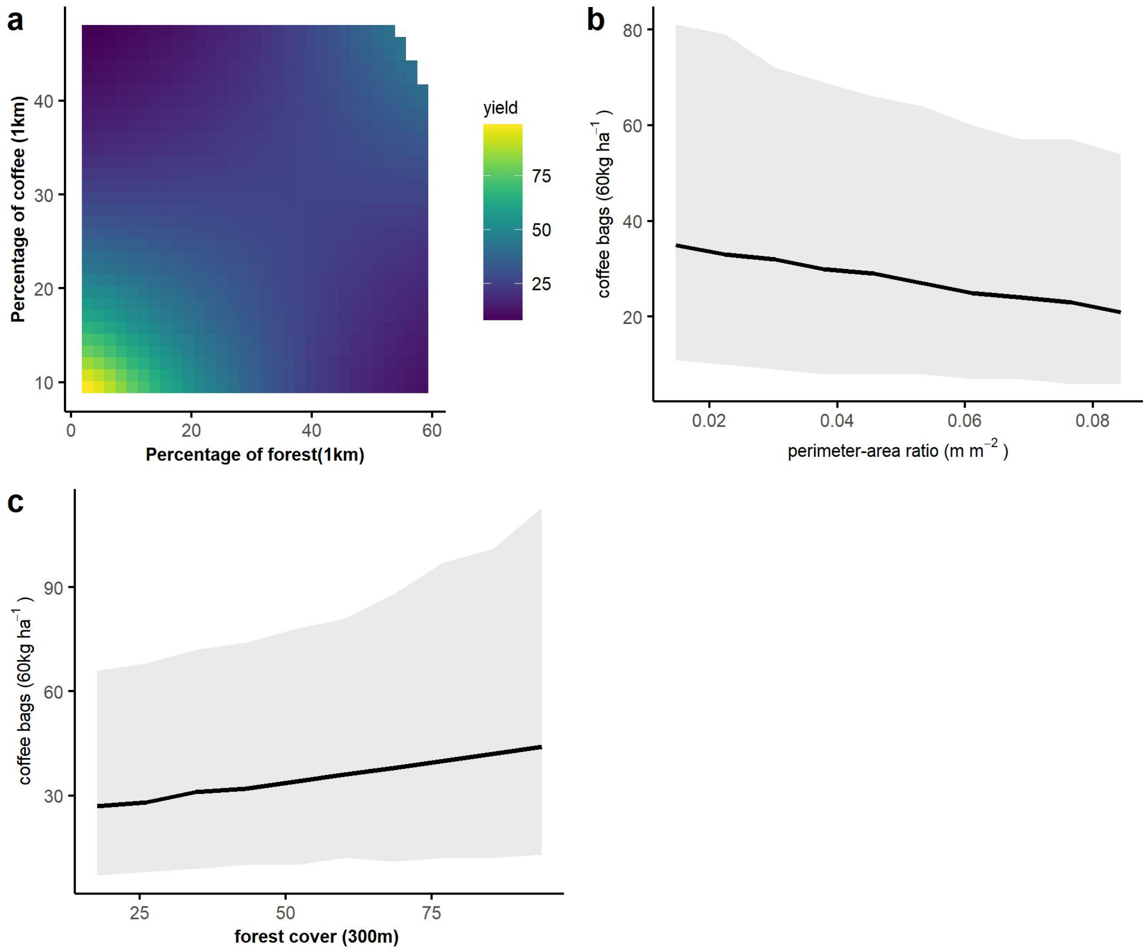


Figure B5 – Final yield model explanatory variables effect on yield. The interaction between the proportion of coffee and forest on a circular buffer surrounding coffee fields (a); the perimeter-area ratio of the coffee fields; and the local forest cover on a circular buffer around the coffee fields.

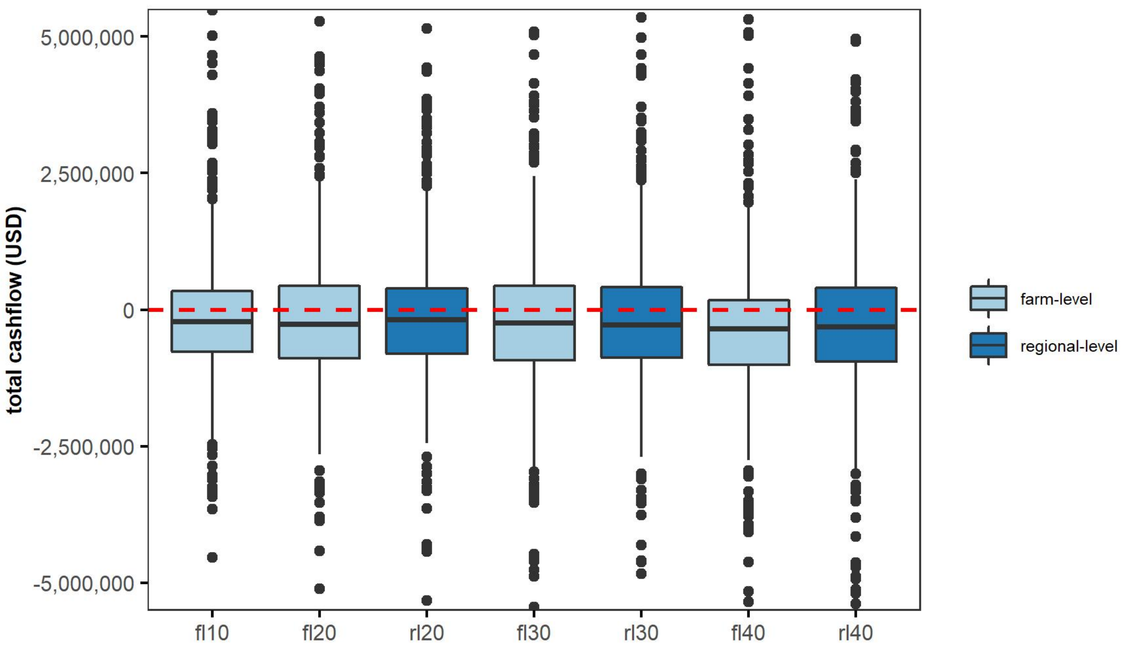


Figure B6 – Farm's cash flow distribution for each scenario. Cash values were converted to 2017 US dollars. Farm-level = fl; regional-level=rl.

