

**University of São Paulo
“Luiz de Queiroz” College of Agriculture**

**Spatial and temporal analysis of native vegetation coverage for
compliance with the New Forest Act**

Paulo André Tavares

Thesis presented to obtain the degree of Doctor in
Science. Area: Soil and Plant Nutrition

**Piracicaba
2021**

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with the New Forest Act**

Advisor:
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“Intelligence is one of the greatest human gifts. But all too often a search for knowledge drives out the search for love. This is something else I have discovered for myself very recently. I present it to you as a hypothesis: Intelligence without the ability to give and receive affection leads to mental and moral breakdown, to neurosis, and possibly even psychosis. And I say that the mind absorbed in and involved in itself as a self-centered end, to the exclusion of human relationships, can only lead to violence and pain.”

Daniel Keyes – Flowers for Algernon

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RESUMO

Análise espacial e temporal da cobertura de vegetação nativa para o cumprimento do Novo Código Florestal

A compensação é uma das formas de cumprimento de passivos de vegetação nativa prevista na legislação brasileira como um mecanismo de contrabalanceamento de impactos ambientais, a qual permite aos proprietários ou possuidores de imóveis rurais que não cumprirem suas metas de Reserva Legal em sua propriedade, compensar em propriedades de terceiros com excedentes de vegetação nativa. O não cumprimento da compensação dos passivos acarreta ao proprietário punição com sanções administrativas. Entretanto, o Código Florestal atual (Lei Federal 12.651/2012), prevê em seu artigo 68 que os proprietários e possuidores rurais que realizaram a supressão antes de 22 de Julho de 2008, são obrigados a cumprirem o passivo de acordo com a legislação vigente na época, sem que haja sanções administrativas. A complexidade da interpretação do artigo em função, por exemplo, das diferentes conceituações sobre fitofisionomias contidas nas leis pregressas, adicionada à dificuldade de comprovação histórica da supressão em relação marco estabelecido por lei, pode tornar lentos os processos de análise de déficit da cobertura da vegetação nativa das propriedades rurais e, conseqüentemente, a assinatura de um Termo de Compromisso por parte do proprietário a fim de cumprir o Programa de Regularização Ambiental (PRA), aumentando assim os custos de transação na aplicação da lei e gerar insegurança em relação a validade dos documentos necessários. Esta tese tem por objetivo analisar a interpretação das regras para demarcação de áreas conservadas em propriedades rurais nas legislações anteriores ao Código Florestal atual, gerar mapas da cobertura vegetal nativa em datas pretéritas com base nessa interpretação, bem como mapas de déficit e excedente de vegetação nativa para compensação de Reserva Legal, munindo o poder público com ferramenta para a efetiva implementação do PRA no Estado de São Paulo.

Palavras-chave: Uso da Terra, Vegetação Nativa, Políticas Ambientais, Conservação da Biodiversidade, Lei de Proteção da Vegetação Nativa.

ABSTRACT

Spatial and temporal analysis of native vegetation coverage for compliance with the New Forest Act

Compensation is one of the forms of compliance provided by Brazilian legislation as a mechanism to offset environmental impacts, which allows landowners of rural properties that do not meet their Legal Reserve requirements on their property, to compensate in third-party properties with surplus native vegetation. Failure to meet liabilities will result in the owner being punished with administrative sanctions. However, the current Forest Act (Federal Law 12.651 / 2012), provides in its article 68 that the rural owners and possessors who carried out native vegetation suppression before July 22, 2008, are obliged to fulfill the liability in accordance with the legislation in force at the time, without administrative sanctions. The complexity of the interpretation of the article due, for example, to the different concepts about phytophysognomies contained in previous laws, in addition to the difficulty of proving historical suppression data in relation to the framework established by law, can slow down the coverage of the analysis of the deficit of native vegetation of rural properties and, consequently, the signature of a Term of Commitment by the owner in order to comply with the Environmental Regularization Program (PRA), thus increasing transaction costs in law enforcement and generating insecurity regarding validity of the chopped documents. This project aims to analyze the interpretation of the rules for the demarcation of conserved areas in rural properties in the legislation prior to current Forest Act, to generate maps of native vegetation in past data based on this interpretation, as well as maps of deficit and surplus of native vegetation to compensate for Legal Reserve, providing the government with tools for the effective implementation of PRA in the State of São Paulo.

Keywords: Land use, Native Vegetation, Environmental Politics, Biodiversity Conservation, Native Vegetation Protection Law.

1. UNFOLDING ADDITIONAL MASSIVE CUTBACK EFFECTS OF THE NATIVE VEGETATION PROTECTION LAW ON LEGAL RESERVES, BRAZIL

ABSTRACT

The Native Vegetation Protection Law – 2012 - (NVPL) is the main Brazilian regulation for protecting native vegetation (NV) on private land. The NVPL, currently in the implementation phase, reduced Legal Reserves (LR) requirements compared to its previous version, the 1965's Forest Act (FA), through several legal mechanisms. Among them, Article 68 (Art.68) exempts landholders from LR obligations if NV was converted without offending the legislation in place at the time of the conversion. The technical implementation of Art. 68 is controversial and its effects are still unknown. We developed a model to estimate the effects of Art.68 on LR using São Paulo State (Brazil) as case study. We analyzed former environmental laws to identify key periods in which NV preservation requirements had changed. After, we searched for past spatial data on NV cover with sufficient accuracy for each legal benchmark. Combining legal benchmarks with spatial data, we created two scenarios for Art.68 effects, plus a baseline scenario. The first scenario considered a single legal benchmark, the 1965's FA (scenario "1965"), while the other included the 1989 Cerrado's protection Federal Law as a second benchmark (scenario "1965/89"). The baseline scenario did not include Art.68 effects. Scenario "1965" reduced LR deficits in 49% compared to the baseline scenario, waiving landholders from restoration or offsetting needs in 423 thousand hectares (kha) of NV. Scenario "1965/89" waved 507 kha of NV from restoration needs and represented a 59% reduction in LR deficit compared to the baseline scenario. The LR reduction by scenario "1965/89" assumed particular importance considering that the additional cutback was concentrated on Cerrado, an already very fragmented and impacted region. Together with reductions from other NVPL rules, the additional effects of Art. 68 unfolded great concerns about the role of LR as a tool for NV preservation on private land, threatening governmental restoration commitments, and pointing that conservation command and control approaches should be complemented with incentive policies to achieve the desired and committed standards.

Keywords: Native Vegetation, Biodiversity Conservation, New Forest Act, São Paulo State, Environmental Regularization Program.

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1.1. INTRODUCTION

Native vegetation (NV) on private land is worldwide recognized as essential for biodiversity conservation, climate regulation and maintenance of ecosystem services (Norton 2001, Doremus 2003, Tikka & Kauppi 2003, Nunes et al. 2016). Strategies that balance NV conservation and economic activities, such as agriculture and animal production, are essential to involve landholders in conservation efforts (Harvey et al. 2008, Blom et al. 2010, Pacheco et al. 2017).

In Brazil, 54% of the remaining NV occurs in private lands (Sparovek et al. 2015). The “Native Vegetation Protection Law” (NVPL) (Brasil 2012) is the main national regulation for protecting NV on private land (Soares-Filho et al. 2014, Brancalion et al. 2016, Garcia et al. 2016). The NVPL replaced the previous Brazilian Forest Act (FA) (Brasil 1965) through a long process of disputes among multiple stakeholders until its approval by the National Congress in 2012 (Metzger et al. 2010, Nazareno et al. 2012, Sparovek et al. 2016). The NVPL’s implementation is behind schedule after several delays of initially foreseen deadlines. For instance, the entering-step of the NVPL, the “Rural Environmental Registry” (Portuguese acronym: CAR), was postponed three times and, currently, landholders have until December 2019 to register to CAR and, this way, benefit from the “Environmental Regularization Program” (Portuguese acronym: PRA). PRA defines several rules that reduce protection of NV to promote easier compliance comparing the 2012 NVPL with the previous FA (1965). Some States have not defined the PRA regulations so far (SFB 2018, Brasil 2018).

The NVPL kept the Legal Reserve (LR) from the 1965’s FA (Brasil 1965), one of the main mechanisms to foster conservation on private lands. LR corresponds to a land fraction of the farm for NV maintenance but allow NV sustainable management. Its size depends on the biome and the vegetation type, varying from 20 to 80% of the farm (Brasil 2012). LR areas have a crucial role in biodiversity conservation (Beca et al. 2017, Farah et al. 2017) and on the provision of environmental services, including water and soil protection, carbon storage, pollination, and agricultural pest control (Brancalion et al. 2016, Garcia et al. 2016, Saturni et al. 2016, Librán-Embíd et al. 2017, Oakleaf et al. 2017). Further, LR vegetation patches act as stepping-stones between public Protected Areas (Conservation Units). Since Brazilian Conservation Units are usually far

from each other, the LR network is essential to functionally connect landscapes (Metzger 2001, Ribeiro et al. 2009, Tambosi et al. 2013).

However, the NVPL reduced substantially the total amount of protected NV in Brazil by granting partial amnesty for illegal deforestation prior to 2008 and allowing the reduction of the required LR in several situations (Brancalion et al. 2016). Previous studies suggested that NVPL reduced 37 Mha of LR total area (Sparovek et al. 2012, Freitas et al. 2017, Guidotti et al. 2017). Those estimations did not consider the controversial Article 68 (Art.68), which promotes additional LR reduction. Art.68 specifies that if the NV was converted without offending the legislation effective at the time of the conversion, the landholder should be waived from LR obligation. The effects of Art.68 are still unknown and may represent a huge cutback in NV protection, mainly in areas of long-established agricultural production, therefore also more degraded. Art68 effects, consequently, may represent a major threat to the maintenance of ecosystem services and biodiversity protection. Further, knowing the effects of Art.68 over LR deficits may guide States strategies for the “Program for Recovery of Degraded Areas” (Portuguese acronym: PRADA), another requirement from the NVPL. It can drive, for example, policies to promote LR compensation enabling a market for the trade of NV surpluses that also result in additional environmental protection (May et al. 2015).

We developed a model to estimate the potential effects of Art.68 on LR using São Paulo State, Brazil, as a case study. São Paulo represents an extreme situation of a State with a long history of consolidated agriculture and early deforestation, what turns it into a valuable proxy of Art.68 maximum effects. Similar conditions would apply to other long-time consolidated agriculture areas in South, Southeast, and part of Central West Brazilian regions (Barretto et al. 2013). We considered two scenarios of law interpretation and application. For this, we analyzed the historical development of the Brazilian environmental legislation and identified periods in which accurate spatial data of NV were available.

1.2. MATERIAL AND METHODS

The effects of Art.68 were determined in two steps. First, the percentage of NV in 2008 was determined for each farm and checked against the LR requirement of the NVPL in São Paulo State (i.e., 20%). The 2008 benchmark refers to the date set by the NVPL to exempt of restoration requirements or offsetting deforestation in disagreement with the 1965' FA. If this percentage was not reached, the farm was considered as non-compliant and potentially eligible to access Art.68 benefits. In a second step, the model verified if the percentage of past NV decreased between the chosen legal benchmark and 2008. If a reduction was observed, the farm loses the Art.68 benefit and the LR deficit was considered to be the same computed for 2008 (described in the first step). If no reduction was observed, the farm was considered eligible to access Art.68 benefit and LR deficit was computed as the area of 1965 NV subtracted by the area of 2008 NV.

The model takes into account that “Areas of Permanent Protection” (APP); i.e., areas that protect fragile environments such as hill tops, steep slopes and riparian forests; can be computed into the LR percentage as established by the NVPL. A detailed description of the modeling procedure and the combination with previous NVPL models is described in Supporting Information (Appendix I, Tables S1, S2, S3). It is also important to note that the model does not include farms smaller than four Fiscal Modules (FM) since NVPL discharge them from LR restoration. In São Paulo State, each FM varies from 5 to 40 ha (INCRA, 2013).

To model Art.68 we first analyzed previous environmental laws to identify key periods in which the minimal requirements for NV preservation in private lands had changed. This step was also important to determine the spatial scope of NV protection of past legislation. A second step was to search for past spatial data on NV cover with sufficient accuracy for each legal benchmark. Finally, we matched historical NV preservation requirements with historical spatial data on NV cover, creating two scenarios for Art.68 application and one baseline scenario.

1.2.1. Native vegetation spatial data availability and previous preservation requirements

Brazilian legal requirements for NV preservation in private lands changed over time, determining different levels of protection through LR (Table 1). The processes of checking the spatial scope of such legislation was ambiguous by the various terminologies and definitions used to describe NV over time (e.g., “matta”, “arvoredo”). These differences lead to several possible legal interpretations about the past legislation amplitude. For instance, it is possible to interpret that all NV types, or that only the forested ones, were protected in the legislations previous to 1989.

Our search for past NV cover databases showed that the first spatial data with the necessary accuracy and precision for the NVPL modeling was generated in the 1960s. This database consists of maps made by the “Brazilian Institute of Geography and Statistics” (IBGE) at the scale 1:50,000 (IBGE 1965). Thus, we do not have a spatial solution for NVPL spatial explicit modeling of Art.68 before the 1965’s FA. To estimate Art.68 effects for previous laws, it would be necessary to rely on spatial equation models (Dias et al. 2016) and, by these, move from a spatial explicit solution to a still comprehensive, but probabilistic approach. Another option would be to keep the spatial explicit approach but narrow it to spatial data documents that are not comprehensively available, such as old farms’ sketches, in some cases only available in old registry office books. In the first case, we would not reach the accuracy to access precise data for each farm, limiting this approach for implementation purpose by the responsible authority. Such a reference may be useful for regional planning or assessment, but improper for farm-level decisions. For the second, we would depend on one-by-one document analysis, where available, that would result in a partial and very time-consuming approach impossible to be applied for the whole State in a modelling research project.

Therefore, we adopted the 1965’s Brazilian FA as the initial legal benchmark, disregarding all previous laws, and addressing the study with a spatial explicit large-scale model solution. The FA from 1965 (Federal Law 4.771/1965) introduces the term “Legal Reserve” for the first time and changes the percentage of protected NV to 20%. Again, the interpretation about the

comprehensiveness of NV protection given by the law is subjective, being uncertain if the protection applies to all physiognomies of NV or only to the forest types.

This outcome has a critical effect over São Paulo State “Environmental Regularization Program” (PRA) (São Paulo 2015). The State legislation indicates that in 1934, farms should keep as LR at least 25% of the existing forests. However, there is no precise spatial information on land cover available for 1934. The manual analysis based on information supplied by landholders may delay even more the implementation of the NVPL in the State, foster juridical queries and legal contests. Further, it could open an over the counter one by one negotiation opportunity that favors interpretation errors, administrative misconduct, and corruption. Other Brazilian States that are still deciding on how to define Art.68 interpretation rules for their PRAs should take into account the availability of accurate spatial data on the past NV cover in order design rules that allows a precise and systematic solution for the Art. 68 application.

In one of the scenarios we included the Federal Law from 1989 (Federal Law 7.803/1989) that complements the 1965 FA and reassures the protection of a 20% LR area for farms located in Cerrado regions.

Table 1. Brazilian main native vegetation protection mechanisms related to Article's 68 modeling and availability of accurate spatial data.

Regulation	Year	Description	Data
São Paulo State Law 2.223	1927	Sets the São Paulo State Forest Service and establishes that properties with vegetation and larger than 100 ha must keep a forest cover over 10% of its area, except when it is homogeneous vegetation ("mattas" in the Portuguese original) or vegetation with spontaneous regrowth (Art. 5).	no
Federal Decree 23.793	1934	First Brazilian Forest Act. Compels landholders to protect 25% of the vegetation present in the property ("mattas" in the Portuguese original) (Art. 23).	no
Federal Law 4.771	1965	Second Brazilian Forest Act. Establishes different percentages of native vegetation protection accordingly to the region where the property is located. Landholders from the southeast, south and central-west Brazilian regions of the country must protect 20% of forests and other forms of native vegetation in their lands (Art. 16).	yes
Federal Decree 49.141	1967	Sets the protection of 20% for a specific Cerrado vegetation type ("Cerradão", in the Portuguese original) (Art. 7).	yes
Federal Law 7.803	1989	Changes the Law 4.771/1965 and reassures the protection of a 20% Legal Reserve for Cerrado areas (Art. 16).	yes
Provisional Act 2.166.67	2001	Sets new limits for Legal Reserves: 80% for forests and 35% for "Cerrado" inside the Legal Amazon boundaries and 20% for forests, "Campos Gerais" and other types of native vegetation outside the Legal Amazon (Art. 16).	yes
Federal Law 11.428	2006	Atlantic Forest Protection Law. Sets special protection mechanisms for the Atlantic Forest biome.	yes
Federal Decree 6.514	2008	Environmental infractions decree. Benchmark used by the Law 12.651/2012 as a cutting line to establish differences in conservation and restoration requirements for Areas of Permanent Preservation and Legal Reserves.	yes
Federal Law 12.651	2012	Third Brazilian Forest Act named "Native Vegetation Protection Law". Sets the Legal Reserve limits of 80% for forests, 35% for "Cerrado" and 20% for "Campos Gerais" inside the Legal Amazon Boundaries and 20% for other biomes (Art. 12). Establishes several Legal Reserve reduction mechanisms (Art. 12, 13, 15, 67 and 68).	yes

1.2.2. Scenarios for article 68 application

We considered two scenarios to assess the effects of Art.68 over LR deficit in SP: scenario “1965” and scenario “1965/89”, plus a baseline scenario to control for such effects (Table 2). The baseline scenario includes LR reduction mechanisms that were modeled by previous studies and based in other articles of the NVPL (i.e., Art. 13, 15 and 67) but do not account for the effects of Art.68 (Sparovek et al. 2012, 2015, Freitas et al. 2017, 2016). This scenario represents a control to isolate the effects of the two possible Art.68’s interpretation rules.

For the scenario “1965”, we considered a single legal benchmark: the 1965 Brazilian FA (Table 1), acknowledging that LR requirements were applied to all types of NV and, consequently, since 1965, NV outside APPs should represent at least 20% of the farm (Table 2).

For the scenario named “1965/89”, we used two legal benchmarks: the Brazilian FA from 1965, and the 1989 Cerrado’s protection Federal law (Law nº 7.803/1989) (Table 1). In this scenario, farms with forested types of NV should comply with a 20% LR since 1965 and, for other types of NV, with more open canopies such as savannahs (all Cerrado vegetation types, excluding the “Cerradão”, which was considered as a forested vegetation) or grasslands (Campo) should comply with a 20% LR only after 1989. To identify the type of NV in each farm we used maps from the RADAM Brasil project (IBGE 2015) and classified it as “forested NV” or “other types of NV”.

For scenarios “1965” and “1965/89”, we used the legal interpretation which states that landholders who, at some time, have not complied with the law in force, lose the benefits from Art.68, demanding 20% of LR at current time.

These two scenarios represent the two most common interpretations of the 1965 and 1989 legal references, being the “1965/89” scenario in line with the State PRA (São Paulo 2015) and the “1965” scenario, that is more protective, in line with the interpretation of the environmental Civil Society and Public Attorney agencies (Loubet 2014, Chiavari & Lopes 2016).

Table 2. Description of the main requirements and data used to perform the three considered scenarios of Article 68 implementation.