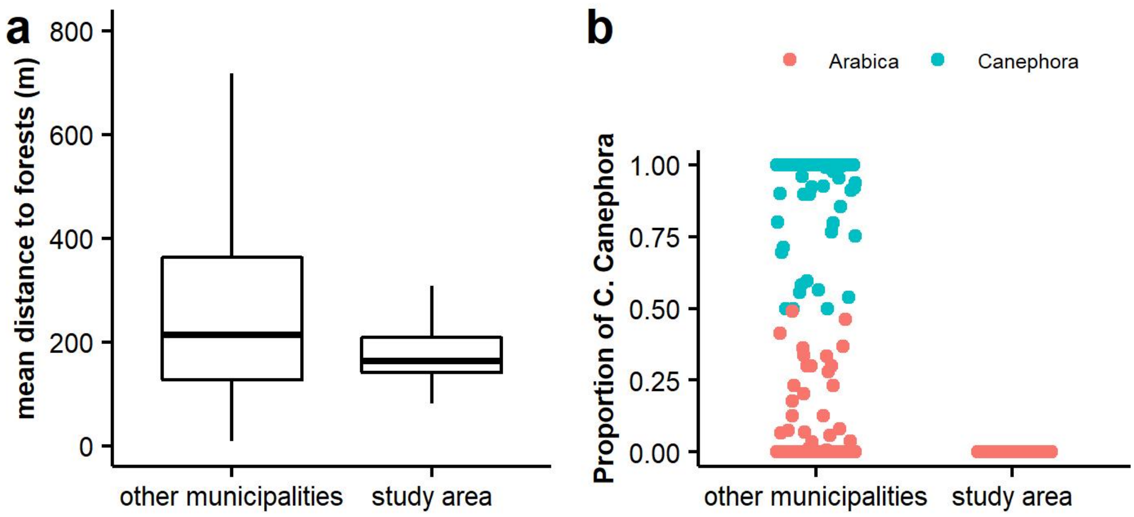


Figure B7 – Comparison between muncipa lities within our study region and other municipalities in the Atlantic Forest growing coffee. Coffee fields are on average 33 % closer to forest patches (163.8m vs. 219.3m) in our region (a). Further, while in our region only C. arabica is grown, 16 % of the municipalities elsewhere grow C. canephora and in 12 % of them, C. canephora is predominant (b). Unlike Coffea arabica, C. canephora is self-sterile and might be more benefited by a higher abundance of pollinators 5 . The boxplots on show the lower quartile, the median, and the upper quartile of the data distribution. Data from Gonzales-Chaves et al(2020).

B.4 SUPPLEMENTARY TABLES

Table B1 – Yield/ha data used to build the yield model. The columns correspond to the harvest year and the numbers bellow are the number of fields per farms (identified in the table with a number ID.)

Farm ID	2006	2008	2009	2010	2013	2014	2015	2016	2018
1	1	2	7	2	0	0	0	0	0
2	0	0	0	0	7	0	0	0	0
3	0	0	0	0	0	0	30	0	0
4	0	0	0	0	0	7	0	0	0
5	0	0	0	0	0	0	8	0	1
6	0	0	0	0	0	8	3	0	0
7	0	0	0	0	3	0	0	0	0
8	0	0	0	0	0	0	2	0	0
9	0	0	0	0	0	0	0	3	0
10	0	0	0	0	0	0	0	0	1
11	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	1
13	0	0	0	0	0	0	0	0	1
14	0	0	0	0	0	0	0	0	2
15	0	0	0	0	0	0	0	0	1
16	0	0	0	0	0	0	0	1	0

Table B2 – Independent variables tested to fit the coffee yield model. We included variables in two different scales: local scale (lo) and landscape scale (ls).

variable	data generation	scale
Minimum distance to forest (m)	Euclidean distance between the coffee field and the closest forest patch	lo
Area (ha)	Area of each farm	lo
Perimeter-area ratio (m/m^2)	Perimeter of each coffee field divided by its area	lo

variable	data generation	scale
Mean agricultural suitability index (0-1)	Mean agricultural suitability of each coffee field based on the index published by Sparovek et al. (2015), in which values clorser to 1 have higher suitability for agriculture.	lo
Coffee-forest edge density (m/m^2)	Length of the contact edges between coffee and forests divided by the area of the landscape surrounding the coffee field	ls
Vegetation cover	Proportion of circular buffer landscape (radius range 100-1000m)surrounding the coffee field covered by forest	ls,lo
Coffee proportion	Proportion of circular buffer landscape (radius range 100-1000m) surrounding the coffee field covered by coffee	ls,lo

Table B3 – AIC table for the landscape variables tested to build the yield model. Models (M) are ranked by their likelihood for each variable tested (proportion of coffee, coffee-forest edges and proportion of forests). The variables were calculated on a multiscale circular buffer surrounding the coffee fields, ranging from 100-1000 meteres. Models with lower AIC were considered more plausible. Df – degrees of freedom; logLik – log likelihood; AIC – Akaike Information Criteria; delta is the diferrence between the AIC of the first ranked model and the rest.

M	Int.	100	200	300	400	500	600	700	800	900	1000	df	logLik	AIC	delta	weight
Coffee proportion																
1	3.584										-0.297	3	-389.807	785.886	0	0.676
2	3.587									-0.285		3	-391.019	788.311	2.425	0.201
3	3.59								-0.279			3	-391.99	790.253	4.367	0.076
4	3.592							-0.278				3	-392.631	791.534	5.649	0.04
5	3.597						-0.26					3	-394.441	795.155	9.27	0.007
6	3.604					-0.23						3	-396.705	799.682	13.796	0.001
7	3.612				-0.185							3	-399.193	804.659	18.773	0
8	3.617			-0.148								3	-400.776	807.824	21.938	0
9	3.62		-0.121									3	-401.663	809.599	23.713	0
10	3.623	-0.092										3	-402.461	811.195	25.309	0
N	3.627											2	-403.666	811.466	25.58	0
edge density																
11	3.602										-0.23	3	-396.088	798.448	0	0.385
12	3.603									-0.223		3	-396.525	799.323	0.875	0.249
13	3.605						-0.223					3	-397.237	800.747	2.299	0.122
14	3.606								-0.212			3	-397.388	801.048	2.599	0.105
15	3.607							-0.21				3	-397.777	801.826	3.378	0.071
16	3.609					-0.207						3	-398.269	802.812	4.363	0.043
17	3.611				-0.193							3	-399.08	804.432	5.984	0.019
18	3.617			-0.151								3	-400.892	808.057	9.608	0.003
19	3.623		-0.098									3	-402.481	811.235	12.786	0.001
20	3.627											2	-403.666	811.466	13.018	0.001
N	3.625	-0.065										3	-403.114	812.501	14.053	0
Forest cover																
21	3.623									-0.088		3	-402.57	811.413	0	0.134
22	3.623										-0.088	3	-402.572	811.416	0.003	0.134
23	3.627											2	-403.666	811.466	0.053	0.131
24	3.624								-0.082			3	-402.729	811.731	0.318	0.114
25	3.624							-0.081				3	-402.747	811.767	0.354	0.112
26	3.624						-0.079					3	-402.808	811.888	0.475	0.106
27	3.625					-0.061						3	-403.165	812.602	1.189	0.074
28	3.626				-0.037							3	-403.485	813.242	1.829	0.054
29	3.627		0.028									3	-403.56	813.393	1.98	0.05
30	3.627	0.012										3	-403.648	813.569	2.156	0.046
N	3.627			0.006								3	-403.661	813.594	2.181	0.045

Table B4 – Comparison among the final models tested. We compared the estimated difference of expected leave-one-out prediction errors (elpd diff) and their standard error difference (se diff). Model 1’ is similar to model 1, but without the agricultural suitability.

	elpd diff.	se diff
1’	0.0	0.0
1	-1.3	0.4
2	-3.6	3.4
3	-4.1	4.0

\newcommand{\beginsupplement2}{

}

\beginsupplement2

APÊNDICE C – SUPPLEMENTARY MATERIAL - CHAPTER 4

C.1 SUPPLEMENTARY FIGURES

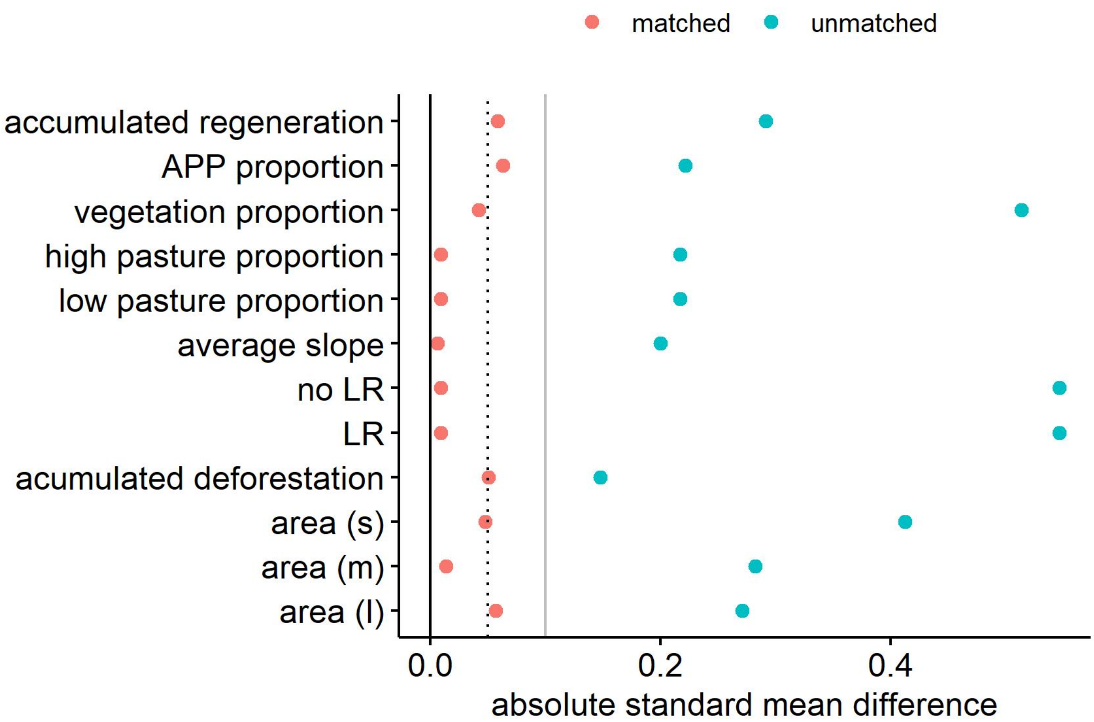


Figure C1 – Balance between matching covariates for properties within the Atlantic Forest. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha). Size ranges for small, medium or large properties are defined by the government at the municipal level, in accordance with intrinsic characteristics of the region. For this reason, there are overlaps between categories. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. .

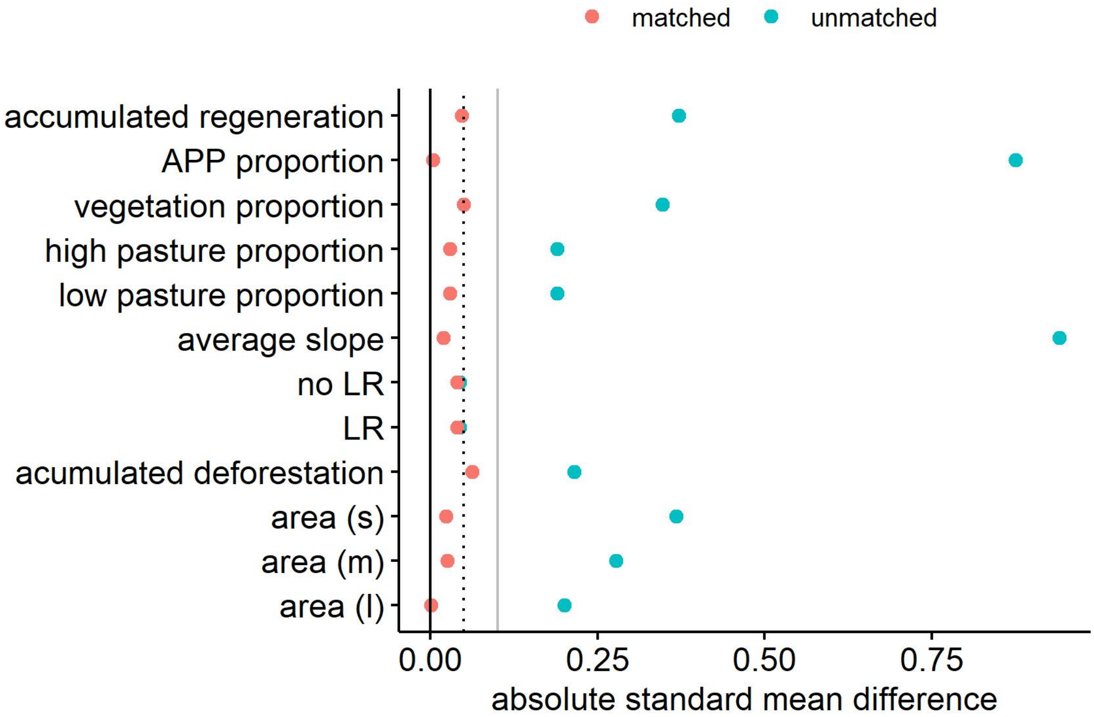


Figure C2 – Balance between matching covariates for properties within the Cerrado. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha). Size ranges for small, medium or large properties are defined by the government at the municipal level, in accordance with intrinsic characteristics of the region. For this reason, there are overlaps between categories. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. .

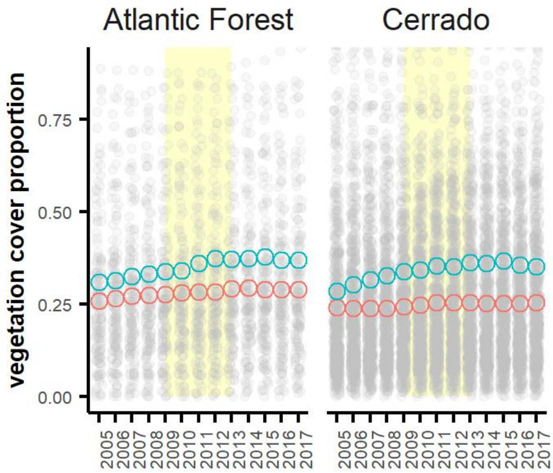


Figure C3 – Exploratory annual trends for the proportion of vegetation cover at certified and non-certified properties. The distribution of values is illustrated by the grey dots and the average annual value by the red and blue dots, for non-certified and certified farms, respectively. The yellow shade is delimited by the minimum and median certification dates.