Scenario	Past Vegetation database	Native	Native Vegetation classification		Legal Reserve requirements
Baseline	n.a. ¹		n.a. ¹		Compliance in 2008 with the NVPL
1965	1:50000 maps ²	IBGE	n.a. ¹		NV outside APP \geq 20% since 1965 Compliance in 2008 with the NVPL
1965/89	1:50000 maps ²	IBGE	RADAM maps ³	Project	NV outside APP \geq 20% since 1965 for forested NV NV outside APP \geq 20% since 1989 for other types of NV Compliance in 2008 with the NVPL

Notes: ¹n.a. = does not apply; ²IBGE, 1965; ³IBGE, 2015.

1.3. RESULTS AND DISCUSSION

1.3.1. São Paulo state LR deficit

For all three scenarios, LR deficits were unevenly distributed among São Paulo State, with a higher concentration at West, Northwest and Mid-West regions (Figures 1, 2 and 3). The “baseline” scenario created a total LR deficit of 865 thousand hectares (kha) (Figure 1), of which 635 kha were located at Atlantic Forest and 230 kha in the Cerrado biome (Table 3).

Scenario “1965” reduced LR deficits in almost 50% in relation to the baseline scenario, waiving landholders from restoration needs in 423 kha (Figure 2). Scenario “1965/89” reduced additional 84 kha from restoration needs when compared to scenario “1965”, a 59% reduction in the LR deficit in relation to the baseline scenario (Figure 3).

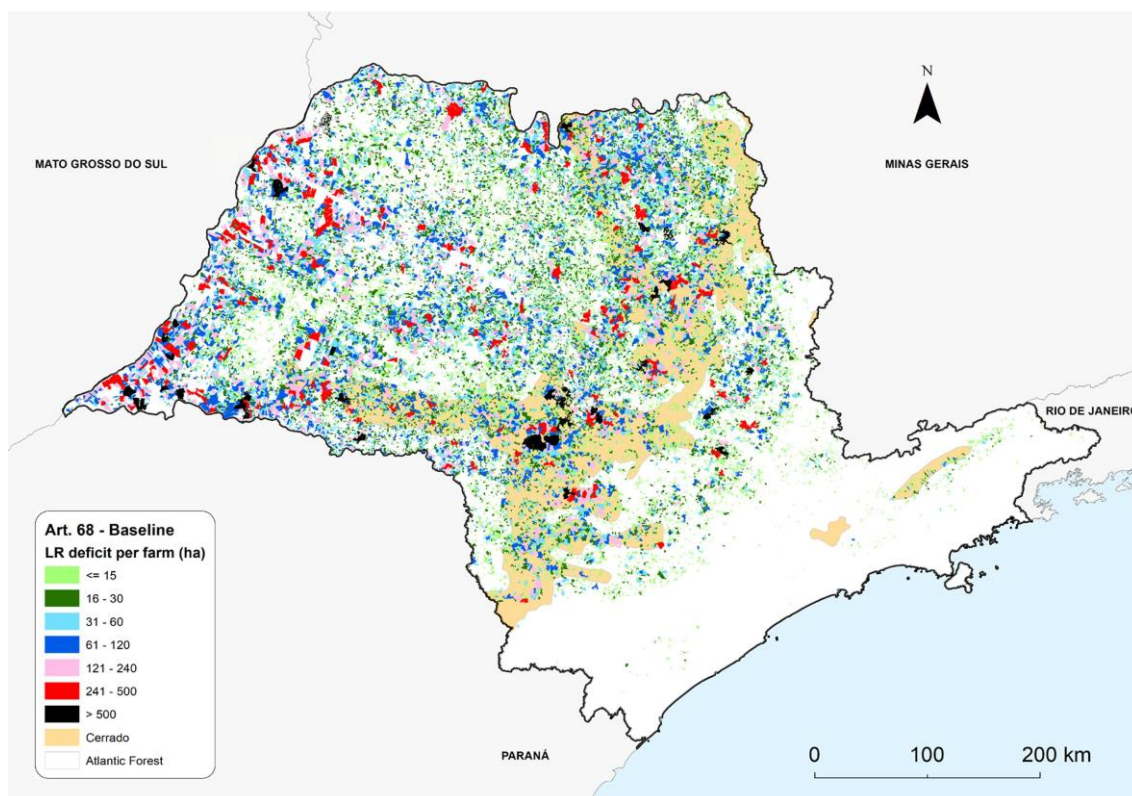


Figure 1. São Paulo State Legal Reserve deficits per farm, in hectares, for the baseline scenario (i.e., without art. 68 inclusion), total deficit of 865 thousand hectares from a total of 30,417 farms with deficit. Each polygon represents farm.

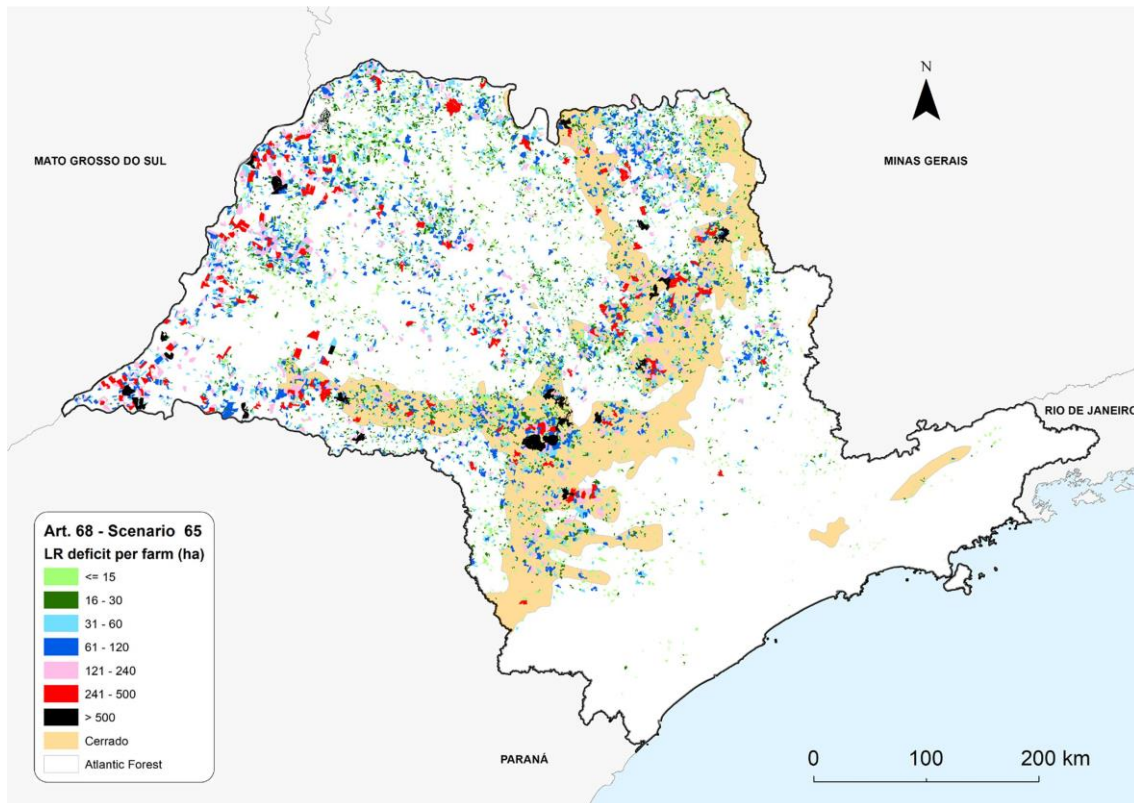


Figure 2. São Paulo State Legal Reserve deficits per farm, in hectares, for the scenario 1965, total deficit of 443 thousand hectares from a total of 12,324 farms with deficit. Each polygon represents one farm.

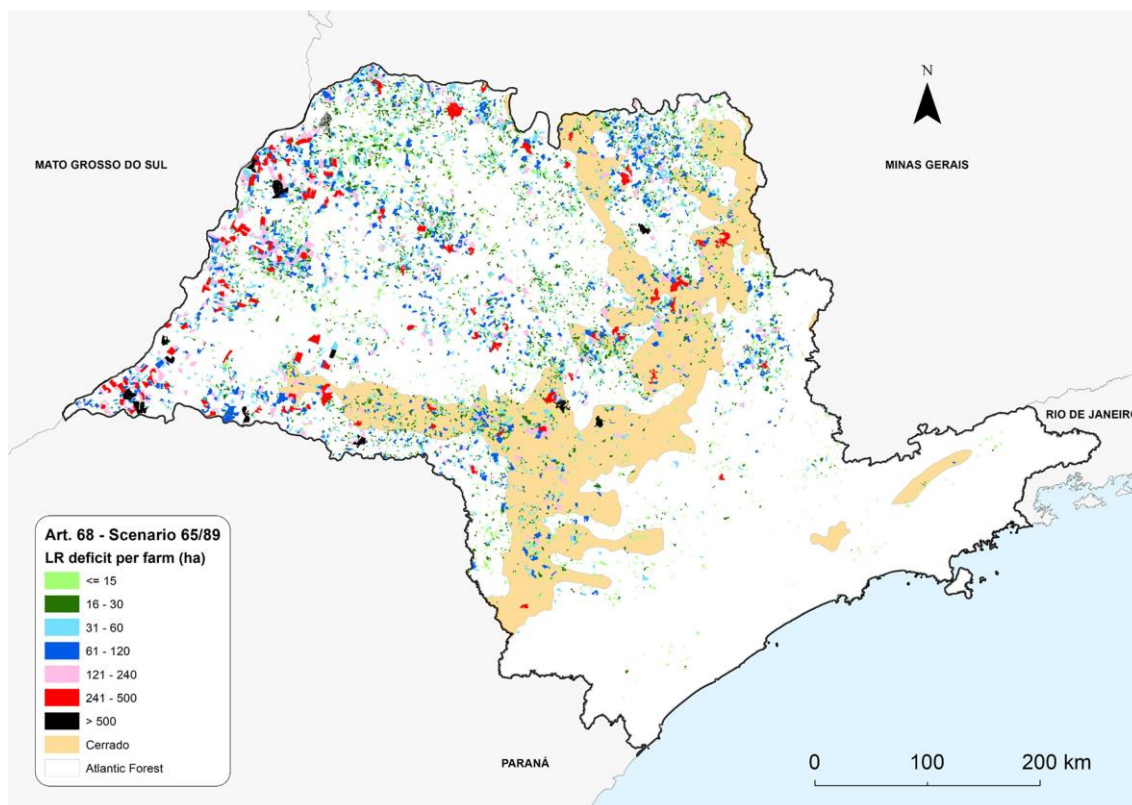


Figure 3. São Paulo State Legal Reserve deficits, hectare, for the "1965/89" scenario, total deficit of 358 thousand hectares from a total of 10,477 farms with deficit. Each polygon represents one farm.

Table 3. Legal Reserve deficit and native vegetation surplus in thousand hectares (kha), for the three considered scenarios

Biome	Native Vegetation Surplus ¹ (kha)	Legal Reserve Deficit (kha) Scenario		
		Baseline	1965	1965/89
Atlantic Forest	776	635	294	283
Cerrado	119	230	149	75
Total	895	865	443	358

Note: ¹ Native Vegetation (NV) surplus accounts for the total amount of NV available for LR offsetting, including large farmlands (more than 4 Fiscal Modules) with more than 20% of NV and any existing NV fragments in small properties (less than 4 Fiscal Modules).

The reduction in LR brought about by scenario "1965/89" was particularly important because the geography of the additional reduction occurs on the Cerrado biome (Figure 4). While the implementation of Art.68, considering scenario "1965/89", reduced the LR deficit in only 4% for Atlantic Forest, it reduced by 50% LR deficit in the Cerrado biome in SP (Table 3). The difference

between both scenarios (“1965” and “1965/89”) can be explained by the fact that scenario “1965/89” adds a second legal benchmark to the model. In this scenario, for forested NV types, the model follows the 1965’s FA (Brasil 1965), for other NV types, it follows the Cerrado’s protection law (Brasil 1989). Thus, suppression of non-forested NV between 1965 and 1989, more common in the Cerrado biome, was exempted from LR restoration or offsetting to the percentage required by the NVPL in scenario “1965/89” (Brasil 2012).

In this period NV was converted mainly for sugarcane plantations, which was expanding quickly in the region, boosted by incentives given through the “National Alcohol Program” (Pró-Alcool) (Bastos 2007, Natale Netto 2007, Camara & Caldarelli 2016). By that time, driven by favorable soil and climate conditions, sugarcane expanded over a large extent of Cerrado NV, increasing deforestation rates at this biome (Durigan et al. 2004, Kronka et al. 2005, Takaaki et al. 2015). Considering that Cerrado has a remarkable low occurrence of protection through Conservation Units – 24 Sustainable Use Conservation Units, representing a total area of 433.674 ha; while Atlantic Forest has 142, representing a total area of 3.412.517 ha (DATAGEO 2018) - the exemption of restoration or offsetting of non-forested NV can have a negative impact over the conservation of this already very fragmented biome (Durigan et al. 2007, Strassburg et al. 2017). Presumably, this effect will also occur in other Brazilian States that had a similar history of agriculture development (e.g., Paraná, South of Minas Gerais, South of Mato Grosso do Sul).

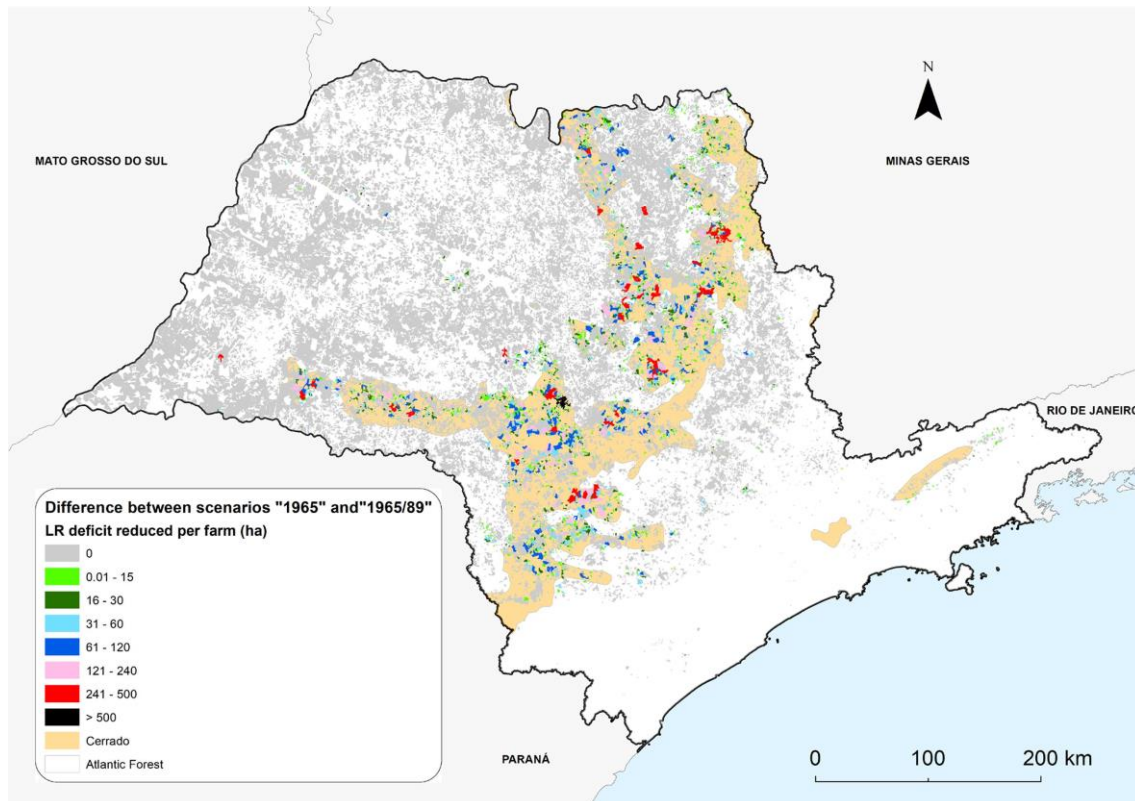


Figure 4. São Paulo State Legal Reserve deficits, difference between scenarios "1965" and "1965/89". Each polygon represents one farm.

1.3.2. São Paulo State native vegetation surplus

According to the NVPL, LR deficits may be restored within non-compliant farms or offset in another farm with NV surplus in the same biome. Presumably, most farmers will opt for offsetting to avoid the conversion of productive farmland to nature protection or the costs with a restoration plan (Bernasconi et al. 2016, Freitas et al. 2017).

In the Atlantic Forest, for scenarios "1965" and "1965/89", the available NV for offsetting— NV surplus – was substantially higher than the LR total deficits (Table 3). This means that the entire LR deficit in the Atlantic Forest could be offset within the State without the need for NV restoration or conversion of productive lands. On the other hand, for Cerrado, only for scenario "1965/89" it would be possible to overcome the need for NV restoration or conversion of productive land.

However, since both biomes are already protected by NV conservation laws (São Paulo 1967, Brasil 2006), LR offsetting would not lead to additionality in

nature protection. Thus, in order to increase NV conservation and the supply of ecosystem services, the only scenario that promoted these by legal enforcement was scenario “1965” and restricted to the Cerrado biome. For scenario “1965/89” it is essential to promote incentives for NV restoration, such as payments for environmental services (PES) and other policies to foster restoration of NV on private land or the creation of public owned Conservation Units.

1.4. CONCLUSION

We could not identify an accurate model solution for Art.68 before 1965. The suggested solutions allow systematic analysis of Art. 68 reducing legal contests and the negative effects of subjectivity in the one-by-one analysis by governmental officials. Since the spatial data we used for 1965 NV cover in São Paulo State was based on the first nationwide aero photographs, we believe this is also the earliest date for other Brazilian States. Thus, any attempt to apply Art.68 before the 1965’s Brazilian FA, e.g., the 1934 FA (Brasil 1934) would have to rely on probabilistic NV maps or one-by-one manual analysis of data provided by the landholders. These options would challenge the development of a large-scale and accurate tool for decision making to be used by governmental agencies during the implementation phase of the NVPL. This fact should be considered for Art.68 definition in the States PRAs, to avoid the undesired effects of unrealistic legal rules that undermine the applicability of the NVPL.

Regarding the effects of Art.68 it decreased the LR deficits between 49% and 59%. This effect adds substantially to the already important reductions caused other rules from the NVPL (Freitas et al. 2016), unfolding great concerns on the role of LR as a conservation aid for NV preservation on private land. Furthermore, we observed a higher LR deficit reduction in areas of Cerrado biome changing from scenario “1965” to “1965/89”. This biome had high deforestation rates in the past and has only a small amount of land protected by public Conservation Units.

It is very likely that the trends observed in São Paulo also apply to other States with a long history of agricultural occupation (e.g., South Region, Minas Gerais, South of Mato Grosso do Sul). In such conditions, the enforcement capacity of command and control mechanisms to promote NV preservation on private land

outside APPs is currently largely overestimated by modeling due to the absence of Art. 68 effects.

In order to keep the benefits of NV restoration, the command and control approach should be complemented by incentive policies. The assessment of NVPL effects on NV conservation and the planning of NVPL implementation could substantially benefit from a national wide modelling of the effects of Art.68.