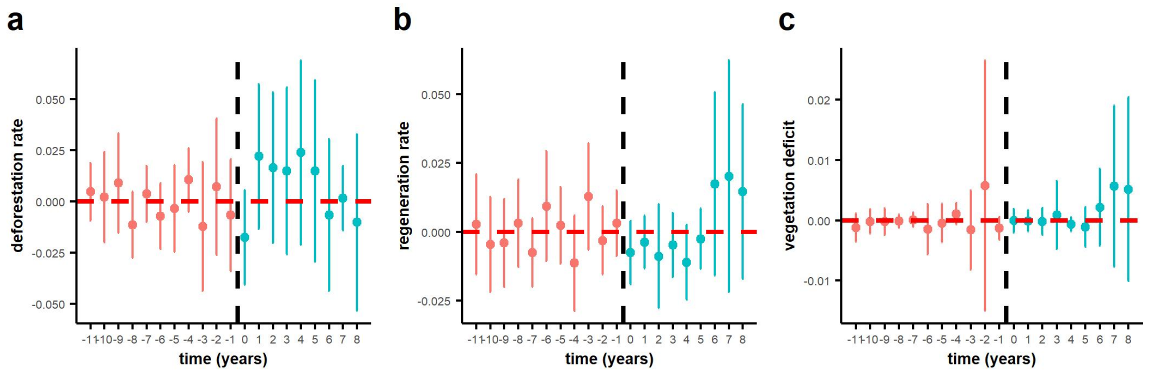


Figure C4 – Average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of one year. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), and in the vegetation deficit outside APPs (c). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

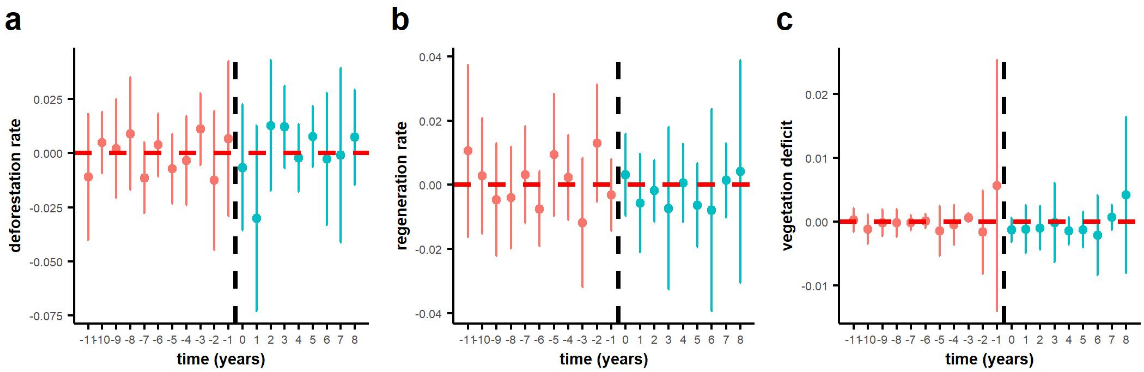


Figure C5 – Average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of two years. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), and in the vegetation deficit outside APPs (c). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

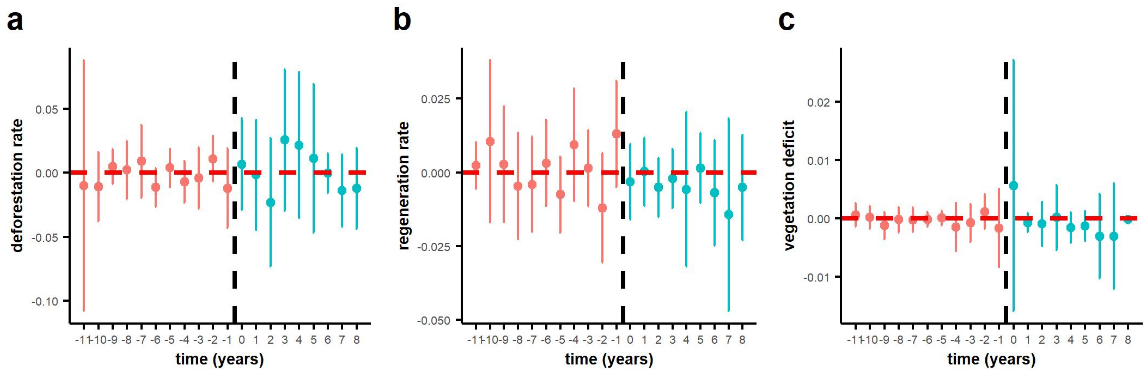


Figure C6 – Average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of three years. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), and in the vegetation deficit outside APPs (c). The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

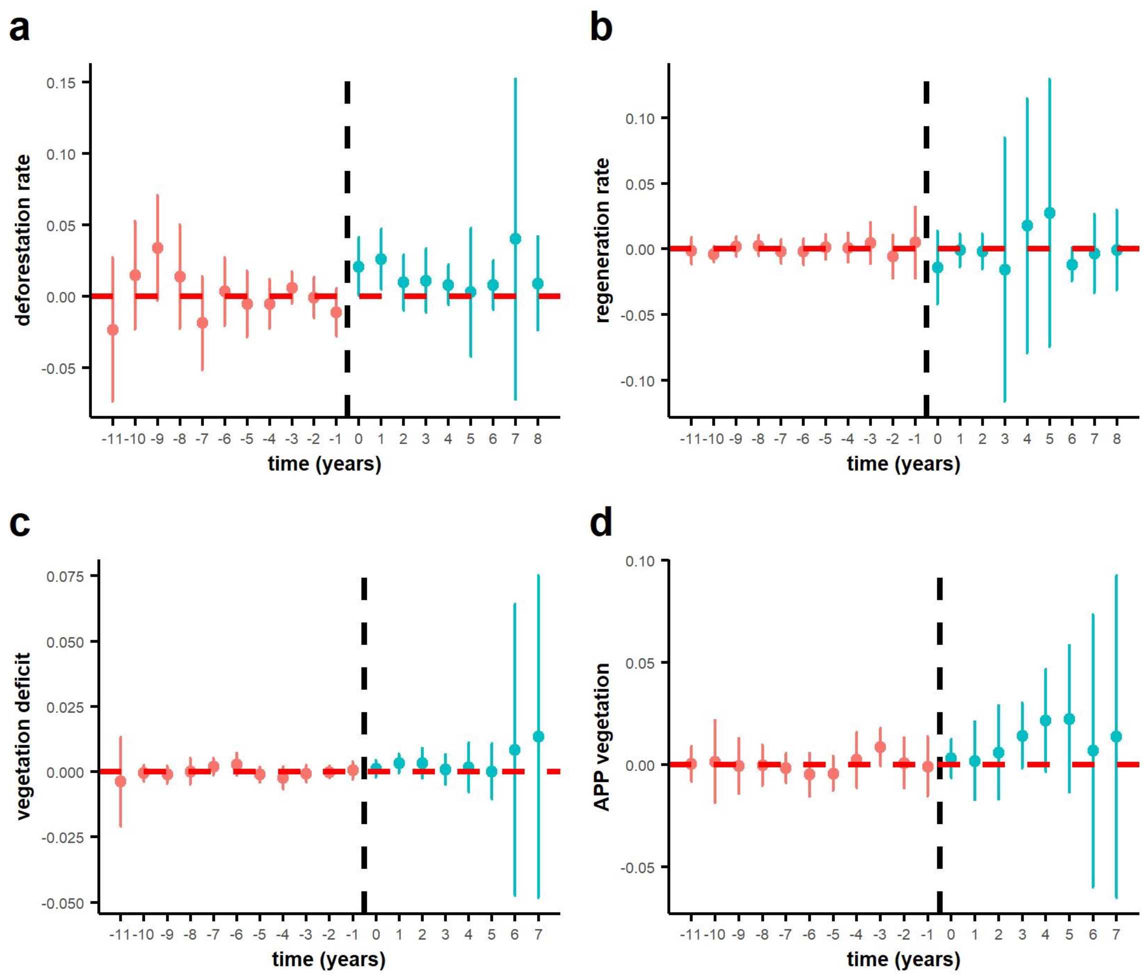


Figure C7 – Average group-time treatment effect for properties within the Cerrado, considering an anticipation effect of one year. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), the vegetation deficit outside APPs (c), and the proportion of APP covered with natural vegetation between certified and non-certified farms. The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

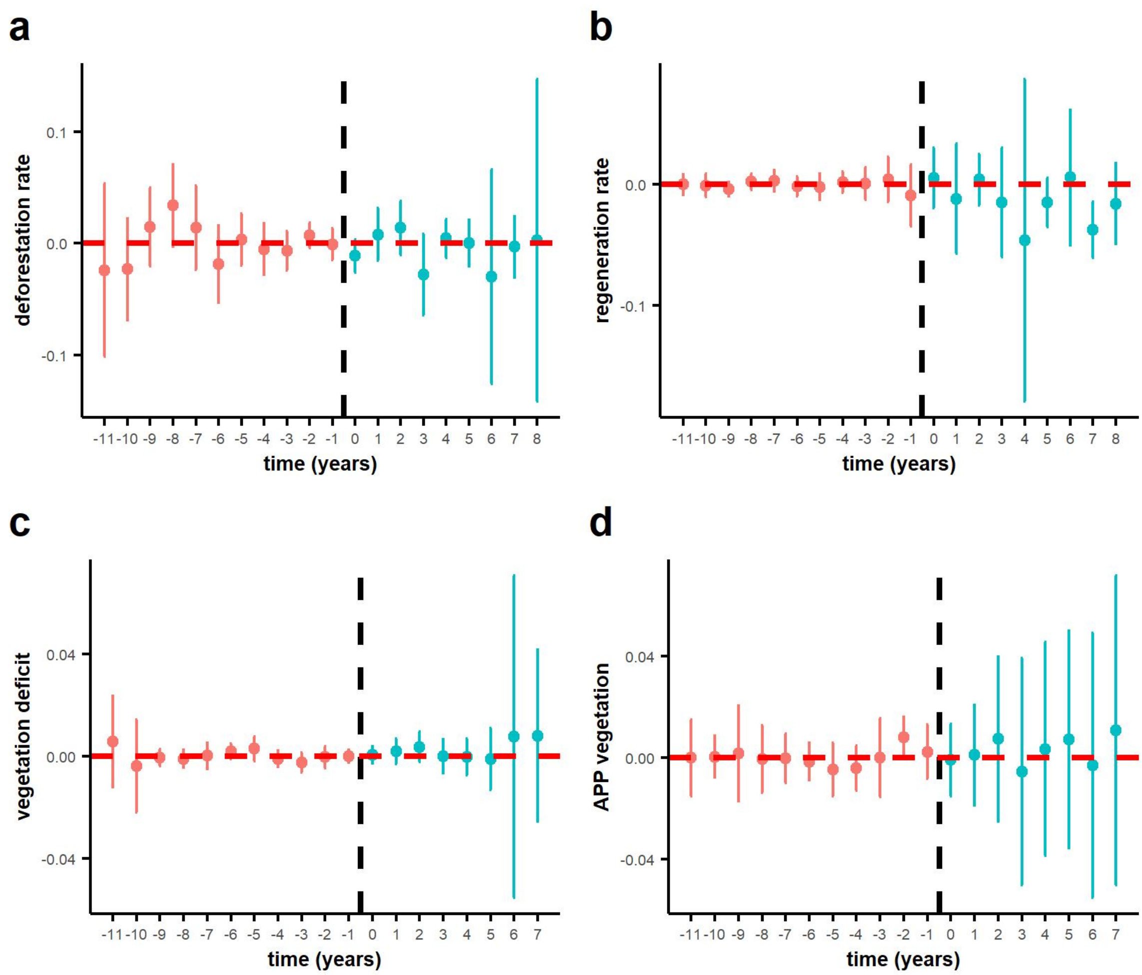


Figure C8 – Average group-time treatment effect for properties within the Cerrado, considering an anticipation effect of two years. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), the vegetation deficit outside APPs (c), and the proportion of APP covered with natural vegetation between certified and non-certified farms. The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