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APPENDIX I

SUPPLEMENTARY INFORMATION

DATA INPUT

São Paulo (SP) State land tenure and rural proprieties boundaries map was updated from the Brazilian land tenure database made by previous studies (Sparovek et al. 2015, Freitas et al. 2016, Sparovek et al. 2010, 2012) using 16 official datasets (Table S1). To build a map of the known land tenure, we followed six steps: (i) cleaning and accessing overlapping polygons from the “National Institute for Agrarian Reform” (Portuguese acronym: INCRA); (ii) analyzing overlapping polygons from INCRA and from the “Rural Environmental Registry” (Portuguese acronym: CAR) datasets; (iii) cleaning and accessing overlaps among proprieties registered in CAR dataset; (iv) assembling all the databases in a single raster file and (v) a final residual cleaning.

Table S1. Datasets used to generate São Paulo State land tenure and boundaries map.

Category	Layer	Scale	Year	Source
Transport	State roads	Not available	2016	DNIT
	National roads	Not available	2016	DNIT
	National railroads	Not available	2016	DNIT
	Mapped roads	1:250.000	2015	IBGE
	Mapped railroads	1:250.000	2015	IBGE
Urban Areas	Urban Areas	1:250.000	2015	IBGE
Hydrography	Water bodies	1:250.000	2015	IBGE
	Rivers and streams	1:250.000	2015	IBGE
	Water bodies	1:1.000.000	2014	IBGE
	Rivers and streams	1:1.000.000	2014	IBGE
Land	National public forests	Not available	2015	SFB
	Indigenous lands	Not available	2015	FUNAI
	Public Protected Areas	Not available	2015	MMA
	“Terra Legal” program	Not available	2015	INCRA
	Rural settlements	Not available	2015	INCRA
	Registered private proprieties	Not available	2015	INCRA
	Registered public proprieties	Not available	2015	INCRA
	“Quilombolas”	Not available	2015	INCRA
	Rural settlements	Not available	2005	ITESP
Military areas	1:1.000.000	2014	IBGE	

Scenario's development

For develop the scenarios we used spatial data of SP native vegetation (NV) cover in 1965, 1989 and 2008 from three distinct sources (Table S2). To classify and identify the current types of NV of Atlantic Forest and Cerrado occurring in SP we used the original classification of the RADAM project map and classified savannahs as “non-forested NV” and ecological transition zones between non-forested and forested ecosystems as “forested NV”.

Table S2. Datasets used to spatialize and classify past NV cover in the state of São Paulo.

Year	Scale	Source
1965	1:50000	IBGE
1989	Not available	Agrosatélite
2008	1:1000000	RADAM Project

Scenarios were made considering the latest accurate and precise data about NV that match a legal reference, using: (i) a model of land tenure and boundaries of farms updated from previous studies (Sparovek et al. 2010, 2015b, Freitas et al. 2016, Sparovek et al. 2012, Freitas et al. 2017); (ii) NV cover in 1965; (iii) NV cover in 1989; (iv) NV cover in 2008 and (v) NV types geographical distribution.

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Article 68 model

The effects of Art.68 are determined in three steps. First, the percentage of pixels with NV in 2008 is determined for each rural property and checked against the LR requirement of the NVPL (Federal Law 12.651/2012) for São Paulo State biomes (i.e., 20%). If this percentage is not reached, the rural property is considered as non-compliant and potentially eligible to access Art.68 benefit. Second, the model verifies if the percentage of pixels of past NV had decreased between the chosen legal benchmark (i.e., 1965 or 1989 depending on the scenario being analyzed) and 2008. If a reduction is observed, the rural property loses the Art.68 benefit and the LR deficit is considered to be the same computed with 2008 NV map (described in the first step). Finally, if no reduction is observed, the rural property is considered eligible to access Art.68 benefit and LR deficit is computed as the area of 1965 NV subtracted by the area of 2008 NV (Table S3, SI).

Table S3. Possibilities of native NV cover at the propriety (in %) along legal benchmarks and applicability of Article 68 (Federal Law nº 12.651/2012) benefits.

Past NV (1965 or 1989)	NV between past legal benchmark and 2008	Art. 68 benefit
> 20%	< 20%	no
20%	< 20%	no
< 20%	< NV in 1965	no
< 20%	= NV in 1965	yes
< 20%	> NV in 1965 & < 20%	yes

2. TRACKING-BACK NATIVE VEGETATION COVER TO AFORE REMOTE SENSING TIMES: A DEMAND CAUSED BY A LARGE-SCALE LEGISLATION BLUNDER

ABSTRACT

Native vegetation inside private lands plays an important role in environmental conservation worldwide. The Native Vegetation Protection Law, known as the New Forest Act, regulates the use and conservation of native vegetation remnants on private land in Brazil. This law fixes a percentage of the rural property that landowners must retain under native vegetation cover, the Legal Reserve. However, the Legal Reserves rule does not apply if the conversion took place before the law was implemented. Since the Forest Act has two versions, one from 1934 and another from 1965, and since there are divergences from when Legal Reserves rule officially applies, it is important to assess the impact of the temporal benchmark on current conservation requirements. Given that the 1934 legal benchmark precedes the first aerial mapping in Brazil, we developed a methodology to estimate past native vegetation cover in the absence of accurate spatialized data. For that, we used an Agriculture Probability Index and a past Agriculture Census to spatialize pixels of agriculture and forest cover using São Paulo State as a study case. This map was then used to compare two legal implementation scenarios, one using the 1934 benchmark, and other starting with the 1965 (the first decade with an accurate map of native vegetation cover for the state). The benchmark change does not have significant effects on the total area of Legal Reserves protection, on the number of farms potentially benefitting from an older benchmark, and on the amount of native vegetation deficit. The forest deficit considering the 1934 benchmark is only 3% higher than the one of the 1965 benchmark. Thus, we conclude that the decision of choosing the 1934 benchmark would add little value for policy implementation, since it lacks an accurate spatialized database. Meanwhile it can delay the implementation of the Forest Act due to a time-consuming farm-by-farm analysis, once this is a probabilistic map that has an intrinsic limitation for an automatic process. However, since the decision of including the 1934 was made by the State, we present the best scientific methodological solution for simulating the past native vegetation cover. It can still support decision makers helping to build an automatic, or semi-automatic, analysis or at least support the technician responsible for decision if it goes to a non automatic solution.

Keywords: Legal Reserve, Biodiversity Conservation, Environmental Policy, Governance, Land Use, Forest cover probability.

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2.1. INTRODUCTION

Native vegetation remnants in private lands have an important role in protecting ecosystem services and biodiversity from the detrimental effects of natural habitats conversion and fragmentation, since they may protect an important part of biodiversity and increase the connectivity among public protected areas, which are frequently distant from each other and represent a small percentage of the territory (Lindenmayer et al., 2001; Metzger, 2001; Tambosi et al., 2013). However, protecting native vegetation in private lands led to conflicts with the agricultural sector. Thus, environmental policies that protect these areas need to combine the economic use of lands with native vegetation conservation, promoting a win-win scenario, and maximizing compliance. In Brazil, about 53% of the remaining native vegetation occurs inside private lands and only 6% of the territory is protected by strictly protected areas (Brancalion et al., 2016; Metzger et al., 2019). Therefore, the legislation that regulates the use and conservation of native vegetation remnants in private lands, the “Native Vegetation Protection Law”, commonly known as the new Forest Act (NFA) (Brasil, 2012), is of paramount importance.

The main NFA mechanism to combine conservation and productive use of the land inside private properties is the Legal Reserve. The Legal Reserve is a proportion of the rural property that must maintain native vegetation cover, where the sustainable management of natural resources is allowed. This proportion depends on the biome and the vegetation type, varying from 20 to 80% of the property. If landowners do not have this amount of native vegetation, they can achieve compliance by restoring or regenerating the vegetation on their property, or by compensating it in another rural property (Brasil, 2012).

Although the NFA is one of the few laws worldwide that set a fixed percentage of native vegetation to be protected (Maron et al., 2018), the concept of the Legal Reserve is not a novelty for the Brazilian environmental legislation. The Legal Reserve is required since the first Brazilian Forest Act in 1934 (Brasil, 1934), which was revised in 1965. However, to foster compliance, the Forest Act was revised again in 2012 creating the NFA, which brought legal mechanisms

that can substantially reduce the amount of protected native vegetation through the Legal Reserve (Freitas et al., 2017, 2016, 2018).

Among these mechanisms, one of the most controversial is the Article 68. This mechanism grants that landholders who converted native vegetation following the legislation requirements at the time of the conversion do not need to restore or compensate their Legal Reserves to the extent required by the NFA (Brasil, 2012). However, there are uncertainties regarding the implementation of this mechanism, including the concern in how to prove the past native vegetation cover at the farm level when land-use/land-cover maps are not available, which database can be used to access this information and how the mechanism would affect the amount of native vegetation that should be protected by Legal Reserve (Tavares et al., 2019). These uncertainties are maximized at the State level, once the States are responsible for the policy implementation through the “Program of Environmental Regularization” (PRA, Portuguese acronym). This challenge in solving these uncertainties is delaying the law implementation throughout the country and putting in danger the sustain of essential ecosystem services provided by native vegetation (Foley et al., 2007; Giulletti et al., 2005; Zarin et al., 2016).

Thus, there is an urgent need for developing methodologies to assess the past native vegetation cover to allow the instrumentalization of this mechanism based on science. In this paper, we used the São Paulo State as a case study to develop a methodology for estimating farms past native vegetation cover in the absence of spatialized data. We used the São Paulo State because the state law set the Forest Act of 1934 as the initial benchmark, which does not present a land-use/land-cover map available. The method can be adapted for other Brazilian States or even for other countries facing the same issue. Using this methodology, we assessed the effects of the Legal Reserve implementation on the amount of native vegetation protected in private lands using two temporal benchmarks: the 1934 Forest Act (using a simulated land use and cover map) and Forest Act from 1965.

2.2. MATERIAL AND METHODS

2.2.1. Study case

We used São Paulo State as a study case for developing the proposed methodology and then comparing the effects of including a benchmark before the first spatialized land-use data (The 1934 Forest Act) on Legal Reserve areas. However, since the NFA is a federal law, the study implications go further than the State limits and the same methodological approach can be applied to the other Brazilian States if the necessary databases are available.

The State is located in the Southeast region of Brazil (Figure 1) and has an area of 248.2 thousand km², an estimated population of 44.3 million inhabitants, a Gross Domestic Product of R\$ 2 trillion, and it is the most industrialized State of Brazil (SEADE, 2019). São Paulo is the largest Brazilian producer of sugar-cane, orange, and coagulated latex, and the agribusiness represents 31% of the State's exportations (SEADE, 2019). Two biomes are present at the State, Atlantic Forest, and Cerrado (Brazilian savanna), both considered as biodiversity hotspots critically threatened (Mittermeier et al., 2011). It has a long history of early deforestation and agriculture expansion before the 1960s (Durigan et al., 2004; Kronka et al., 2005; Takaaki et al., 2015) and, currently, only 32% from Atlantic Forest and 3% from Cerrado original cover remnants at the State (SIMA, 2020).

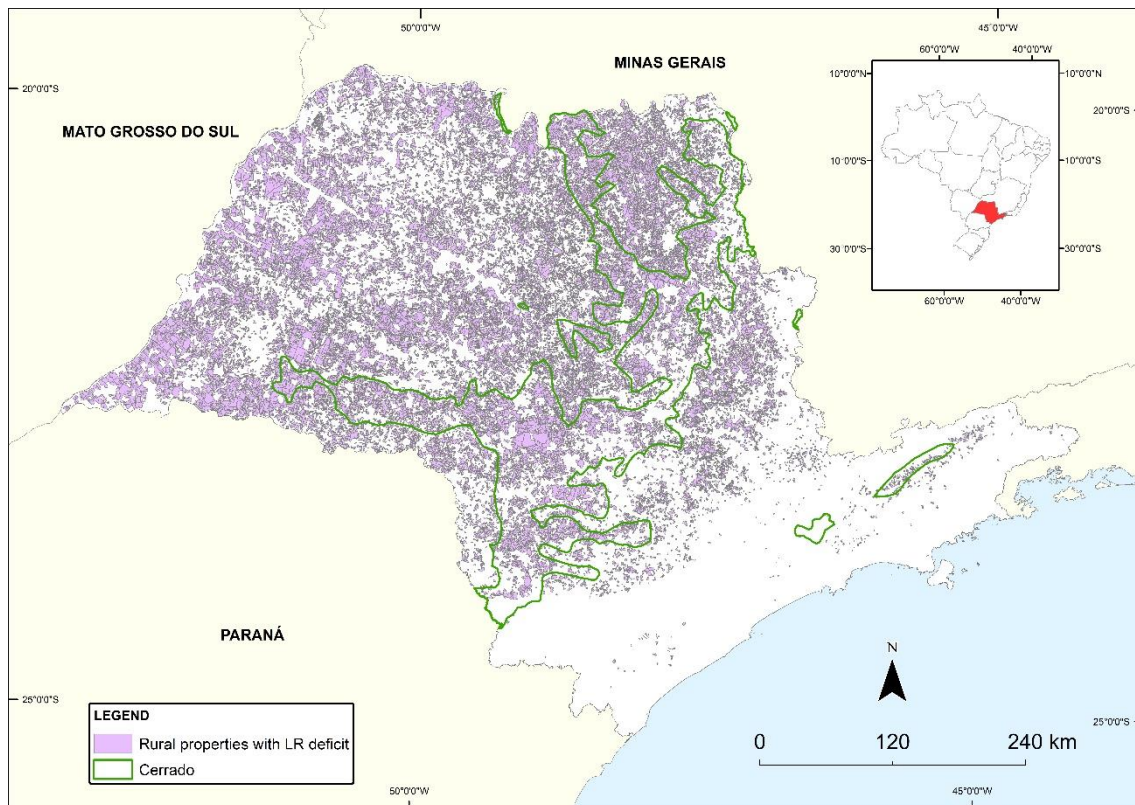


Figure 1. São Paulo State location, with the delimitation of biomes and farms with Legal Reserve (LR) deficit.

In this paper, we compared two scenarios for the Article 68 application, one considering the 1934 Forest Act as the initial benchmark (before the first spatialized land-use data in the State) and other considering the 1965 Forest Act as the initial benchmark (after the first aero-photogrammetric flight made in 1962).

2.2.2. Estimating the spatialization of native vegetation cover for the 1934 legal benchmark

There is no accurate spatialized data for native vegetation distribution before the 1960' (Tavares et al., 2019). Thus, we developed a methodology of land-use/land-cover probability, based on the methods proposed by Dias et al. (2016) for historical patterns of land-use, to estimate and spatialize the native vegetation for the 1934 Brazilian Forest Act benchmark.

For this, we used spatial and non-spatial data available from years close to 1934 in São Paulo State: (i) a logistic network map; (ii) a map of land-suitability for agriculture; (iii) municipalities boundaries; (iv) not spatialized census data about native vegetation amount by municipalities; and (v) not spatialized census data about rural properties areas. The methodology first estimates and

spatializes agriculture patches for this period based on proxy variables, as detailed in the next session. Then, on a second step, we obtained the native vegetation cover spatialization by allocating the native vegetation amount from the census in the remaining areas in the State. The resulting map was then used for the modeling process of the effects of Article 68 starting with the 1934 Forest Act legal benchmark and compare it with a scenario starting with the 1965 Forest Act.

2.2.2.1. Creating an index for the estimated agriculture spatialization

The first step to estimate and spatialize agriculture patches in a period close to the 1934 Forest Act legal benchmark was to create an index representing the probability of a given area be occupied by agriculture. We named this index as the “Agriculture Probability Index” (API) and it represents the probability of a 30m x 30m pixel being used for agriculture.

To calculate the API we used the following variables: (i) logistic network; and (ii) land-suitability for agriculture, assuming that agriculture expansion occurred as closer as possible to roads for production transportation and in regions where environmental conditions were more favorable for agricultural practices. We describe below the construction of these two variables.

Logistic network

The logistic network variable represents a proxy of market access and it was included since areas closer to roads of production transportation (i.e., roads and railroads) and urban areas are more likely to be used for agriculture activities. The logistic variable consisted of the geometric mean of distance data for all variables. The geometric mean served to increase the value of urban centers with the presence of roads and railways, being a potential area for the disposal of products such as coffee produced in the State interior (James, 1933). Among three parameters that affect the disposal of agricultural products: (i) distance to roads, (ii) distance to railroads, and (iii) distance to São Paulo State urban areas.

For distance to roads and railroads, we first vectorized these paths using maps from the 1920s (Cardoso, 1915). Then we used Euclidian distance to

produce a map of distance from logistic network. We reclassified this map with value zero for distances higher than 10 km from the transportation network. For distances between 0 to 10 km, we generated a standardized index ranging from 0 to 1000. Zero stands for pixels with distances equal to 10 km from land transportation networks, and 1000 for pixels with distances lower than 1 km (see Figures S1 and S2, Supplementary Information – SI). The maximum distance of 10 km was used because it is the average distance made by a horse in one day, the usual way of transportation in 1920 (Zsoldos et al., 2010).

There is no precise spatial data of São Paulo State urban area in 1920. Thus, to estimate the distance to urban area variable we first reduced the 2005 urban area (DataGEO, 2005), which corresponds to the most recent and accurate data that we found, proportionally to the rate between population density in 2005 (IBGE, 2010) and 1920 (Directoria Geral de Estatística, 1923). Then we calculated the Euclidian distance from the pixel to the urban area and created a standardized index ranging from 0 to 1000. Zero stands for pixels with distances higher than 10 km from the urban area, and 1000 stands for pixels with distances lower than 1km.

Land-suitability for agriculture

Land-suitability for agriculture refers to the productive agricultural potential of an area with minimal human interference (Ramalho-Filho and Beek, 1995; Singha and Swain, 2016) and depends on three main factors: (i) soil, (ii) topography, and (iii) climate. In turn, these factors can be characterized by multiple attributes. Here, we used the ones proposed by previous methodologies for Brazilian land-suitability for agriculture (Barretto, 2013; Sparovek et al., 2015): (i) depth, clay content, drainage and fertility for soil; (ii) slope and altitude for topography and (iii) temperature index, water index and water capacity for climate. We adapted two attributes from these methodologies to reflect the agricultural practices or conditions in 1920. Back in 1920, most of Brazilian agriculture did not depend on machinery, thus it could reach lands with higher declivities. Thus, our methodology considers as suitable for agriculture both: flat areas and areas with higher slope degrees. Additionally, in 1920 the soil fertility was not artificially enhanced; thus, the methodology considers optimal values for base saturation (> 50%) and cation exchange capacity (> 8 cmol/kg),

predominant characteristics in eutrophic soils. Finally, we generated a standardized index where 0 stands for lands unsuitable for agriculture and 1000 for highly suitable lands, considering a 900 m² pixel (Figures S3; S4).

Agriculture Probability Index

Using the logistic network and the land-suitability for agriculture variables we calculated the API that is represented by the geometric mean of both variables as follow:

$$API = \sqrt{(logistic\ network * land\ suitability\ for\ agriculture)}$$

We used the geometric mean and the same weight for both variables because we consider that both are essential for the index. Thus, with one of the variables equals to zero the API will also be zero.