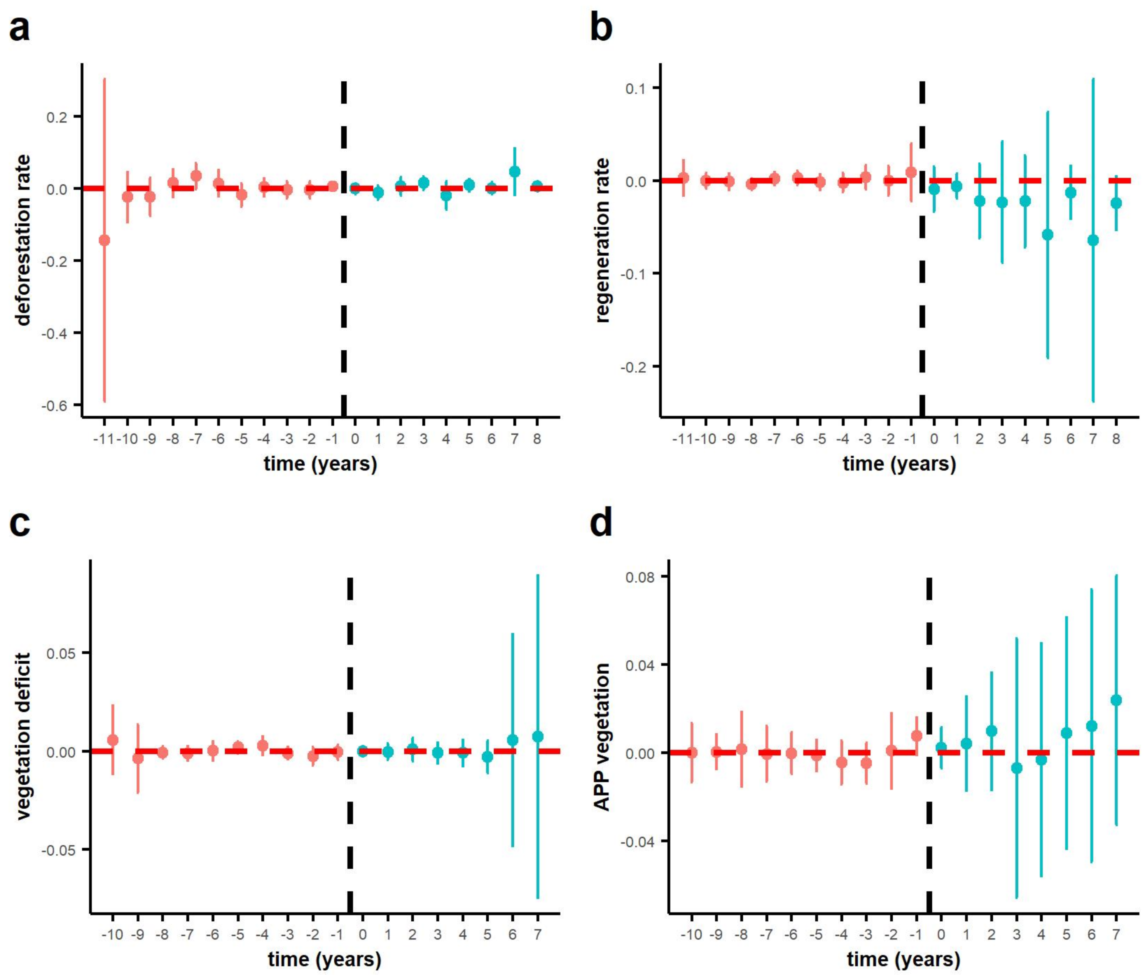


Figure C9 – Average group-time treatment effect for properties within the Cerrado, considering an anticipation effect of three years. The red dots show the point estimates and 95 % confidence bands for the period pre-treatment. The blue dots show the point estimates and 95 % confidence bands for the period post-treatment. The figure shows the average effect in deforestation (a), natural regeneration (b), the vegetation deficit outside APPs (c), and the proportion of APP covered with natural vegetation between certified and non-certified farms. The x-axis represents the certification time: negative values are years before the certification and positive values are years after the certification, which is represented in time zero. Confidence bands crossing the zero on the y axis (red dotted line) are non-significant. Positive values mean that the treatment had a positive effect and negative values the opposite.

C.2 SUPPLEMENTARY TABLES

Table C1 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Atlantic Forest. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection.

variable	mean value treated	mean value control	standard mean difference	matching
area (large properties)	0.0756	0.0039	0.2711	unmatched
	0.0592	0.0442	0.0567	matched
area (medium properties)	0.1453	0.0458	0.2826	unmatched
	0.1479	0.1432	0.0134	matched
area (small properties)	0.7791	0.9503	-0.4127	unmatched
	0.7929	0.8126	-0.0475	matched
accumulated deforestation	0.0350	0.0201	0.1475	unmatched
	0.0349	0.0298	0.0504	matched
no LR	0.0814	0.2308	-0.5465	unmatched

Table C1 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Atlantic Forest. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. *(continued)*

variable	mean value treated	mean value control	standard mean difference	matching
	0.0828	0.0805	0.0087	matched
LR	0.9186	0.7692	0.5465	unmatched
	0.9172	0.9195	-0.0087	matched
average slop	13.2438	12.1266	0.2000	unmatched
	13.2396	13.2057	0.0061	matched
low pasture proportion	0.4884	0.3799	0.2169	unmatched
	0.4911	0.4868	0.0087	matched
high pasture proportion	0.5116	0.6201	-0.2169	unmatched
	0.5089	0.5132	-0.0087	matched
vegetation proportion	0.3381	0.1793	0.5137	unmatched

Table C1 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Atlantic Forest. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. *(continued)*

variable	mean value treated	mean value control	standard mean difference	matching
	0.3373	0.3502	-0.0418	matched
APP proportion	0.0861	0.1080	-0.2216	unmatched
	0.0854	0.0792	0.0631	matched
accumulated regeneration	0.0334	0.0160	0.2913	unmatched
	0.0337	0.0372	-0.0586	matched

Note:
* Size ranges for small, medium or large properties are defined by the government at the municipal level,in accordance with intrinsic characteristics of the region
. For this reason, there are overlaps between categories.

Table C2 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Cerrado. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection.

variable	mean value treated	mean value control	standard mean difference	matching
area (large properties)	0.0740	0.0216	0.2001	unmatched
	0.0746	0.0748	-0.0007	matched
area (medium properties)	0.2247	0.1087	0.2778	unmatched
	0.2238	0.2341	-0.0247	matched
area (small properties)	0.7014	0.8697	-0.3678	unmatched
	0.7017	0.6912	0.0229	matched
accumulated deforestation	0.0693	0.0339	0.2147	unmatched
	0.0692	0.0589	0.0623	matched
no LR	0.1616	0.1456	0.0437	unmatched

Table C2 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Cerrado. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. *(continued)*

variable	mean value treated	mean value control	standard mean difference	matching
	0.1575	0.1720	-0.0395	matched
LR	0.8384	0.8544	-0.0437	unmatched
	0.8425	0.8280	0.0395	matched
average slop	4.6872	6.6673	-0.9408	unmatched
	4.7059	4.6644	0.0197	matched
low pasture proportion	0.2082	0.2851	-0.1894	unmatched
	0.2099	0.1983	0.0286	matched
high pasture proportion	0.7918	0.7149	0.1894	unmatched
	0.7901	0.8017	-0.0286	matched
vegetation proportion	0.1958	0.2632	-0.3472	unmatched

Table C2 – Covariates mean values and standard mean difference before (unmatched) and after the matching procedure (matching) for properties at the Cerrado. The farms were divided in large (267 - 8761 ha), medium (64 ha– 974 ha) and small farms (0.5 ha – 260 ha)*. The accumulated deforestation and regeneration are the sum of the deforestation and regeneration ratios between 2004-2009. The farms were also divided on the ones with no Legal Reserve (LR) and the ones with LR. We have also treated the proportion of pasture as categorical, using a threshold of 0.25 to divide them into low and high pasture proportion. The APP proportion is the proportion of the farm's area covered with areas of permanent protection. *(continued)*

variable	mean value treated	mean value control	standard mean difference	matching
	0.1952	0.1855	0.0498	matched
APP proportion	0.0566	0.1260	-0.8757	unmatched
	0.0570	0.0568	0.0031	matched
accumulated regeneration	0.0508	0.0163	0.3714	unmatched
	0.0466	0.0422	0.0466	matched

Note:

* Size ranges for small, medium or large properties are defined by the government at the municipal level,in accordance with intrinsic characteristics of the region
. For this reason, there are overlaps between categories.

Table C3 – Accuracy results of the land-use and land-cover classification at the property level. We generated 168 random points within the boundaries of the certified farms. Then, we performed a visual analysis comparing the Mapbiomas collection 5 classification with a RGB composition with Landsat TM 5 bands for the year 2007. When in doubt, we also used satellite images from Google Earth.

class	correct classification	number of points	accuracy(%)
mosaic crops and pastures	14	27	51.90
pasture	39	55	70.90
temporary crops	27	29	93.10
natural vegetation	24	30	80.00
Total accurarcy			73.76

Table C4 – Deforestation average group-time treatment effect for properties within the Atlantic Forest: average treatment effect (ATT), standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-10	0.0057	0.0113	-0.0227	0.0340
-9	-0.0276	0.0186	-0.0741	0.0190
-8	0.0055	0.0045	-0.0057	0.0168
-7	-0.0026	0.0066	-0.0191	0.0140
-6	-0.0012	0.0051	-0.0141	0.0117
-5	0.0061	0.0067	-0.0107	0.0229
-4	-0.0042	0.0052	-0.0173	0.0089
-3	-0.0004	0.0050	-0.0128	0.0121
-2	0.0037	0.0041	-0.0065	0.0140
-1	-0.0051	0.0042	-0.0157	0.0055
0	0.0098	0.0121	-0.0204	0.0400
1	0.0103	0.0079	-0.0095	0.0300
2	0.0047	0.0047	-0.0071	0.0165
3	0.0079	0.0052	-0.0051	0.0208
4	0.0118	0.0055	-0.0021	0.0256
5	0.0012	0.0116	-0.0278	0.0302
6	0.0064	0.0108	-0.0207	0.0335
7	0.0061	0.0161	-0.0341	0.0464

Table C5 – Deforestation average group-time treatment effect for properties within the Cerrado: average treatment effect (ATT), standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-10	0.0057	0.0113	-0.0227	0.0340
-9	-0.0276	0.0186	-0.0741	0.0190
-8	0.0055	0.0045	-0.0057	0.0168
-7	-0.0026	0.0066	-0.0191	0.0140
-6	-0.0012	0.0051	-0.0141	0.0117
-5	0.0061	0.0067	-0.0107	0.0229
-4	-0.0042	0.0052	-0.0173	0.0089
-3	-0.0004	0.0050	-0.0128	0.0121
-2	0.0037	0.0041	-0.0065	0.0140
-1	-0.0051	0.0042	-0.0157	0.0055
0	0.0098	0.0121	-0.0204	0.0400
1	0.0103	0.0079	-0.0095	0.0300
2	0.0047	0.0047	-0.0071	0.0165
3	0.0079	0.0052	-0.0051	0.0208
4	0.0118	0.0055	-0.0021	0.0256
5	0.0012	0.0116	-0.0278	0.0302
6	0.0064	0.0108	-0.0207	0.0335
7	0.0061	0.0161	-0.0341	0.0464

Table C6 – Regeneration average group-time treatment effect for properties within the Atlantic Forest: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-10	0.0316	0.0262	-0.0343	0.0975
-9	0.0019	0.0128	-0.0303	0.0342
-8	-0.0086	0.0078	-0.0283	0.0112
-7	0.0039	0.0029	-0.0035	0.0113
-6	0.0037	0.0041	-0.0065	0.0139
-5	-0.0117	0.0037	-0.0210	-0.0025 *
-4	0.0102	0.0041	-0.0001	0.0205
-3	-0.0022	0.0041	-0.0125	0.008
-2	0.0027	0.0039	-0.0070	0.0124
-1	-0.0070	0.0028	-0.0141	0.0002
0	0.0004	0.0016	-0.0036	0.0045
1	0.0043	0.0021	-0.0011	0.0097
2	0.0029	0.0038	-0.0067	0.0125
3	-0.0017	0.0016	-0.0057	0.0023
4	0.0065	0.0028	-0.0006	0.0136
5	0.0031	0.0046	-0.0085	0.0148
6	0.0090	0.0144	-0.0272	0.0451
7	0.0007	0.0017	-0.0035	0.005

Table C7 – Regeneration average group-time treatment effect for properties within the Cerrado: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%	
-11	-0.0057	0.0023	-0.0120	0.0006	
-10	0.0089	0.0106	-0.0203	0.0381	
-9	-0.0033	0.0080	-0.0253	0.0188	
-8	0.0014	0.0062	-0.0157	0.0185	
-7	-0.0055	0.0054	-0.0204	0.0094	
-6	0.0057	0.0046	-0.0070	0.0184	
-5	0.0053	0.0037	-0.0049	0.0155	
-4	-0.0006	0.0041	-0.0120	0.0107	
-3	-0.0042	0.0030	-0.0126	0.0041	
-2	0.0018	0.0027	-0.0057	0.0093	
-1	-0.0042	0.0021	-0.0099	0.0015	
0	0.0034	0.0027	-0.0040	0.0108	
1	0.0001	0.0023	-0.0062	0.0064	
2	0.0062	0.0032	-0.0026	0.015	
3	-0.0001	0.0023	-0.0064	0.0062	
4	0.0131	0.0044	0.0011	0.0251	*
5	-0.0014	0.0028	-0.0091	0.0062	
6	-0.0017	0.0030	-0.0099	0.0066	
7	-0.0126	0.0066	-0.0308	0.0055	
8	-0.0124	0.0071	-0.0318	0.007	

Table C8 – Vegetation deficit average group-time treatment effect for properties within the Atlantic Forest: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%	
-9	0.0013	0.0005	0.0002	0.0024	*
-8	0.0012	0.0004	0.0003	0.0021	*
-7	-0.0007	0.0023	-0.0060	0.0046	
-6	-0.0007	0.0017	-0.0045	0.0031	
-5	0.0002	0.0006	-0.0011	0.0015	
-4	-0.0017	0.0025	-0.0074	0.0039	
-3	0.0013	0.0005	0.0001	0.0024	*
-2	-0.0002	0.0007	-0.0019	0.0014	
-1	-0.0001	0.0008	-0.0019	0.0017	
0	0.0008	0.0006	-0.0006	0.0022	
1	0.0007	0.0009	-0.0014	0.0029	
2	0.0007	0.0010	-0.0016	0.0031	
3	0.0003	0.0013	-0.0028	0.0034	
4	0.0002	0.0016	-0.0034	0.0038	
5	0.0050	0.0023	-0.0004	0.0103	
6	0.0075	0.0063	-0.0071	0.0221	
7	0.0068	0.0057	-0.0062	0.0199	

Table C9 – Vegetation deficit average group-time treatment effect for properties within the Cerrado: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-11	0.0010	0.0003	0.0001	0.0018 *
-10	0.0013	0.0004	0.0002	0.0024 *
-9	0.0009	0.0003	0.0002	0.0017 *
-8	0.0003	0.0005	-0.0011	0.0017
-7	0.0009	0.0005	-0.0004	0.0022
-6	-0.0006	0.0012	-0.0038	0.0025
-5	-0.0024	0.0016	-0.0064	0.0017
-4	-0.0010	0.0007	-0.0027	0.0008
-3	-0.0001	0.0008	-0.0022	0.002
-2	-0.0004	0.0011	-0.0032	0.0024
-1	0.0008	0.0012	-0.0023	0.004
0	0.0014	0.0010	-0.0012	0.0039
1	0.0013	0.0015	-0.0025	0.0051
2	0.0010	0.0017	-0.0034	0.0054
3	0.0006	0.0027	-0.0062	0.0074
4	0.0001	0.0031	-0.0079	0.0082
5	0.0011	0.0038	-0.0087	0.0109
6	0.0026	0.0048	-0.0098	0.015
7	0.0142	0.0272	-0.0554	0.0838
8	0.0142	0.0307	-0.0644	0.0928