2.2.2.2. Spatialization of the Agriculture Probability Index and estimated areas of native vegetation

We performed the API spatialization following a three steps procedure. First, to obtain the area in rural properties without native vegetation, here called consolidated area, we subtracted the total area of rural properties per municipality by the total amount of native vegetation inside rural properties per municipality. To do that we used data from the 1920 Brazilian agriculture census (Directoria Geral de Estatística, 1923). From this census we extracted São Paulo State's: (i) municipalities boundaries; (ii) non spatialized census data about native vegetation area; and (iii) non spatialized census data about rural properties areas.

Then, on a second step, we divided the consolidated area by the municipality area to obtain the percentage of consolidated area per municipality. In a third step, considering pixels with a regular size of 900 m², we allocated the agricultural lands in the pixels with the highest to the lowest values of API until meeting the percentage of the consolidated area. The remaining pixels were considered as native vegetation cover.

The resulting map was qualitatively compared with a map from 1915 that represents the State native vegetation and agriculture areas but which do not have accuracy at farm level nor an accurate geospatial datum (Cardoso, 1915).

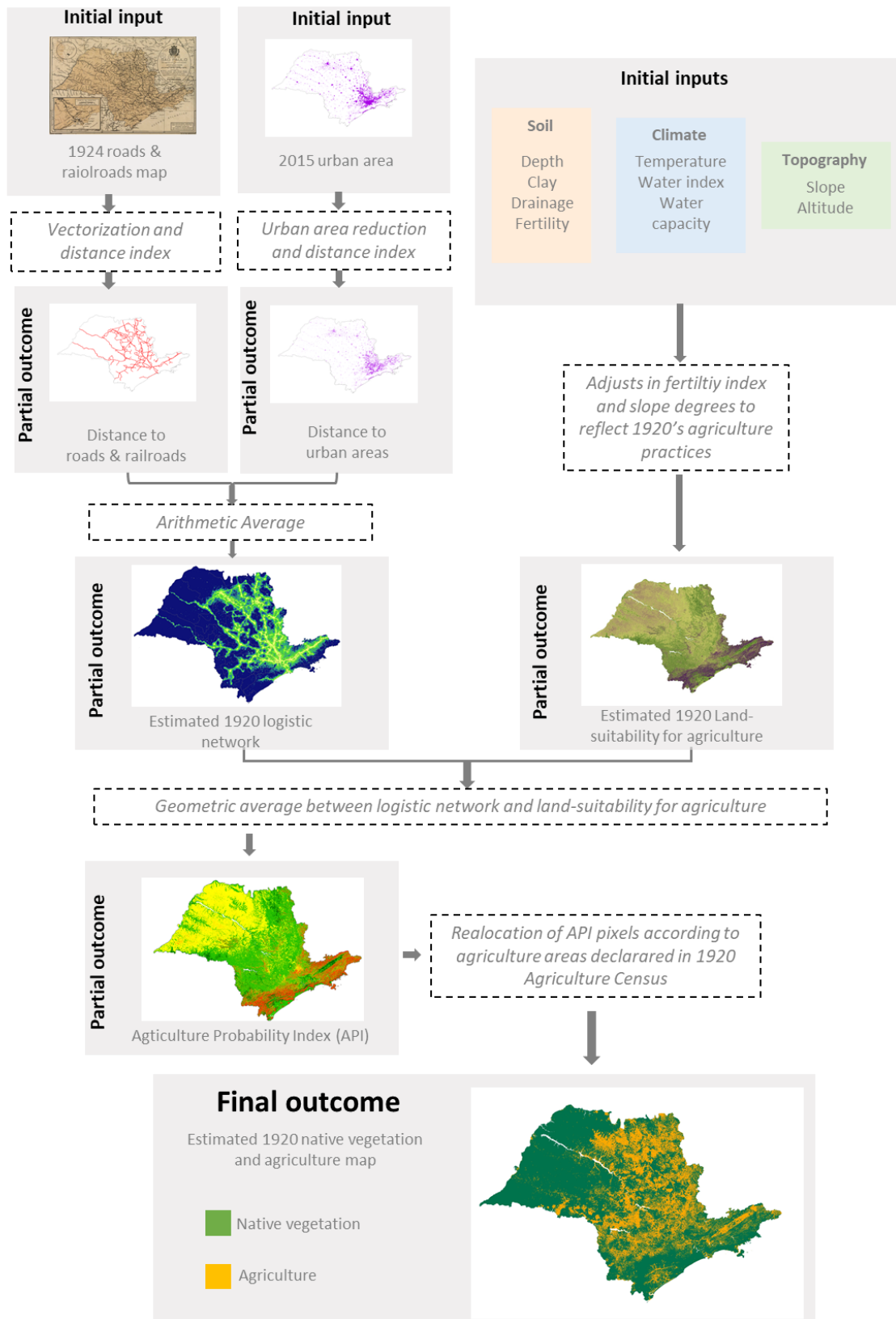


Figure 2. Steps of the probabilistic native vegetation and agriculture map development.

2.2.3. Article 68 application scenarios

We compared two scenarios for Article 68 application, one starting with the 1934 Forest Act as the initial benchmark and other starting with the 1965 Forest Act. Also, we included a baseline scenario that does not account for the effects of Article 68 (Tavares et al., 2019) to control and isolate the effects of Article 68. For this baseline scenario, farms have to be in compliance with the NFA since 2008. The date of July 22 2008 is used as a benchmark by the NFA because it is the data of a federal decree which sets the rules for environmental crimes. All the scenarios included other Legal Reserve reduction mechanisms existing in the NFA (i.e., Articles 13, 15, and 67).

For the scenario starting in 1934, we considered the three legal benchmarks stated by São Paulo State PRA for Article 68 application, i.e., the 1934, 1965 Brazilian Forest Acts, the 1989 Federal Law that sets a Legal Reserve of 20% for Cerrado (Brasil, 1989), and the 2012 NFA. Following the requirements of these benchmarks, the scenario considers that between 1934 and 1965 farms have to maintain 25% of existing native vegetation according to the 1934 Forest Act. From 1965 onwards, farms with forest should keep 20% Legal Reserve since 1965 and, for other types of native vegetation, with open canopies such as savannahs (all Cerrado physiognomies, excluding the “Cerradão”, which was considered as forest) or grasslands (Campo) should comply with a 20% Legal Reserve only after 1989. The scenario starting with the 1965 Forest Act legal benchmark used the same rules, excluding the period before 1965.

For all the scenarios, we calculated the Legal Reserve deficits, i.e., the missing amount of native vegetation of the farm to comply with the legal benchmarks. We also calculated the native vegetation surplus, i.e., the total extent of native beyond what is required by the NFA for all São Paulo State farms, which is the same for all scenarios. We used the legal interpretation of Article 68 which states that landholders who have deforested more native vegetation than the allowed by the law in force at the time, lose the benefits from Art.68, demanding 20% of Legal Reserve on the farm at the current time.

The effects of Article 68 were determined in three steps following the methodology used by Tavares et al. (2019). First, the percentage of pixels with

native vegetation in 2008 was determined for each farm and checked against the Legal Reserve requirement of the NFA for São Paulo State biomes (i.e., 20%). If this percentage was not reached, the farm was considered as non-compliant and potentially eligible to access Article 68 benefit. Second, the model verified if the percentage of pixels of past native vegetation had decreased between the chosen legal benchmark (i.e., 1934, 1965, or 1989 depending on the scenario being analyzed) and 2008. If a reduction was observed, the farm loses the Article 68 benefit. Finally, if no reduction was observed, the farm was considered eligible to have the Article 68 benefit and Legal Reserve deficit was computed as the native vegetation area required from the 1934, 1965 or 1989 benchmarks subtracted by the remaining native vegetation area in 2008.

2.3. RESULTS

2.3.1. Past native vegetation distribution

Results from the spatialization of the 1920's São Paulo State native vegetation cover and agriculture distribution map (Figure 3) estimated 8.4 million hectares were likely covered by agriculture and 20.3 million hectares by native vegetation. Agriculture patches were concentrated in the central region of the State and 27% of it was located in the Cerrado biome, which represents only 18% of the State.

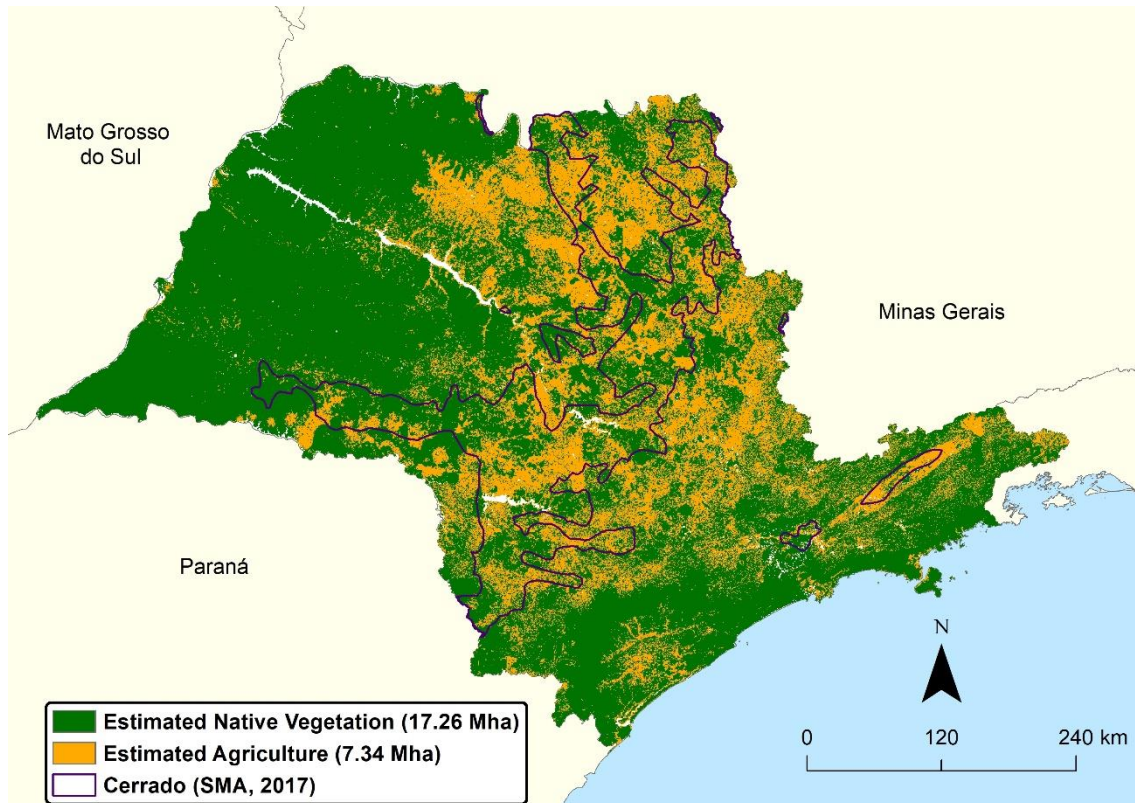


Figure 3. Estimated map of 1920's native vegetation cover and agriculture distribution for São Paulo State.

Comparing the native vegetation and agriculture distribution map that we generated with an existing map from 1915 (Figure 4) it was possible to note some similarities. For instance, the path of agricultural expansion in the region of Paraíba Valley is observed on both maps, 1915 and our simulated map, which is associated to the road that connected the two largest cities in Brazil: Rio de Janeiro and São Paulo (Figure 5A). Also, the widely dispersed stain of agricultural use in the region of Araraquara, close to the Jataí's Ecological Station can be observed in both maps (Figure 5B). Lastly, the Paranapanema region pointed out by the 1915 map and the simulated map show that the region is practically all covered with native vegetation in both maps (Figure 5C).

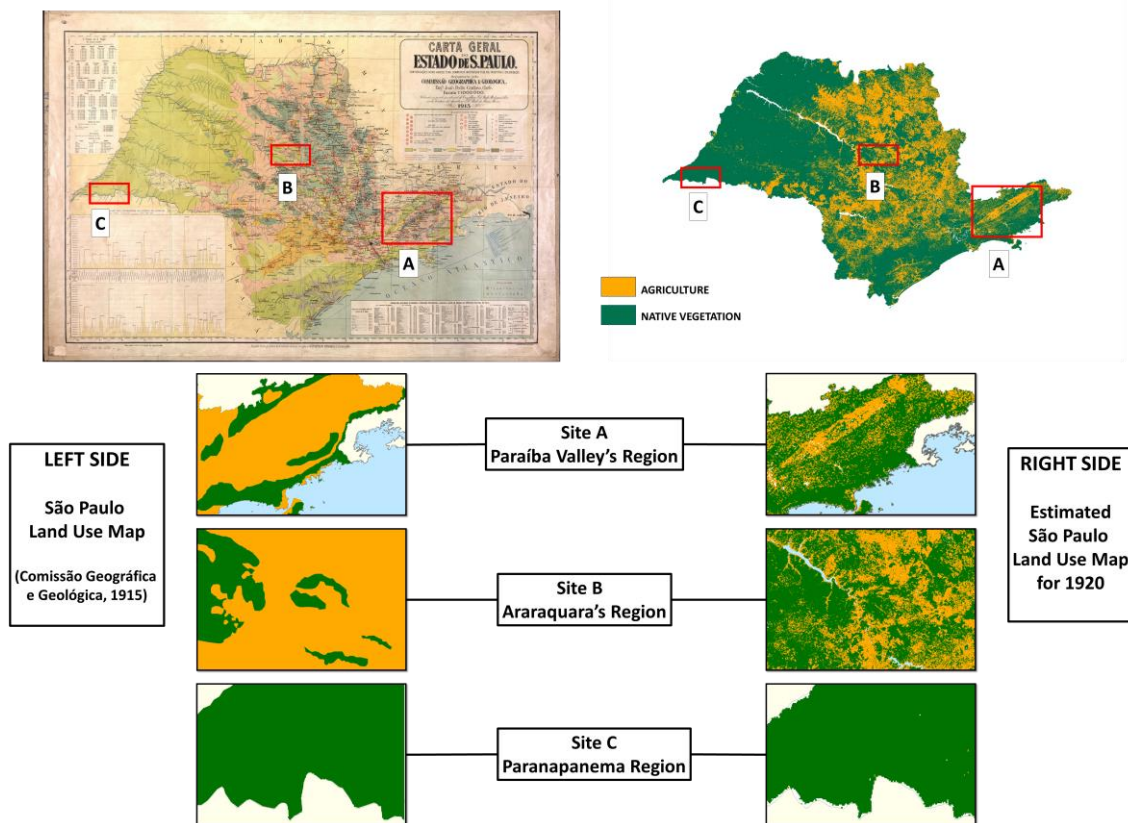


Figure 4. Comparison between the 1915 São Paulo State map representing areas of native vegetation and agriculture and the estimated 1920 map.

2.3.2. Article 68 Scenarios outcomes

The scenario starting at the 1934 Forest Act benchmark reduced by 62% the Legal Reserve area required in São Paulo State comparing to the baseline scenario (Table 2). From this reduction, 366,000 ha occurred in the Atlantic Forest biome areas and 171,000 ha in the Cerrado. The scenario starting at the 1965 Forest Act benchmark represented a total reduction of 59% the Legal Reserve area required compared to the baseline. From this reduction, 352,000 ha were in Atlantic Forest areas and 155,000 ha in Cerrado (Table 1).

The inclusion of the 1934 Forest Act benchmark decreased the total Legal Reserve in 30,000 ha when compared to the scenario starting with the 1965 Forest Act, being 14,000 located at Atlantic forest areas and 16,000 at Cerrado. Comparing both scenarios, the inclusion of the 1934 Forest Act as an initial benchmark led to a reduction of 1,255 farms with Legal Reserve deficit from a total of 30,417 (Table 1). For both scenarios, Legal Reserve deficits were

concentrated in the West, Northwest, and Mid-west regions of the state (Figure 5).

The model generated a total of 606 thousand ha of native vegetation surplus in 45,801 farms. From this total, 530 thousand ha (40,264 farms) were in the Atlantic Forest biome, and 76 thousand ha (5,537 farms) in the Cerrado. The total surplus was two times higher than the Legal Reserve deficit for scenario 1934 and scenario 1965. For Atlantic Forest biome the surplus was also two times higher than the Legal Reserve deficit for both scenarios. Finally, for Cerrado biome, the surplus was 13 times higher than the Legal Reserve deficit for scenario 1934 and 10 times higher for scenario 1965.

Table 1. Legal Reserve deficit estimated for the Baseline Scenario (without the Article 68 application), Scenario 1934 (considering the Forest Act of 1934 as initial benchmark) and Scenario 1965 (considering the Forest Act of 1965 as initial benchmark).

Scenario	Nº of farms with deficit			Deficit area (10 ³ ha)		
	Atlantic Forest	Cerrado	Total	Atlantic Forest	Cerrado	Total
Baseline	22,782	7,635	30,417	635	230	865
1934	7,317	1,905	9,222	269	59	328
1965	7,949	2,528	10,477	283	75	358

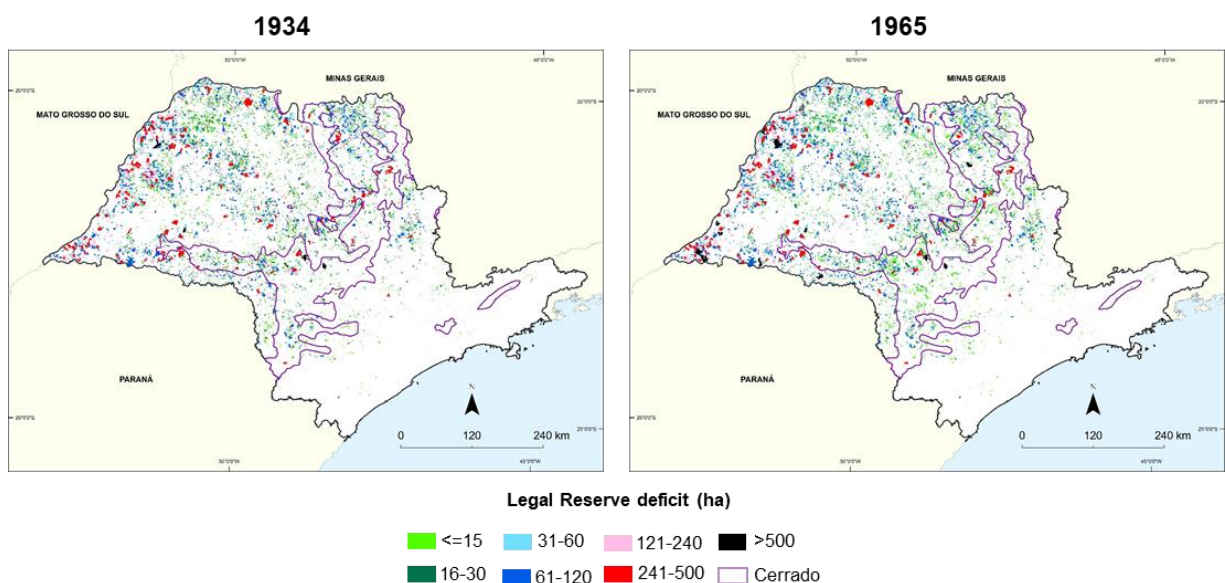


Figure 5. Estimated Legal Reserve deficits for São Paulo State, with Article 68 application, per rural property, in hectares. Scenario 1934 considering the Forest Act of 1934 as initial

benchmark), and Scenario 1965 considering the Forest Act of 1965 as initial benchmark. Each polygon represents one property.