Table C10 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-9	-0.0117	0.0050	-0.0251	0.0017
-8	-0.0177	0.0095	-0.0431	0.0076
-7	0.0003	0.0063	-0.0165	0.0171
-6	0.0013	0.0043	-0.0100	0.0127
-5	0.0075	0.0046	-0.0049	0.0198
-4	0.0043	0.0054	-0.0102	0.0189
-3	-0.0023	0.0048	-0.0151	0.0105
-2	0.0039	0.0071	-0.0150	0.0229
-1	0.0039	0.0064	-0.0132	0.0211
0	0.0161	0.0061	-0.0003	0.0324
1	0.0179	0.0076	-0.0025	0.0383
2	0.0230	0.0128	-0.0110	0.0571
3	0.0367	0.0147	-0.0027	0.0760
4	0.0389	0.0182	-0.0097	0.0875
5	0.0497	0.0237	-0.0135	0.1128
6	0.0508	0.0200	-0.0027	0.1042
7	0.0528	0.0209	-0.0030	0.1087

Table C11 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of one year: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-11	0.0019	0.0054	-0.0124	0.0162
-10	0.0067	0.0083	-0.0152	0.0287
-9	0.0004	0.0134	-0.0348	0.0357
-8	-0.0141	0.0094	-0.0389	0.0107
-7	-0.0024	0.0048	-0.0150	0.0102
-6	0.0058	0.0070	-0.0125	0.0242
-5	-0.0024	0.0047	-0.0147	0.0099
-4	0.0003	0.0052	-0.0135	0.0141
-3	0.0053	0.0072	-0.0137	0.0243
-2	-0.0171	0.0152	-0.0572	0.0229
-1	-0.0124	0.0127	-0.0458	0.021
0	0.0134	0.0104	-0.0139	0.0408
1	0.0291	0.0127	-0.0043	0.0625
2	0.0498	0.0123	0.0174	0.0821 *
3	0.0645	0.0160	0.0225	0.1065 *
4	0.0801	0.0207	0.0256	0.1347 *
5	0.0933	0.0173	0.0479	0.1387 *
6	0.1170	0.0246	0.0521	0.1818 *
7	0.1136	0.0213	0.0575	0.1698 *

Table C11 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of one year: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero. *(continued)*

event time	ATT	standard error	2.5%	97.5%
8	0.1120	0.0245	0.0476	0.1764 *

Table C12 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of two years: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-11	-0.0031	0.0050	-0.0164	0.0101
-10	0.0019	0.0058	-0.0135	0.0174
-9	0.0067	0.0080	-0.0148	0.0282

Table C12 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of two years: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero. *(continued)*

event time	ATT	standard error	2.5%	97.5%
-8	0.0004	0.0125	-0.0330	0.0338
-7	-0.0141	0.0088	-0.0376	0.0094
-6	-0.0024	0.0047	-0.0149	0.0102
-5	0.0058	0.0068	-0.0125	0.024
-4	-0.0025	0.0048	-0.0153	0.0102
-3	-0.0025	0.0059	-0.0182	0.0132
-2	0.0045	0.0071	-0.0144	0.0235
-1	-0.0171	0.0149	-0.0569	0.0226
0	-0.0124	0.0119	-0.0442	0.0194
1	0.0046	0.0163	-0.0390	0.0482
2	0.0471	0.0126	0.0135	0.0807 *
3	0.0464	0.0198	-0.0066	0.0995
4	0.0697	0.0213	0.0127	0.1267 *
5	0.0846	0.0139	0.0474	0.1218 *
6	0.0961	0.0283	0.0204	0.1718 *
7	0.1185	0.0347	0.0257	0.2113 *
8	0.1152	0.0284	0.0394	0.1910 *

Table C13 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of three years: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%	
-11	0.0163	0.0103	-0.0123	0.0449	
-10	-0.0031	0.0047	-0.0163	0.0101	
-9	0.0019	0.0057	-0.0138	0.0177	
-8	0.0067	0.0076	-0.0143	0.0278	
-7	0.0004	0.0129	-0.0355	0.0364	
-6	-0.0141	0.0092	-0.0396	0.0113	
-5	-0.0024	0.0044	-0.0147	0.0099	
-4	0.0057	0.0067	-0.0129	0.0243	
-3	-0.0059	0.0062	-0.0233	0.0114	
-2	-0.0043	0.0069	-0.0234	0.0148	
-1	0.0044	0.0062	-0.0130	0.0217	
0	-0.0171	0.0152	-0.0593	0.0251	
1	-0.0079	0.0159	-0.0521	0.0362	
2	0.0287	0.0121	-0.0050	0.0624	
3	0.0419	0.0171	-0.0056	0.0893	
4	0.0469	0.0208	-0.0109	0.1048	
5	0.0687	0.0146	0.0282	0.1092	*
6	0.0680	0.0293	-0.0135	0.1494	
7	0.0878	0.0321	-0.0013	0.1769	

Table C13 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Atlantic Forest, considering an anticipation effect of three years: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero. *(continued)*

event time	ATT	standard error	2.5%	97.5%
8	0.1102	0.0341	0.0155	0.2048 *

Table C14 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Cerrado: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero.

event time	ATT	standard error	2.5%	97.5%
-11	-0.0098	0.0067	-0.0276	0.0081
-10	0.0041	0.0059	-0.0115	0.0197
-9	-0.0030	0.0018	-0.0078	0.0019
-8	0.0040	0.0045	-0.0080	0.016

Table C14 – Areas of permanent protection vegetation cover average group-time treatment effect for properties within the Cerrado: average treatment effect (ATT), the standard error and the confidence error band aggregated by the length of exposure to certification (event time). Negative event time values represent the length in years before the certification and positive values the length in years after the certification. (*) – confidence band do not overlap zero. *(continued)*

event time	ATT	standard error	2.5%	97.5%
-7	-0.0037	0.0028	-0.0110	0.0037
-6	-0.0075	0.0025	-0.0142	-0.0009
-5	0.0046	0.0048	-0.0083	0.0174
-4	0.0061	0.0031	-0.0020	0.0143
-3	0.0056	0.0027	-0.0017	0.0128
-2	0.0027	0.0026	-0.0043	0.0096
-1	0.0030	0.0016	-0.0011	0.0071
0	0.0036	0.0032	-0.0050	0.0122
1	0.0077	0.0036	-0.0020	0.0174
2	0.0114	0.0042	0.0003	0.0225*
3	0.0167	0.0054	0.0023	0.0312*
4	0.0193	0.0061	0.0030	0.0356*
5	0.0177	0.0064	0.0007	0.0347*
6	0.0132	0.0080	-0.0080	0.0344
7	0.0081	0.0156	-0.0334	0.0497
8	0.0144	0.0185	-0.0347	0.0636