2.4. DISCUSSION

2.4.1. Methodology applications and limitations for decision making.

Our methodology was able to estimate the past native vegetation cover in rural properties. The qualitative comparison with the São Paulo State 1915 land-use map showed consistencies with the 1920 map that we generated, suggesting that the variables used to estimate the past native vegetation cover were reliable. Although this is a probabilistic map of land-use/land-cover distribution with its intrinsic restrictions, this is the best solution for estimating the past native vegetation cover to support environmental policies as the Forest Act when this information is demanded and spatial information is not available.

Because it is a probabilistic map, the inclusion of the 1934 Forest Act legal benchmark for the application of the Article 68 of the NFA brings uncertainty and can delay the implementation of the law. The map can be useful for regional planning, but the implementation of the law on the ground will require data at the rural property level of real vegetation cover, e.g., old farms sketches or other local registers available in offices registry books. For a large-scale analysis, this double-check would imply a long time period for one-by-one analysis and interpretation. This manual analysis will further delay the implementation of the law and may foster legal queries and, depending on data quality and interpretation abilities, may also allow an unfair benefit or restriction to the concession of Article 68. Second, by providing room for subjective interpretation, it may open up the door for corruption, create an atmosphere of insecurity for the government technicians responsible for the evaluation and expose both, technicians and landholders, to legal queries. The implementation of environmental policies needs for high quality and consistent spatial information on the levels of the environmental resources or services which are being managed (in our study, the rural property level) (Schulp et al., 2014).

Another potential limitation of our methodology is that we used the data available from the census closer to the 1934 benchmark, the 1920 Brazilian Agriculture Census (Directoria Geral de Estatística, 1923). However, this census

was criticized for not using the most accurate methodology disregarding farms with an annual production of less than 500,000 Réis¹ and with self-reporting native vegetation data from landowners, which makes it difficult to conclude whether the agricultural area of the state data is overestimated or underestimated (Florida, 2004).

Even with these limitations, our methodology brings the best solution to estimate past native vegetation cover to apply the Article 68 when the legal benchmark of 1934 is required. The best option would be setting the Forest Act of 1965 as the initial legal benchmark (Tavares et al., 2019), once there is a land-use/land-cover map based on aerial photograph for this period, avoiding uncertainties during the policy implementation. However, when the decision is for the inclusion of the 1934 as the initial benchmark as it was in the São Paulo State, our probabilistic map can support decision makers helping to build an automatic or semi-automatic analysis or at least support the technician responsible for decision if it goes to a nonautomatic solution.

2.4.2. Article 68 scenarios comparison

Although from the 1965 scenario to the 1934 scenario there was a 30 thousand ha reduction in the total Legal Reserve deficit, this change represents only 3% from the total deficit without Article 68 application. It means that changing the initial legal benchmark from the 1965 to the 1934 Forest Act does not present a major impact in terms of native vegetation protection. However, even if it is a small change, it is important to note that both São Paulo State biomes, i.e., Atlantic Forest and Cerrado, are already very fragmented and affected by past deforestation. Changing from the 1965 initial benchmark to the 1934 exempted from restoration Legal Reserve deficits from earlier periods. This exemption occurs over a period marked by high deforestation rates, mainly due to agricultural expansion, urban area development, and coal exploration by large industries (Victor et al., 2005). These were the main drivers of deforestation in the state before the 1960s, leading the State to have only about 13% of its area

¹ Réis are an old Brazilian currency that worth approximately R\$ 0.123 (Diniz, 2020) or USD 0.024 (June 2020 exchange rate).

covered by a disrupted and unevenly distributed native vegetation (Victor et al., 2005). Further, even if the first Brazilian Forest Act was established in 1934, in São Paulo State its actual implementation started only nine years later, with the establishment of institutions responsible for monitoring and controlling illegal deforestation (Victor et al., 2005). Thus, considering the 1934 Forest Act as the initial benchmark, the State loses the opportunity to restore areas of very damaged and fragmented native vegetation patches.

At the same time, changing from scenario 1965 to scenario 1934 leads to an increase of only 1,255 farms that can receive the benefits of Article 68, representing only 4% from the total number of farms with Legal Reserve deficit without Article application. That means that very few farms will benefit from this change being exempted from Legal Reserve restoration obligation. Thus, this change does not represent a huge gain in areas available for agricultural exploitation and economic gains. Consequently, the adoption of the 1934 legal benchmark would represent an increase in the uncertainties of land regularization without representing a great benefit to farmers.

Finally, the balance between native vegetation surplus and Legal Reserve deficit was very similar between both scenarios, and in either cases São Paulo State is able to solve Atlantic Forest and Cerrado biomes deficits through compensation outside the property without the conversion of productive lands (Mello et al., *in press*). However, considering that the native vegetation from both biomes in São Paulo State is already protected by other laws (Brasil, 2006; São Paulo, 1967), compensation schemes can lead to the absence of conservation additionality. In this context, the development of strategies to incentive native vegetation restoration, such as payments for environmental services (Garcia et al., 2013), and economic incentives for the sustainable production of timber and non-timber forest products (Brancalion et al., 2012) could help to reach additionality.

2.5. CONCLUSION

Our methodology allows estimating farms past native vegetation cover in the absence of spatialized data. The methodology allows us to estimate native vegetation and agriculture areas before the first spatial land-use data in the São

Paulo State. This map is used to compare two scenarios for Article 68, from the NFA, application, one starting with the 1934 Brazilian Forest Act, and other starting with the 1965 Brazilian Forest Act.

Changing the initial legal benchmark from 1934 to the 1965 Forest Act does not have significant effects over the total area and distribution of Legal Reserves deficit, the total of benefited farms, and the balance between native vegetation surplus and deficit. Thus, starting with the 1934 Forest Act does not represent an increase in native vegetation conservation nor notable economic gains for rural landowners and, therefore, does not worth the challenges that will be faced by using a legal benchmark that lacks an accurate spatialized database. Although we present a scientific methodological solution to estimate past native vegetation cover before the first spatial land-use data, it still a probabilistic map with its intrinsic limitation of uncertainty to be applied in policy implementation. This can delay the law implementation by requiring a case-by-case analysis of the rural properties' land regularization. However, if this past native vegetation cover information is required, this is the best solution to guide government technicians in the analysis of Legal Reserve reduction requirements. It can still help to build an automatic or semi-automatic analysis or at least support the technician responsible for decision if it goes to a nonautomatic solution. If the other Brazilian States follow São Paulo's decision, we can expect that this slowdown in the policy implementation will spread throughout the country threatening a large amount of native vegetation.

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APPENDIX I

SUPPLEMENTARY INFORMATION

Methodology Details

Description of the data used for each scenario and main legal requirements used in the methodology are presented in Table S1.

Table S1. Description of the main requirements and data used to perform the scenarios of Article 68 implementation.

Scenario	Past Vegetation database	Native	Native Vegetation classification	Legal Reserve requirements
Baseline	n.a. ¹		n.a. ¹	Compliance in 2008 with the NFA
1934	1:50000 maps (IBGE, 1965); estimated native vegetation map	IBGE (IBGE, 1920 native	1920 estimated native vegetation map	Native vegetation \geq 25% from 1934 to 1965 for all Native vegetation types Native vegetation outside APP \geq 20% since 1965 for forested Native vegetation Native vegetation outside APP \geq 20% since 1989 for other types of Native vegetation Compliance in 2008 with the NFA
1965	1:50000 maps (IBGE, 1965)	IBGE (1965)	RADAM maps (2015) Project (IBGE,	Native vegetation outside APP \geq 20% since 1965 for forested Native vegetation Compliance in 2008 with the NFA
1989	1:50000 maps (IBGE, 1965)	IBGE (1965)	RADAM maps (2015) Project (IBGE,	Native vegetation outside APP \geq 20% since 1989 for no forest Native Vegetation Compliance in 2008 with the NFA

¹ n.a. = not apply.

To calculate the “Agriculture Probability Index” (API) we used the following variables: (i) logistic network (Figures S1; S2); and (ii) land-suitability for agriculture.

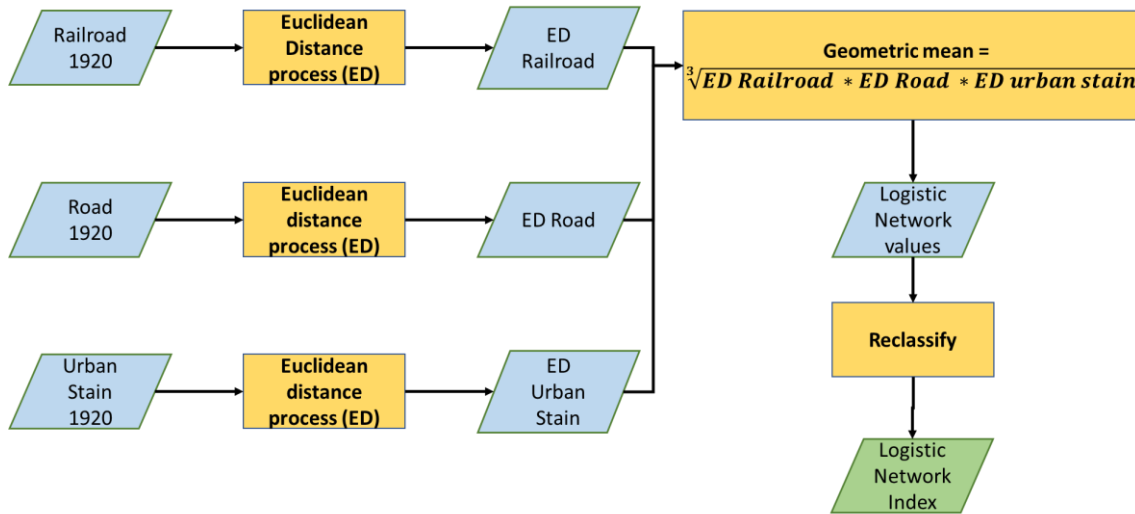


Figure S1. GIS procedures to generate the logistic variable.

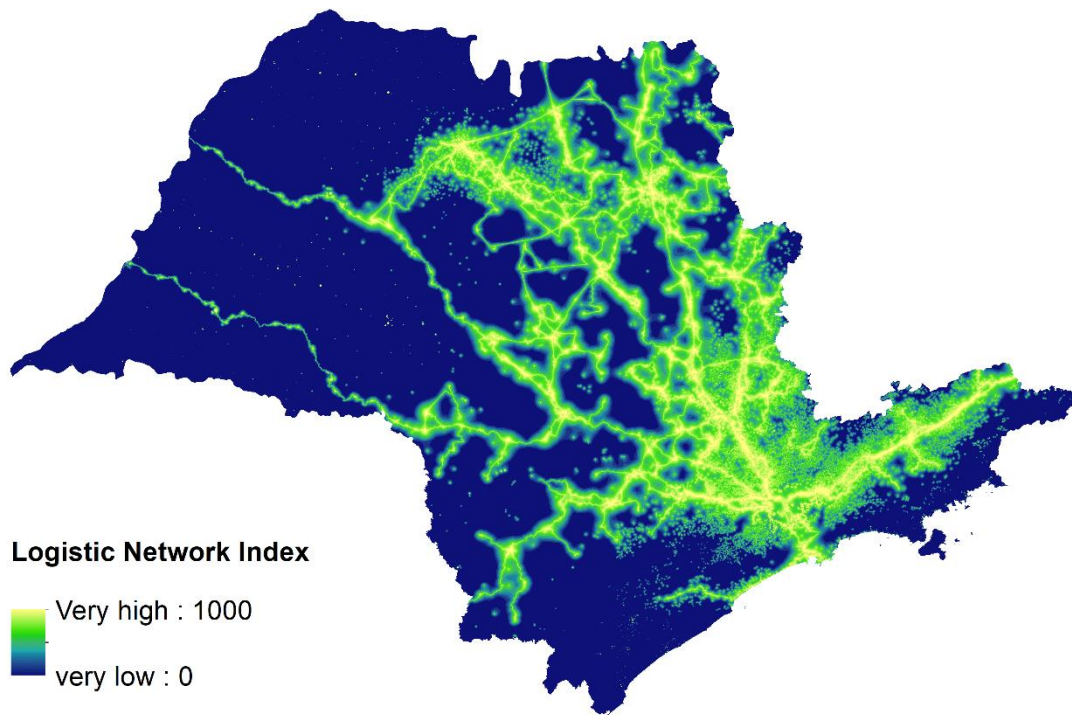


Figure S2. Logistic map of proximity to roads for São Paulo State in 1920.

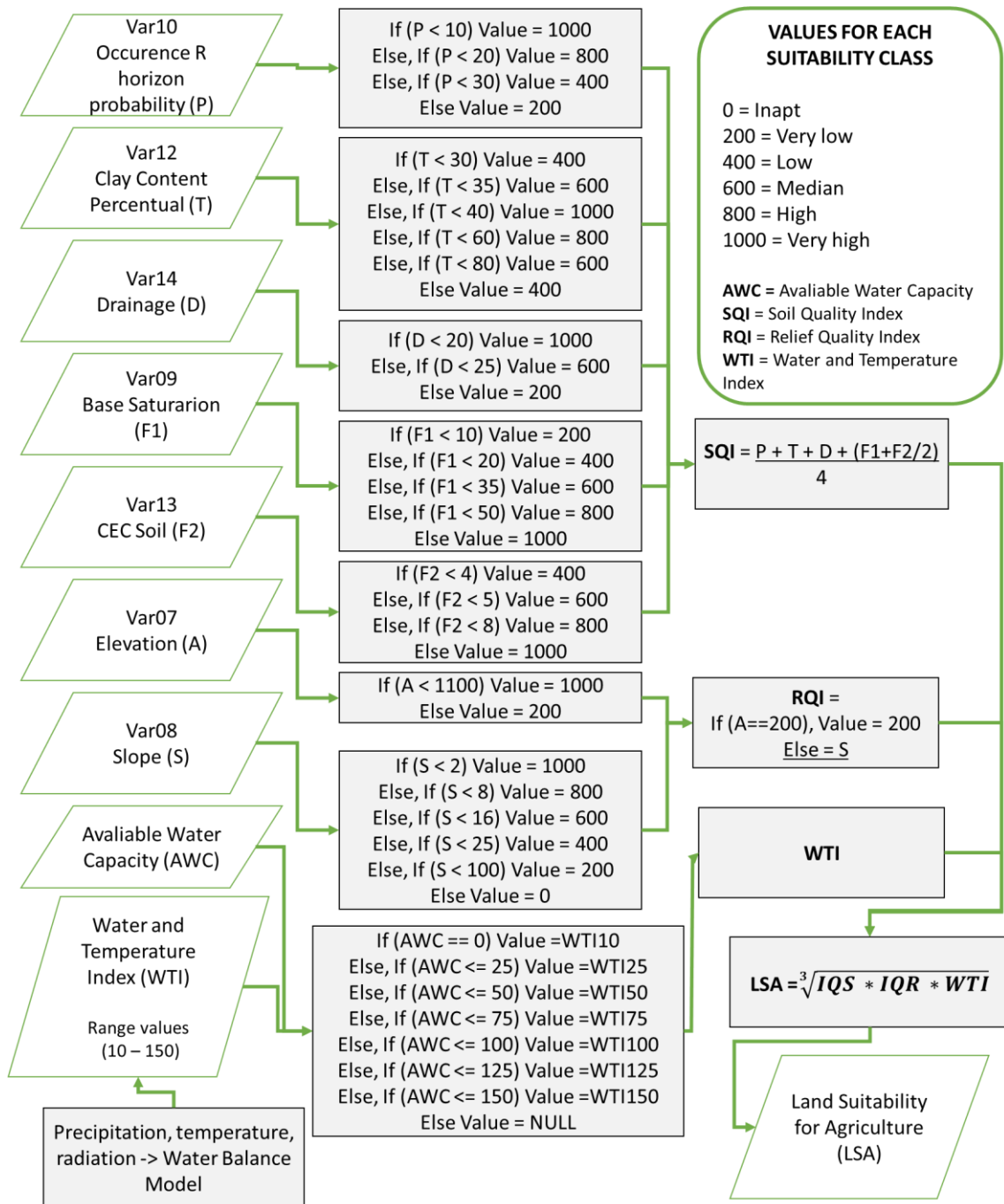


Figure S3. GIS procedures used to generate the Land Suitability for Agriculture index.

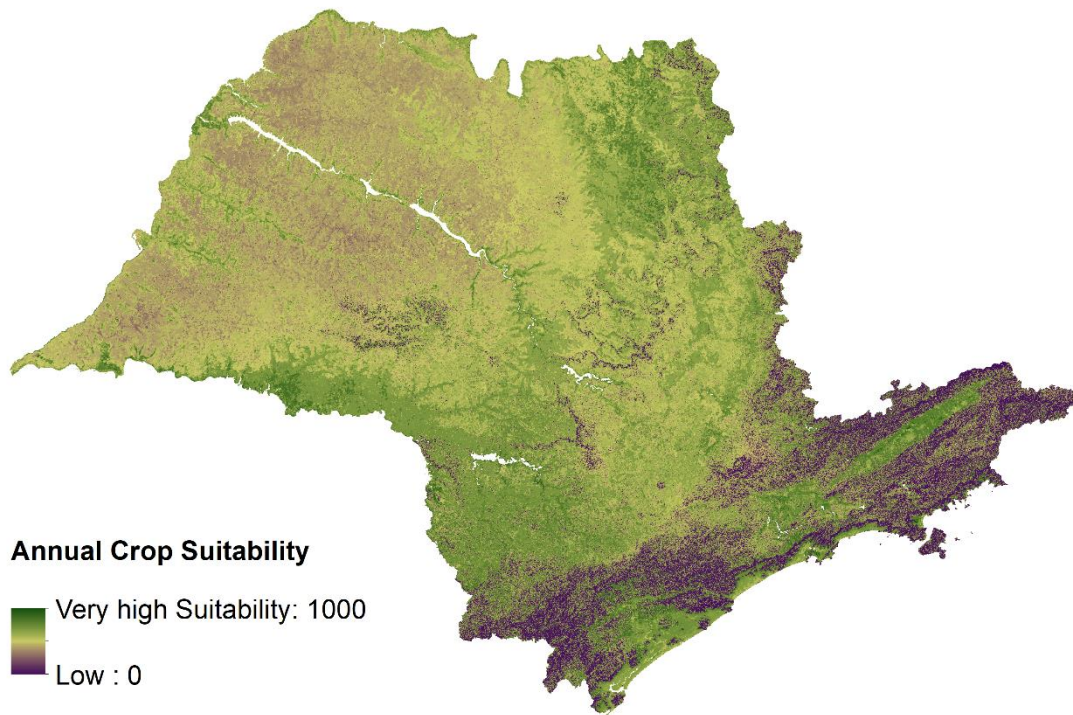


Figure S4. Agriculture land-suitability for São Paulo State in 1920.

3. WHAT ARE THE IMPACTS OF THE DELAY IN IMPLEMENTING THE FOREST ACT ON NATIVE VEGETATION PROTECTION AND RESTORATION?

Abstract

After conflicts between agribusiness and environmental sector related to the use of rural land, in 2012 the New Brazilian Forest Act was created, bringing various compensation mechanisms and benefits to landowners to carry out an environmental regularization of their farm. Nine years after the law was created, few States have implemented the law and the effect of this delayed implementation is still unknown. In this study we explored the impact of this delay on the Legal Reserve in the state of São Paulo, Brazil, considering the benefits of articles 67 and 68 from the Forest Act and loss of benefits for not complying with the legislation, according to its timeframe. We developed a model to quantify the native vegetation inside the farm in 2018 and compare it with the amount of native vegetation in the timeframe foreseen in the New Forest Act, using spatially explicit information. The model compares whether there has been an increase in native vegetation since the New Forest Act compared to 2018, maintaining the benefits provided by law for a farm, or whether there has been suppression of native vegetation, with the loss of benefits in Articles 67 and 68, if the farm has a percentage of native vegetation below what is required for Legal Reserve. We observed an increase in the native vegetation of the State of São Paulo of 354 kha, being 201 kha in the Cerrado and 152 kha in the Atlantic Forest. However, the farms had losses of 373 kha of native vegetation that occurred in 89% of the Atlantic Forest and were highly concentrated in the Midwest region of the State, a zone of pressure and expansion of agricultural production and with the largest Legal Reserve deficits. With the loss of native vegetation until 2018, large and medium farms increase of 765 kha in deficits of Legal Reserve in the State, losing the benefits of article 68. In relation to small farms, was observed an increased Legal Reserve deficit of 168 kha. We also identified that 50% of the largest deficits in the Legal Reserve in 2018 were distributed in less than 2% of all farms in the state, with the varied land use observed being sugarcane with 64% and pasture with 27%. The delay in implementation harms producers of different sizes, increasing environmental deficits to enforce and the threat of biodiversity due to loss of native vegetation and fragmentation of habitats.

Keywords: Forest Conservation, Environmental Policy, Legal Reserve, Forest Act.

3.1. INTRODUCTION

Native vegetation inside rural farms has been recognized worldwide as essential for biodiversity conservation, climate regulation, and the maintenance of ecosystem services provision (Ainscough et al., 2019; Lindenmayer et al., 2000; Tambosi et al., 2014). In Brazil, from a total of 569 million hectares of native vegetation remnants, 53% occurs inside private lands that are widely distributed throughout the country (Soares-Filho et al., 2014; Sparovek et al., 2015). The Brazilian public protected areas, the Conservation Units, are not enough to protect biodiversity and ecosystem services since only 6.4% of the Brazilian territory is protected under strictly protected areas (MMA, 2019). Also, these areas are unequally distributed throughout the country, they are concentrated in the Amazon region and located in areas of low agricultural expansion suitability as mountainous areas in the Atlantic Forest. Thus, the native vegetation in private lands is essential to increase the connectivity among Conservation Units and, consequently, to increase the protection of ecosystem services such as pollination, water supply, prevention of floods or dries, and local climate regulation (Guidotti et al., 2020; Hasan et al., 2020).

This scenario shows the importance of the Native Vegetation Protection Law (NVPL) (Federal Law 12.651/2012), commonly known as the New Forest Act, the main Brazilian environmental policy that regulates the conservation and use of native vegetation inside farms. Its main mechanisms for protecting native vegetation are the Legal Reserves and the Areas of Permanent Preservation (APP). The Legal Reserve is a percentage of the farm that must be maintained with native vegetation, but low-impact economic activities are permitted as small-scale fruit or wood production. The percentage of land that must be protected as Legal Reserve depends on the farm's location, varying from 20 to 80% of the total farm area (Brasil, 2012; Metzger et al., 2019).

The former Forest Act (1965) went through a long process of revision marked by disputes between sectors, until the approval of the NVPL in 2012 (Brancalion et al., 2016). On one side, the agribusiness sector argued that the compliance with the previous law would impair the agriculture development in Brazil (Diniz and Ferreira Filho, 2015). On the other side, scientists and

environmentalists argued that the proposed changes would threaten the native vegetation remnants conservation (Metzger, 2010).

After ten years of its approval, the Forest Act is still not totally implemented and it still causing controversies, compromising the biodiversity and ecosystem services conservation in Brazil (Mello et al., 2021). The lack of political will, stakeholder support, policy regulation, monitoring, and enforcement have delayed the implementation of environmental policies worldwide, and it compromises the protection of natural resources as forest and water (WWF, 2010). One of the main aspects that contributed to the delay in the Forest Act implementation, is the uncertainties regarding the mechanisms that allowed the reduction of the Legal Reserve required areas. Recently, studies had modeled the effects on the reduction of areas to be protected by Legal Reserves by applying three of these mechanisms: article 15, 67, and 68 (Brasil, 2012). article 15 allows computing APP in the area to be protected by Legal Reserves. article 67 states that Legal Reserve of small farms is equal to its native vegetation area existent on July 22, 2008, when the farm does not have the percentage of native vegetation established by law. Lastly, article 68 grants native vegetation conversions following the legislation in force at the time of the conversion do not lead to the obligation of Legal Reserve restoration or compensation to the extent required by the Forest Act.

However, there are no studies that analyze the impacts of the delay in the Forest Act implementation on native vegetation clearing and the debit of farmers who have deforested in the past. Here we accessed farms' compliance with the NVPL until 2018 and its right to articles 67 and 68 using São Paulo State as our case study.

In this context, the study null hypothesis is that the farms are following the requirements of the Forest Act and, consequently, maintaining their rights to articles 67 and 68. The alternative hypothesis is that, even after the Forest Act approval, there is still illegal deforestation inside farms, and, thus, landholders lose their rights to articles 67 and 68.

3.2. MATERIAL AND METHODS

3.2.1. Study Area

We used São Paulo State as article 67 and 68 application analysis. Four main characteristics made São Paulo State a good case study. First, the State has a history of intensive deforestation, turning it in to a valuable case for article 68 analysis. Second, the State has spatial and tabular needed for the analysis. Third, it has already established, through its Environmental Regularization Program (Portuguese acronym: PRA) the legal benchmarks for article 68 implementation. Lastly, São Paulo has strong institutions involved in the Forest Act implementation debate, making it a valuable representant of the national debate.

Besides São Paulo state is the biggest Brazilian economy, representing almost one third of the national gross domestic product (U\$ 389 billion) and the largest producer of one of the main Brazilian commercial crops, the sugar cane. The sugarcane crops cover an area ranging from 5.17 to 6.19 Mha of the State, with a production value of U\$ 4.9 billion (IBGE, 2018a, 2018b; Mapbiomas, 2020). The state also has the presence of the two most threatened Brazilian biomes: Atlantic Forest and Cerrado. Both biomes have suffered pressure in the past due to the expansion of crops and pastures (Da Silva and Bates, 2002; ; Rezende et al., 2018). Currently, only 19% of Atlantic Forest and 3% of Cerrado original native vegetation cover remain in the State (Mapbiomas, 2020). The Legal Reserve requirement for both São Paulo State's biomes is 20% of the farm area (Brasil, 2012).

3.2.2. Adopted Legal Benchmarks

Legal Reserve is regulated by the article 12 of the Forest Act, demanding the protection of 20% of the total area of the farm in the Cerrado and Atlantic Forest in São Paulo state. The law enables the reduction of the required Legal Reserve in some specific conditions. We used the reduction described in articles 15, 67 and 68. article 15 enables to allocate the permanent preservation areas (e.g., riparian zone to be protected) in the calculation of Legal Reserves. article 67 except small farms from the need to restore the native vegetation of Legal

Reserves converted before July 26, 2008. Article 68 excludes the need for restoration in farms, where removal of native vegetation took place following the previous legislation that was in place when the conversion occurred until July 26, 2008, date referring to environmental crimes law (Freitas et al., 2017), which is the benchmark adopted by the New Forest Act to apply articles 67 and 68.

Because of that we considered the application of article 68 provides the legislative frameworks to be used aiming at the analysis of suppression of native vegetation and each state is responsible for determining its benchmarks prior to the current law. In the state of São Paulo, the benchmarks of 1934, 1965 and 1989 were established. The first benchmark was the Forest Act in 1934, in which it was mandatory to maintain 25% of the existing vegetation on the farm (Brasil, 1934; São Paulo, 2015). The second benchmark was the Forest Act of 1965 in which the existing vegetation protection mechanism was altered to the percentage of the farm size and the conservation of 20% of forests within the farm, ignoring the protection of open vegetation types such as savanna and rocky grasslands formations (Brasil, 1965). Federal Law 7803 in 1989 increased protection by 20% for all native vegetation formations in the country (Brasil, 1989). Within the context to carry out the analysis of the time frames provided for in the law, we used spatial bases that represented each legislative frame: 1934, 1965, 1989 and 2008 and we checked if the native vegetation suppression inside the farm was in accordance with the law benchmark.

After modeling article 68 until 2008, we compared it with the native vegetation information from 2018 to understand the impact of the delay in implementing the Forest Act on the dynamics of native vegetation within farms.

3.2.3. Database

The farm boundaries were defined from a composed dataset of land tenure, which integrates the available databases of georeferenced rural farms boundaries including the Rural Environmental Registry (CAR in Portuguese acronym, from 2018), indigenous reserves, rural agrarian reform settlements, military land, urban areas and national, state and municipal protected areas (Freitas et al., 2018; Freitas et al., 2018; Sparovek et al., 2019). Geometries and overlaps errors in the CAR dataset and among all the databases were corrected.

For modeling the Legal Reserve deficit (which must be restored or compensated by the farm's owner) we used different native vegetation databases to generate a historical analysis with the application of article 68 considering all legal benchmarks (Figure1).

For the 2008 benchmark, we used data of native vegetation cover from the Brazilian Foundation for Sustainable Development (FBDS) (scale 1:25.000) (Table 1). For the 1965 and 1989 benchmarks we used the native vegetation cover from the 1965 IBGE map. This database consists of maps made by the "Brazilian Institute of Geography and Statistics" (IBGE) at the scale 1:50,000 (IBGE, 1965). We only considered the native vegetation fragments from 1965 for the year 1989 that remained when compared to Landsat imagery, with spatial resolution of 30m, from January to December 1989.

Before 1960s there is no explicit spatial database for native vegetation in the farm scale. Thus, for the 1934 benchmark we created a 1920's simulated land use, (see Chapter II for details).

For the current benchmark, we used 2018 data native vegetation from Mapbiomas 5.0, with a spatial resolution of 30m. The land cover types that composed the native vegetation class can be seen in the complementary material S1 appendices.

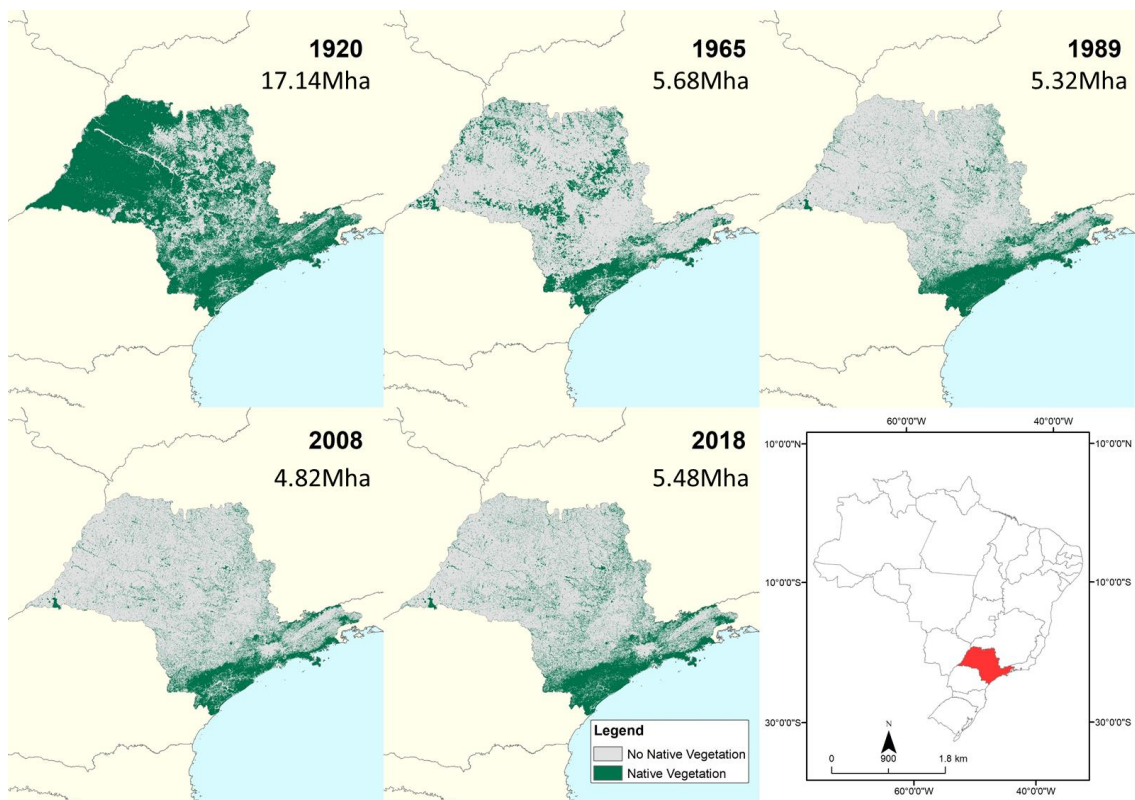


Figure 1. São Paulo State location and the changes of native vegetation over 98 years using the law benchmarks as temporal reference.

Table 1. Description of the main requirements and data used to perform the Forest Act implementation.

Regulation	Year Reference	Native Vegetation Database	Native Vegetation Classification	Data type
Federal Decree 23.793	1934	Native vegetation simulated based on Census 1920	n.a. ⁵	Simulated
Federal Law 4.771	1965	1:50000 IBGE maps ¹	RADAM Project maps ²	Explicit and Precise
Federal Law 7.803	1989	Landsat jan/89 – dez/89; 1:50000 IBGE maps ¹	RADAM Project maps ²	Explicit and Precise
Federal Law 12.651	2008	1:25.000 FBDS ³	n.a. ⁵	Explicit and Precise
Federal Law 12.651	2018	(30m) Mapbiomas 5.0 ⁴	n.a. ⁵	Explicit and Precise

Notes: ¹IBGE, 1965; ²IBGE, 2015; ³FBDS,2011; ⁴Mapbiomas, 2020; ⁵n.a. = does not apply.

3.2.4. Model Processing for Current Legal Reserve application

First, we modeled the baseline scenario, which is the Legal Reserve deficit in 2008. For that, the area of native vegetation for each farm in 2008 was calculated and the percentage of native vegetation remaining was calculated according to the requirements for Legal Reserve in São Paulo State (i.e., 20%). The following discounts provided by the articles 15, 67 for the Legal Reserve. If the native vegetation percentage required for Legal Reserve was not reached, farms were considered as non-compliant and potentially eligible to access the article 67 or 68 benefits.

In a second step, the model verified if farms with more than four Fiscal Modules that had Legal Reserve deficit in 2008 were in accordance with the law at the time in which the suppression of native vegetation was carried out. In this way, the amount of native vegetation was verified for the time frames of 1989, 1965 and 1934. If the farm was in compliance with the law at the time the native vegetation was converted into another land use, it receives the benefit and its Legal Reserve deficit was canceled (Figure 2).

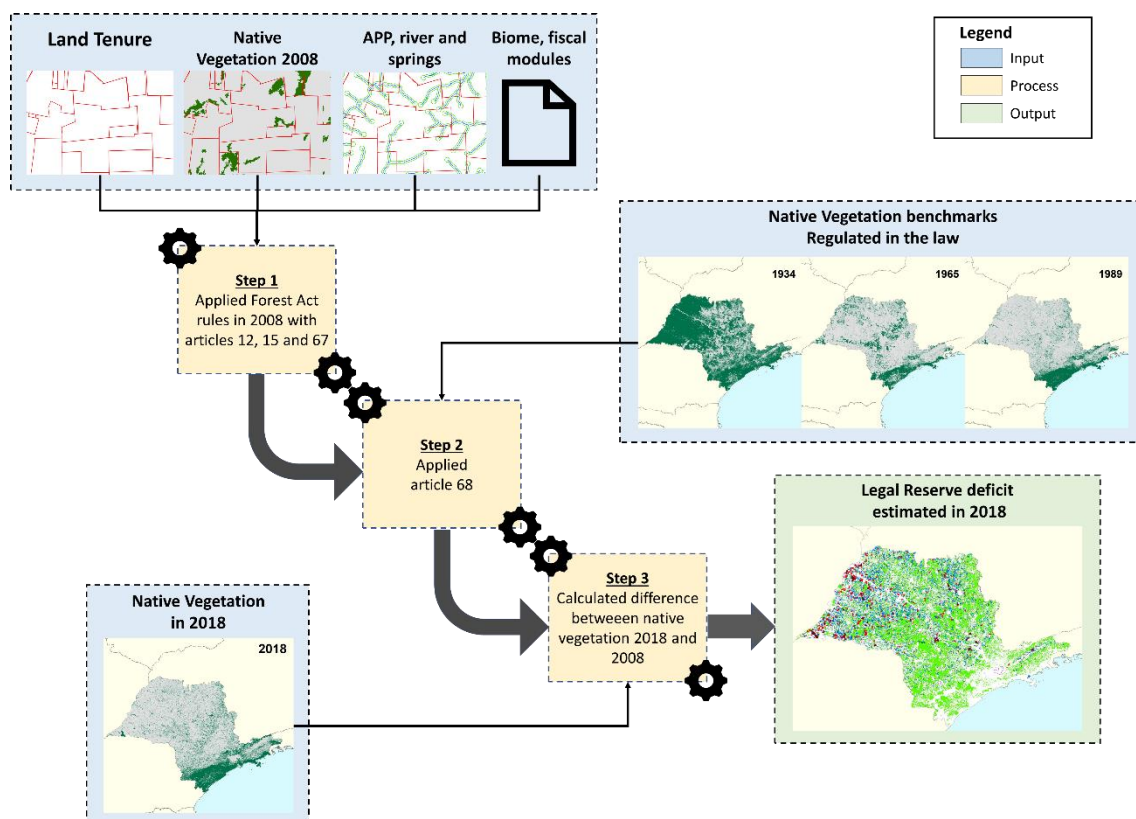


Figure 2. Methodology applied to calculate the Forest Act on farms, considering articles 15, 67 and 68 and Legal Reserve deficit in 2018.

After modeling the 2008 scenario (baseline) including Legal Reserve reduction mechanisms that were modeled, we evaluated the impacts of the delay

in the Forest Act implementation comparing the native vegetation in 2008 and 2018 considering four different conditions where farmers keep or lose the benefits of the articles 67 and 68 (Table 2).

Table 2. Resume of the conditions considered for delay in implementing of Forest Act. NV = Native Vegetation; LR = Legal Reserve

Condition	Relation between NV 08 and NV 2018	Percentual of NV in farm area	Effect
1	NV 2008 > NV 2018	NV 2018 \geq LR required	n.a.
2	NV 2008 > NV 2018	NV 2018 < LR required	Lose article 67 and 68 benefits and need to comply with required LR
3	NV 2008 \leq NV 2018	NV 2018 < LR required	Maintain the benefits of article 67 or article 68
4	NV 2008 \leq NV 2018	NV 2018 \geq LR required	n.a.

In the first condition, the landowner cleared native vegetation between the period of analysis, but the native vegetation remains greater than or equal than the Legal Reserve requirement (i.e., 20%). In this condition, the farm comply with what is required by the 2012 Forest Act and have no changes in its benefits.

In the second condition the landowner cleared native vegetation between 2008 and 2018 and the vegetation cover is smaller than required by the Forest Act Legal Reserve. In this situation, the farmer would lose all benefits (article 47 or 48) and be obliged to comply with the compensation or restoration according to the Legal Reserve requirement.

In the third condition, we assumed that the amount of native vegetation had increased over time, but it still a lower percentage than required by the Forest Act. The benefits from articles 67 and 68 will be maintained.

In the fourth condition we assumed that the farm had an increase in native vegetation over time and its area is greater than the Forest Act Legal Reserve requirement. In this condition, the farm complies with what is required by the Forest Act and have no changes in its benefits.

To reduce the error between the use of different land use maps, we analyzed the histogram of native vegetation patches distribution according to

their size considering absolute and relative values at 95% confidence level (Figure S2). We adopted as an acceptable error a ratio greater than 5% between the native vegetation area of 2018 and 2008 for small farms, smaller or equal than 4 Fiscal Modules (FM), and 2% for medium and larger farms with more than 4 FM. According to the literature, we also used the minimum difference of 0.5 ha in order to avoid spatial uncertainties due to dynamics of uses that can be associated with the transition of native vegetation (Hamunyela et al., 2017; Souza et al., 2020).

3.3. RESULTS

3.3.1. Balance of native vegetation gains and losses

We considered 334911 rural farms between the periods of 2008 and 2018, obtaining a positive balance of native vegetation of 353 kha, with a gain of 201 kha in the Cerrado and 152 kha in the Atlantic Forest. This value is the result of a balance between a gain of 727 kha of native vegetation and a loss of 374 kha across the São Paulo State. The losses are concentrated in the western part of the State, and the gain in the Cerrado and South Coast of the Atlantic Forest (Figure 3)

Of the 331 kha native vegetation cleared in the Atlantic Forest between 2008 and 2018, 76% were distributed in 18580 farms larger than 4 FM and 24% in 39358 farms with less than or equal to 4 FM (small farms). Atlantic Forest concentrated 89% of the losses, mainly in the west of the State. In the Cerrado biome, there was a loss of 42 kha of native vegetation, 21% of this loss occurred in small farms and 79% in farms larger than 4 MF (Table 3).

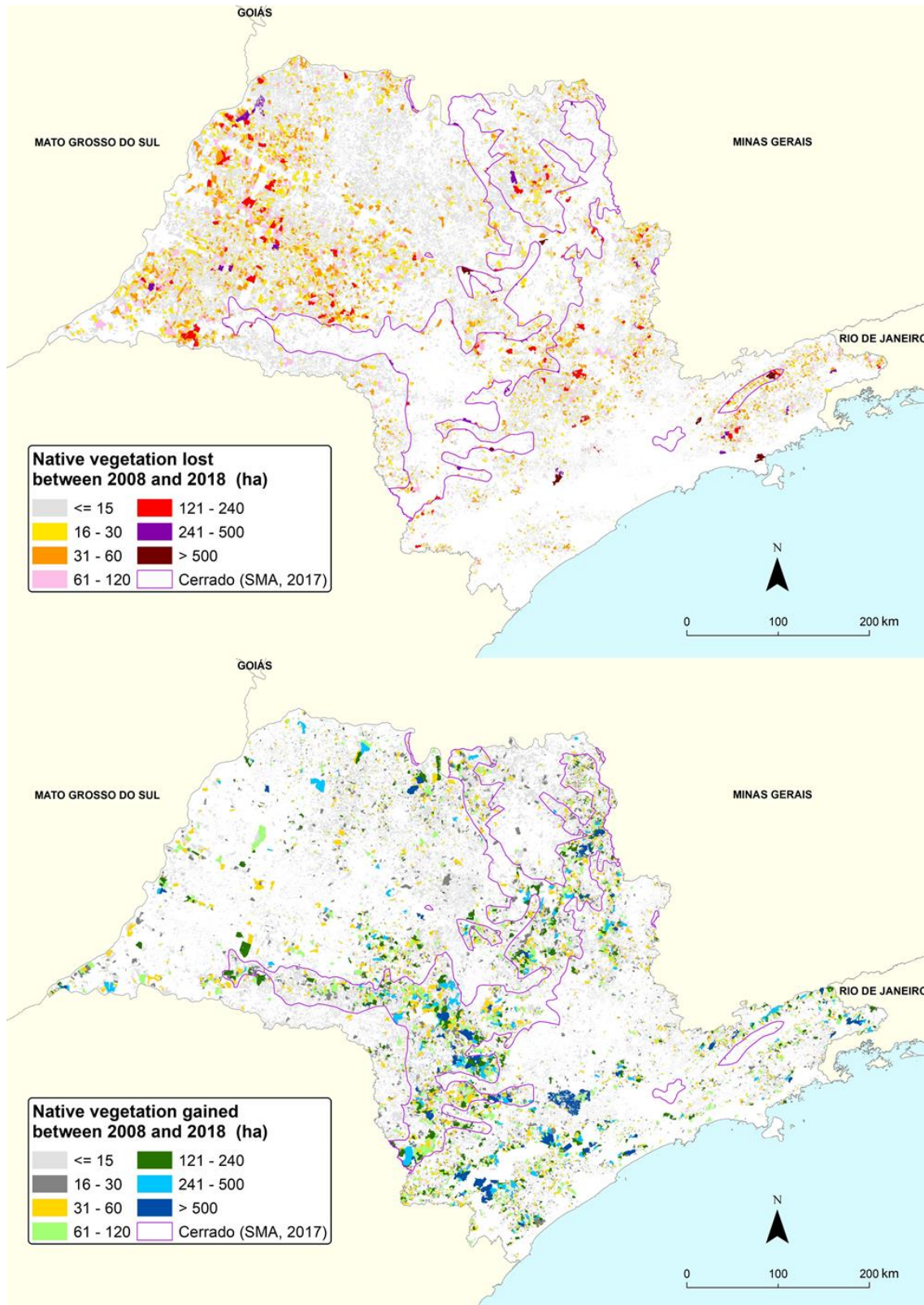


Figure 3. Distribution of the native vegetation losses and gains in São Paulo State Between 2008 and 2018.

Table 3. Number of farms that lost or gained native vegetation between 2008 and 2018 and area of native vegetation lost or gained for the same period. MF = fiscal module

Biome	Fiscal Module	Native Vegetation			Native Vegetation losses		Native Vegetation Gain	
		Nº farms (10 ³)	Area in 2008 (kha)	Area in 2018 (kha)	Nº farms (10 ³)	Area (kha)	Nº farms (10 ³)	Area (kha)
Cerrado	≤ 4MF	16.45	69.31	105.99	4.05	8.93	12.404	45.61
	> 4MF	9.77	451.45	615.55	3.04	33.31	6.728	197.41
Atlantic Forest	≤ 4MF	86.77	437.52	512.59	39.36	80.08	47.414	155.15
	> 4MF	31.22	1627.45	1704.77	18.58	251.19	12.642	328.51

3.3.2. Evaluation of the loss of article 68 and 67 benefits

Article 68 benefits

Of the 46398 rural farms greater than 4 FM existing in São Paulo State, 46% had the benefit of article 68 in 2008. From this total, 15465 farms were in the Atlantic Forest and 57,30 in the Cerrado. However, only 37% maintained the benefits in 2018 (kept or increased their native vegetation within the farm). Over the ten years analyzed, 10074 farms lost their benefits, increasing the Legal Reserve deficit of the state from 328 kha in 2008 to 765 kha in 2018, which 84% occurs in the Atlantic Forest biome (Figure 4 and Figure 5). The Cerrado has 103 kha of deficit to be compensated, and it was observed that 5420 farms did not have Legal Reserve deficits until 2008, but they had lost native vegetation until 2018, and now have a legal obligation to recover 91 kha (Table 4).

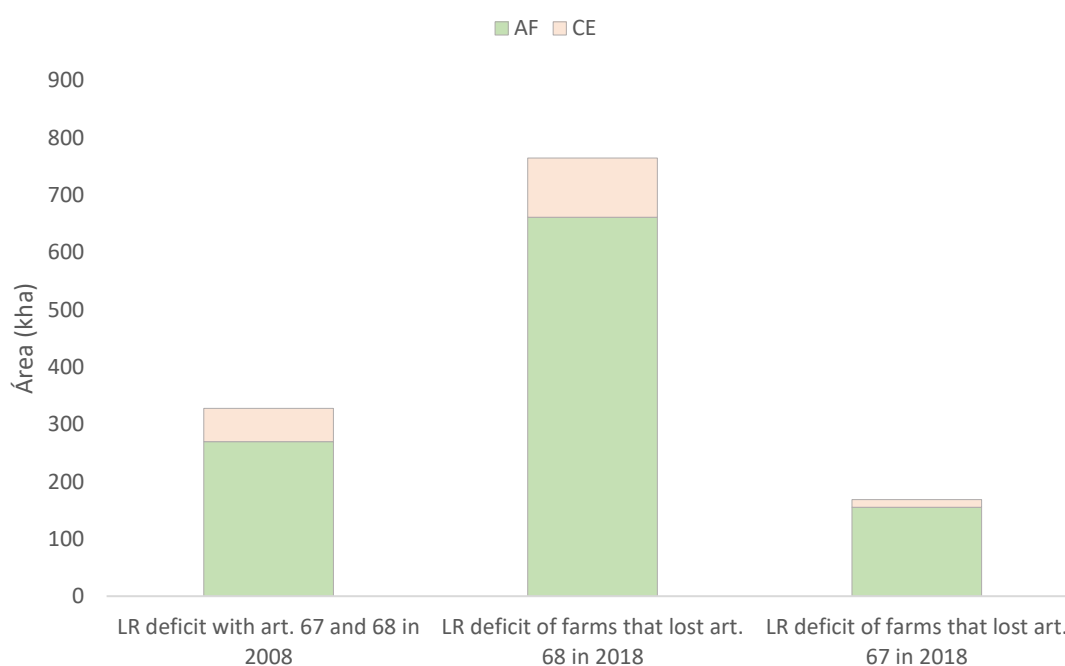


Figure 4. Legal Reserve deficit estimated in 2008 with application of articles 67 and 68 and ten years after the year reference in Forest Act. LR = Legal Reserve; AF = Atlantic Forest; CE = Cerrado.

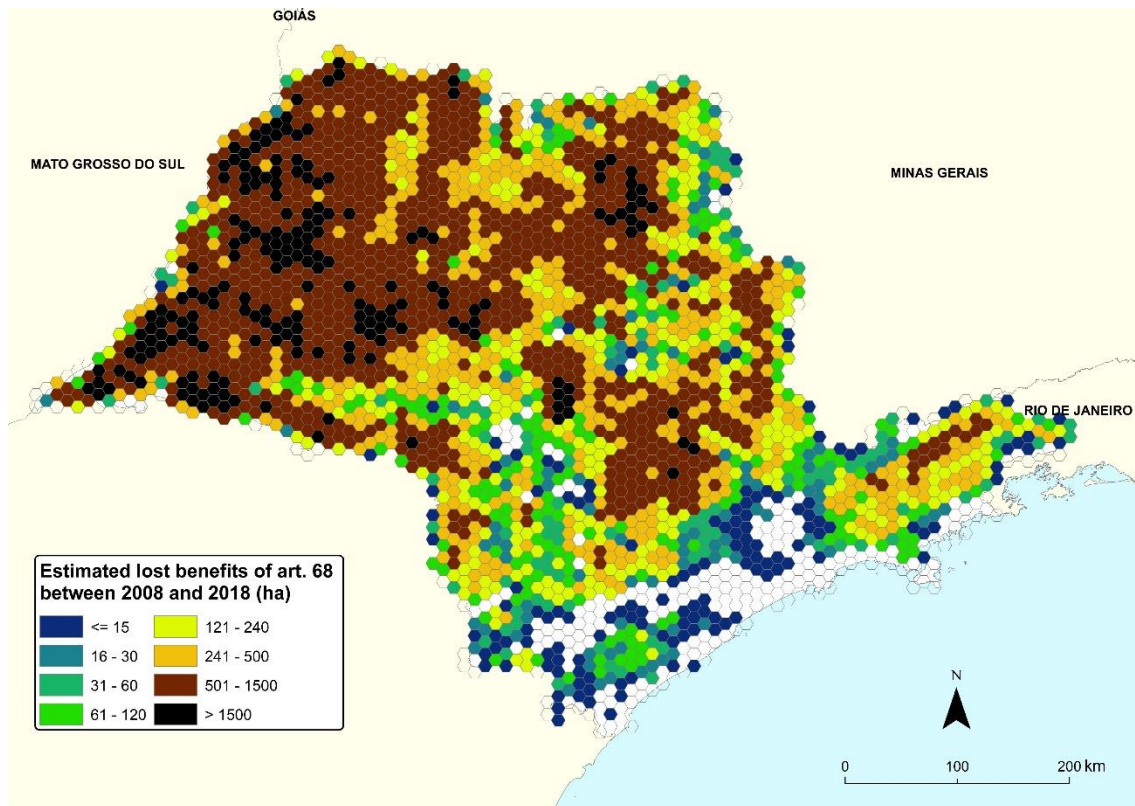


Figure 5. Distribution of 10074 of 30417 farms that would potentially lose the benefit of article 68 in São Paulo State. Hexagons in the maps represent 100 km² landscapes.

Table 4. Maintenance and loss of the benefits of articles 68 and 67 on the farm per biome. LR = Legal Reserve; AF = Atlantic Forest; CE = Cerrado

Biome	LR deficit in 2008 with art. 68	Farms eligible for application of art 68 with LR deficit in 2018	Farms that lost art. 68	Farms that maintained art. 68	LR deficit of small farms that lost art. 67	Small farms that maintained art. 67
Nº farms (10 ³)						
AF	7.3	17.9	8.5	7.0	28.8	7.2
CE	1.9	3.5	1.6	4.2	2.9	249.6
TOTAL	9.2	25.0	10.1	11.1	31.7	256.8

Article 67 benefits

São Paulo State has a total of 288513 small farms, and 31695 of them (11%) had lost the right to article 67 between 2008 and 2018, representing an increase of 168 kha in the Legal Reserve deficit (Figure 4 and Figure 6). From this total, 92% were concentrated in the Atlantic Forest and 8% in Cerrado. 89% of the farms remain with the benefits proposed in article 67, from which, 97% occurs in the Cerrado biome (Table 4).

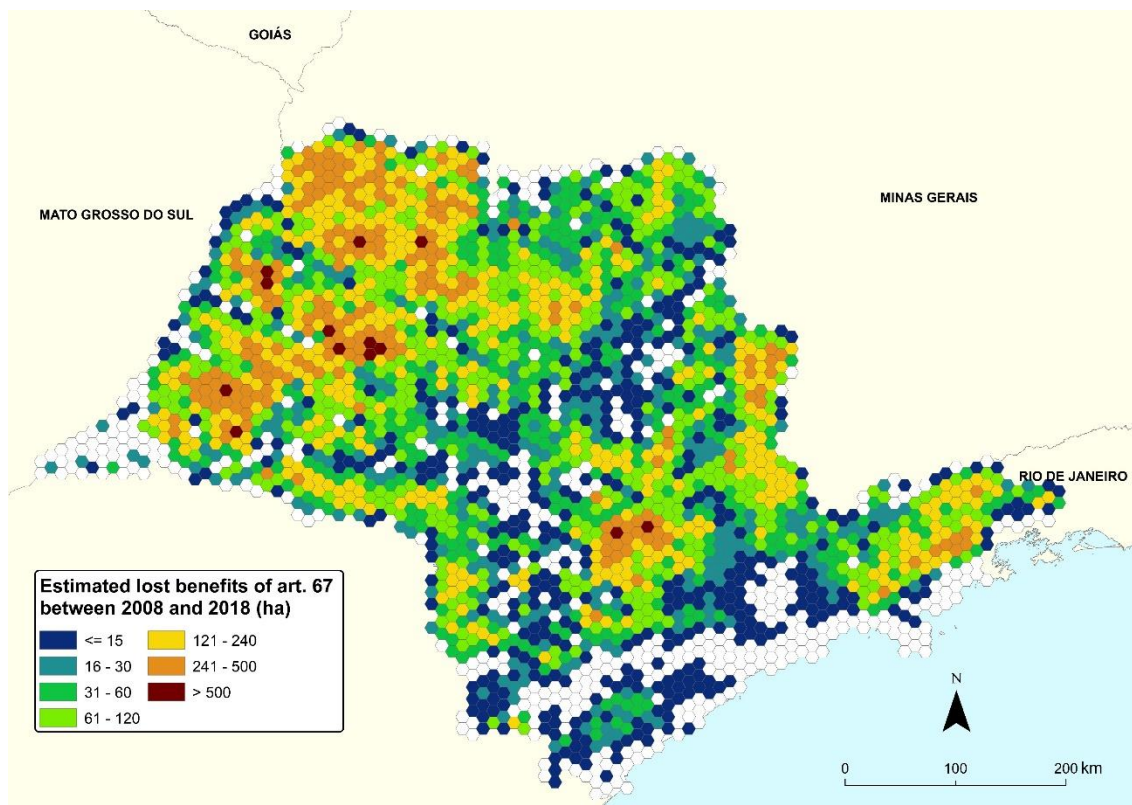


Figure 6. Distribution of 31695 of 288513 small farms that would potentially lose article 67 benefits in São Paulo State. Hexagons in the maps represent 100 km² landscapes.

It was observed that 50% of the largest Legal Reserve deficits in 2018 were concentrated in 4921 farms, which is equivalent to 1% of the total farms in São Paulo State, with large farms was responsible 84% of the deficit area while medium farms concentrated 16% of the deficit area. Besides, 4273 farms distributed in the Atlantic Forest (Figure 7).

Sugarcane production and pastures are the major land use of these farms with the largest 50% Legal Reserve deficits, occurring in 91% of the farms (Figure 8). When was observe at the range of the 75% largest Legal Reserve deficits, 98% (688 kha) were concentrated in medium and large farms, while only 2% were in small farms.

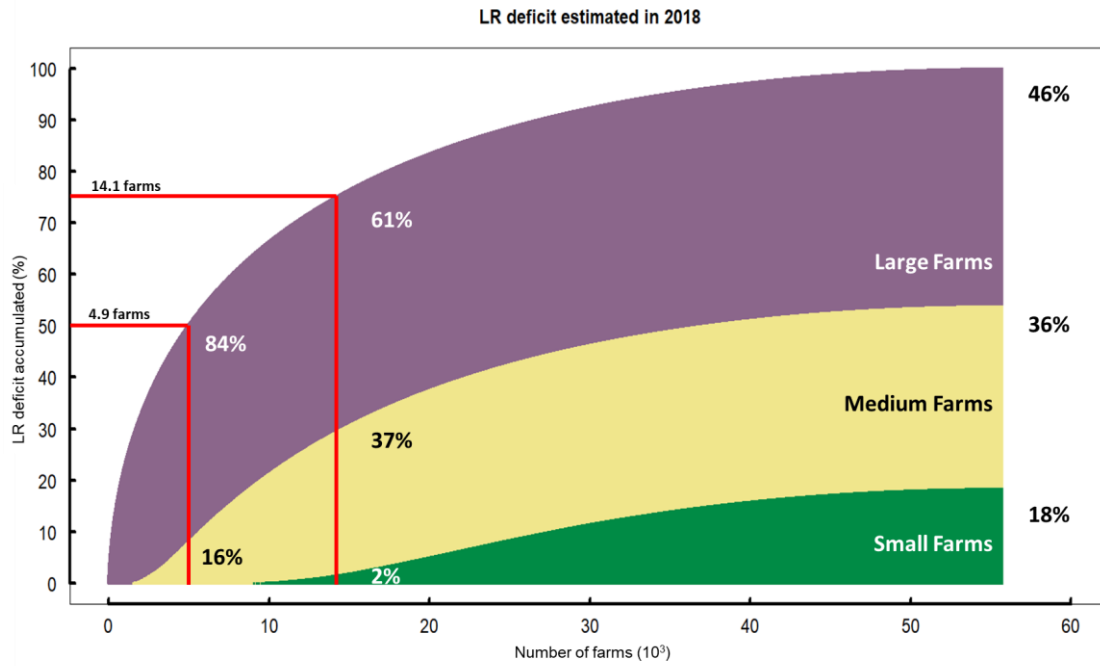


Figure 7. Distribution of the 936 kha largest areas of Legal Reserve deficits in the State of São Paulo by number of farms.

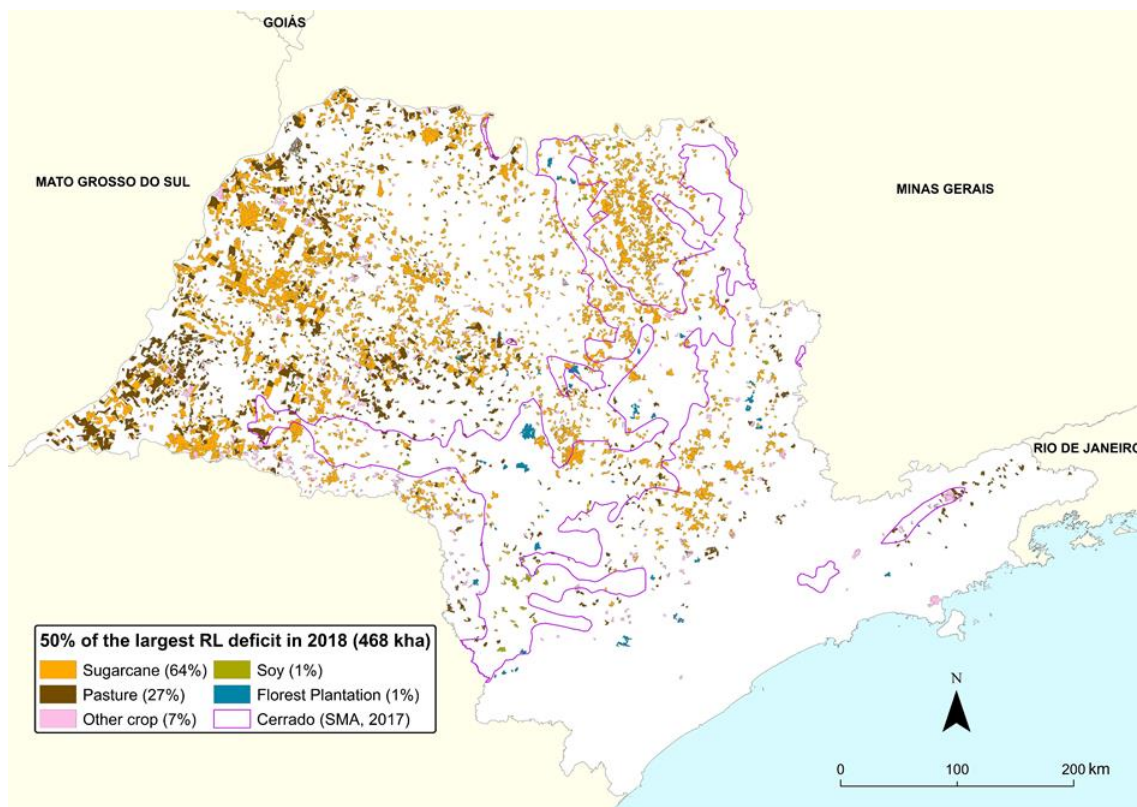


Figure 8. Geographic distribution of farms that contain the 50% largest Legal Reserve deficits and their main activity.

3.4. DISCUSSION

In ten years that were considered in this study, we observed an increase in São Paulo State native vegetation of 353 kha, a total gain equivalent to 4% of the total native vegetation existing in rural farms, when compared to 2008 (Brançalion et al., 2016; Soares-Filho et al., 2014). For the Cerrado, this increase was of 201 kha, representing almost five times more than the loss of native vegetation. For Atlantic Forest the increase was of 152 kha, corresponding to 1.46 times more than the loss native vegetation. However, the loss of 373 kha of native vegetation occurred 89% in the Atlantic Forest and were highly concentrated in the central-west region of the State, a zone of pressure and expansion of agricultural production (Takaaki et al., 2015) and with the largest deficits of Legal Reserve in the State (Tavares et al., 2019). With the loss of native vegetation until 2018, large and medium farms presented an increase of 765 kha in Legal Reserve deficits in the State, with 10074 farms losing the benefits of article 68. Regarding small farms, 31695 would lose the benefit of article 67, representing an increase of 168 kha Legal Reserve deficit. In other words, the delay in implementing the New Forest Act represented an increase of 608 kha in the Legal Reserve deficit in São Paulo State, which represents 285% of the deficit in 2008. Also we observed that 50% of the largest deficits in the Legal Reserve in 2018 were distributed across 4921 farms, which represent 1% of the total farms in the State and were divided into 84% in large farms and 12% in medium farms and the major land use observed was sugarcane with 64% and pasture with 27%.

Two factors can explain the better scenario in the Cerrado than the Atlantic Forest in the State, regarding the losses of native vegetation and losses of the articles 67's and 68's benefits. First, it is possible that the map used for 2018, i.e., the Mapbiomas, can fail to distinguish between native vegetation and citrus plantations that occur in the Cerrado region and the transition areas, attributing a greater amount of native vegetation in the biome. Second, the fact that São Paulo State has a specific law to protect this biome, forcing a more intense projects evaluation that involve native vegetation conversion (São Paulo, 2009).

In the Atlantic Forest, despite the increase of 152 kha of native vegetation in 10 years, the results showed that this increase was concentrated in the coastal zone, where the forest remnants are concentrated, and there is a low number of farms with Legal Reserve deficits. On the other hand, in the countryside of the State, where there is a low native vegetation cover and a high Legal Reserve deficit, there were native vegetation losses during the ten years. This threatens the conservation of important forest types in this region that are already threatened, as the semideciduous Atlantic Forest, causing severe impacts on biodiversity conservation and the ecosystem services provision such as keeping water quality and availability, soil conservation, and pollination (Guidotti et al., 2020; Ribeiro et al., 2009; Rosa et al., 2021). These ecosystem services are essential to agricultural production, thus the native vegetation protection under Legal Reserves is crucial once there are a few protected areas in this region (Metzger et al., 2019).

The native vegetation losses in this region can be related to the expansion of the agricultural lands of sugarcane and pasture, mainly of medium and large farms, in terrains that allow agriculture mechanization (Pacheco et al., 2021 and Rosa et al., 2021). According to Pacheco et al. (2021) and Rosa et al. (2021), farmers tend to clear native vegetation in this region because the land has greater agricultural suitability than in the mountain region close to the coast as the Ribeira Valley, where they can compensate their Legal Reserve deficit in cheap land with low agricultural sustainability.

However, the geographic boundaries for Legal Reserve compensation remain uncertain for the main compensation instrument in the New Forest Act: The Environmental Reserve Quotas (CRA in the Portuguese acronym). In 2018 the Supreme Federal Court decided that Legal Reserve compensation sites under CRA should be 'ecologically equivalent to the vegetation cleared/lost from the farm for which the compensation deficit arises. Other compensation mechanisms would keep the requirement in the law that is the same biome. However, the term 'ecological equivalence' remains undefined in the legislation, i.e., there is no definition of the degree of ecological equivalence and how to measure it (Mello et al., 2021). If a more restrictive compensation requirement than biome is applied in São Paulo State, this would prevent the Legal Reserve

deficits in the west part of the State from being compensated in the Ribeira Valley (Mello et al., in press).

The conversion of native vegetation in small farms, representing losses of the benefit of article 67 and generating a deficit of 168 kha, can be explained by the perception among landowners that there is no monitoring and the New Forest Act will not punish those who deforest, as what has happened since its creation in 1965 (Probst et al., 2016). To mitigate the increase in deforestation, action focused on small farmers must come in the form of incentive policies such as payments for ecosystem services (Alarcon et al., 2015), ecological taxes (i.e., Ecological ICMS) allocation (Rocha et al., 2019). Such incentives would allow small producers to obtain access to technical assistance and low-impact technologies to increase production in cultivated areas and decrease opportunity costs for restoration through the implementation of agroforestry systems since the adherence of the restoration strategy tends to be greater in this class land ownership (Medina et al., 2021; Mello et al., 2021; Pacheco et al., 2021; Strassburg et al., 2019).

3.5. CONCLUSION

Since 2012, the year of the New Forest Act approval, until 2018, there was an increase in the native vegetation of São Paulo State. However, this increase comes from a balance of losses and gains of native vegetation, which directly impact the requirements of compliance with the legislation.

In this study it was possible to identify the effect of this balance on the Legal Reserve, causing the loss of benefits of articles 67 and 68, increasing the deficit in the State almost three times than the benchmark in the New Forest Act.

The delay in the New Forest Act implementation resulted in a great increase in the total Legal Reserve deficit, mainly from medium and large farms, but also a considerable amount from small farms. These outcomes impact both: biodiversity and farmers. The native vegetation clear keeps expanding over private lands and the Legal Reserve deficits increase, causing biodiversity and ecosystem losses and an increase in Legal Reserve compensation/restoration

costs for farmers. The native vegetation loss on private lands over ten years resulted in the loss of benefits that were created in the New Forest Act to help the farms' regularization. Therefore, the delay in implementing the law, often caused by pressure from part of the agricultural sector harms the sector itself, especially small farmers that would not have Legal Reserve if the law had been implemented shortly after its approval.

3.6. LIMITATIONS

The data used for native vegetation used for the benchmarks 2008 and 2018 were from different sources, with different spatial resolution, pixel classifiers, and image treatments, which may cause differences in the quantities of native vegetation. However, the option to choose a FBDS database for 2008, was because the raster contained a resolution of 5m, allowing the spatially precise computation of APP to its inclusion in the New Forest Act which allows its computation in Legal Reserve areas (i.e., article 15). With respect to the 2018 benchmark, the only database fully classified and available for all the São Paulo state is the Mapbiomas collection.

Another limitation of the study is related to the understanding of what would happen with articles 67 and 68 after the enactment of the law on the protection of native vegetation. Despite ten years since the creation of the law, the rule is still unclear as to who does not comply with the regulation. In this study we have adopted the interpretation of the loss of benefits and obligation under article 12 of the current law. However, it is also possible to interpret the scenario of returning to the amount of native vegetation existing in 2008, however this scenario was not modeled in this study. Further, it is beyond the objective of the present study to determine which is the correct legal interpretation. Once São Paulo State decided about these mechanisms, we can adapt our model to reflect it in a future work.

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APPENDIX I

SUPPLEMENTARY MATERIAL

Table S1. Database used for classification of native vegetation in the São Paulo state. Native vegetation corresponds to Land use code equal to 200.

Source	Year reference	Law reference	Value	Name	Land use code
Geolab	1934	23.793/1934	100	agriculture	100
Geolab	1934	23.793/1934	200	native vegetation	200
Agrossatelite	1965	4.771/1965	" "	empty	100
Agrossatelite	1965	4.771/1965	"CERRADO"	cerrado	200
Agrossatelite	1965	4.771/1965	"MATA ATLANTICA"	atlantic forest	200
Agrossatelite	1989	7.803/1989	" "	empty	100
Agrossatelite	1989	7.803/1989	"CERRADO"	cerrado	200
Combined 5m	2008	12.651/2012	3	water body	100
Combined 5m	2008	12.651/2012	4	anthropic use	100
Combined 5m	2008	12.651/2012	5	urban area	100
Combined 5m	2008	12.651/2012	6	sugarcane	100
Combined 5m	2008	12.651/2012	8	forestry	200
Combined 5m	2008	12.651/2012	9	native vegetation non forestry	200
Combined 5m	2008	12.651/2012	10	pasture	100
Combined 5m	2008	12.651/2012	11	silviculture	100
Combined 5m	2008	12.651/2012	14	soy	100
Combined 5m	2008	12.651/2012	15	Transport	100
Mapbiomas 5.0	2018	12.651/2012	3	natural forest	200
Mapbiomas 5.0	2018	12.651/2012	4	forest formation	200
Mapbiomas 5.0	2018	12.651/2012	5	savanna formation	200
Mapbiomas 5.0	2018	12.651/2012	9	forest plantation	100
Mapbiomas 5.0	2018	12.651/2012	11	wetland	200
Mapbiomas 5.0	2018	12.651/2012	12	grassland formation	200
Mapbiomas 5.0	2018	12.651/2012	13	other non-forest natural formation	200
Mapbiomas 5.0	2018	12.651/2012	15	pasture	100
Mapbiomas 5.0	2018	12.651/2012	18	agriculture	100
Mapbiomas 5.0	2018	12.651/2012	19	temporary crop	100
Mapbiomas 5.0	2018	12.651/2012	20	sugarcane	100
Mapbiomas 5.0	2018	12.651/2012	39	soybean	100
Mapbiomas 5.0	2018	12.651/2012	41	other temporary crops	100
Mapbiomas 5.0	2018	12.651/2012	36	perennial crop	100
Mapbiomas 5.0	2018	12.651/2012	21	mosaic of agriculture and pasture	100
Mapbiomas 5.0	2018	12.651/2012	23	beach and dune	200

Mapbiomas 5.0	2018	12.651/2012	24	urban structure	100
Mapbiomas 5.0	2018	12.651/2012	25	other non-vegetated area	200
Mapbiomas 5.0	2018	12.651/2012	26	water body	100
Mapbiomas 5.0	2018	12.651/2012	27	non observed	200
Mapbiomas 5.0	2018	12.651/2012	29	rocky outcrop	200
Mapbiomas 5.0	2018	12.651/2012	30	mining	100
Mapbiomas 5.0	2018	12.651/2012	31	aquaculture	100
Mapbiomas 5.0	2018	12.651/2012	32	salt flat	200
Mapbiomas 5.0	2018	12.651/2012	33	river, lake and ocean	100

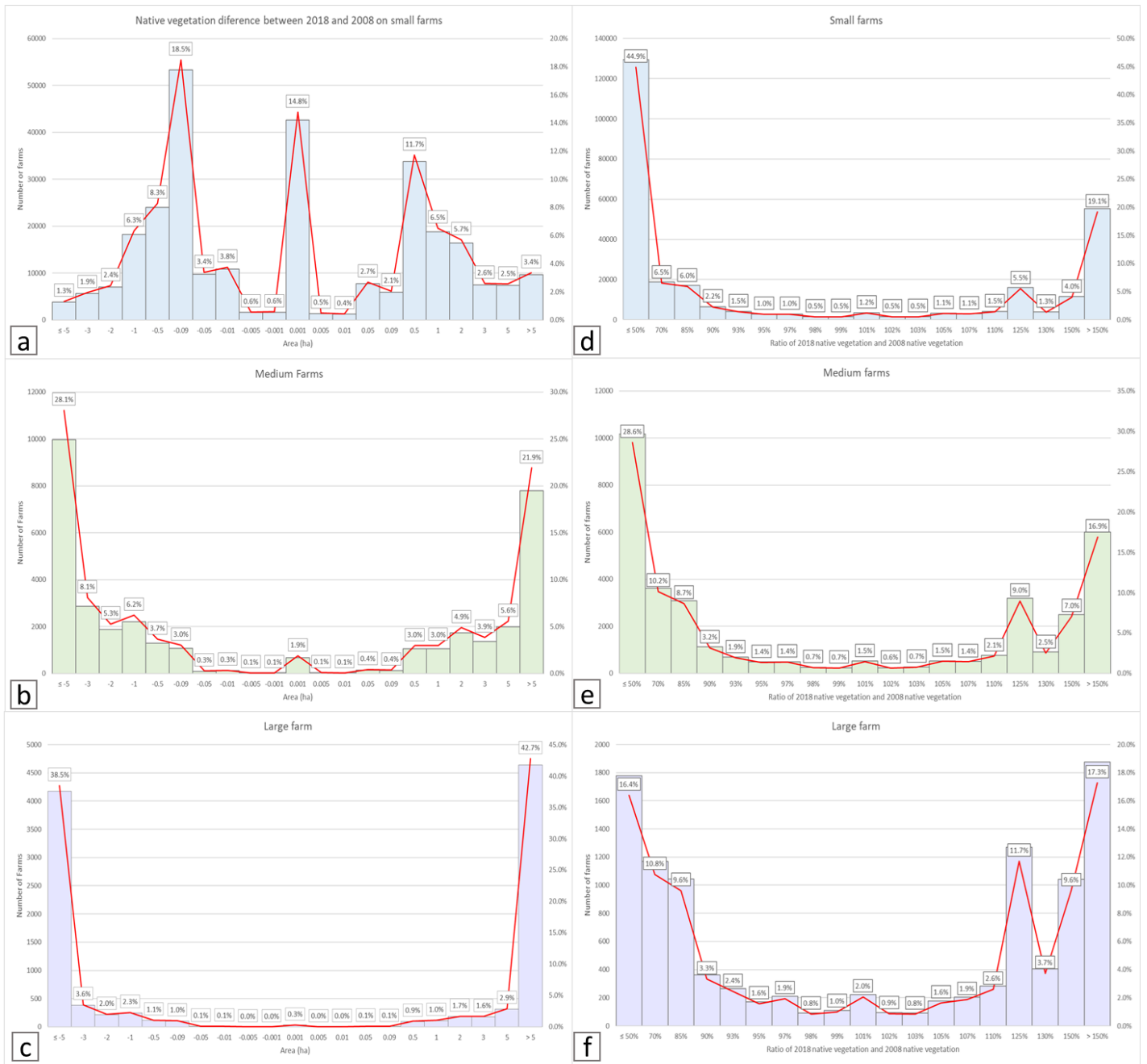


Figure S2. Difference of native vegetation area between 2008 and 2018 for farms: a) Small size b) Medium size c) Large size. And ratio of native vegetation area between 2008 and 2018 for farms: d) Small size. e) Medium size f) Large size.

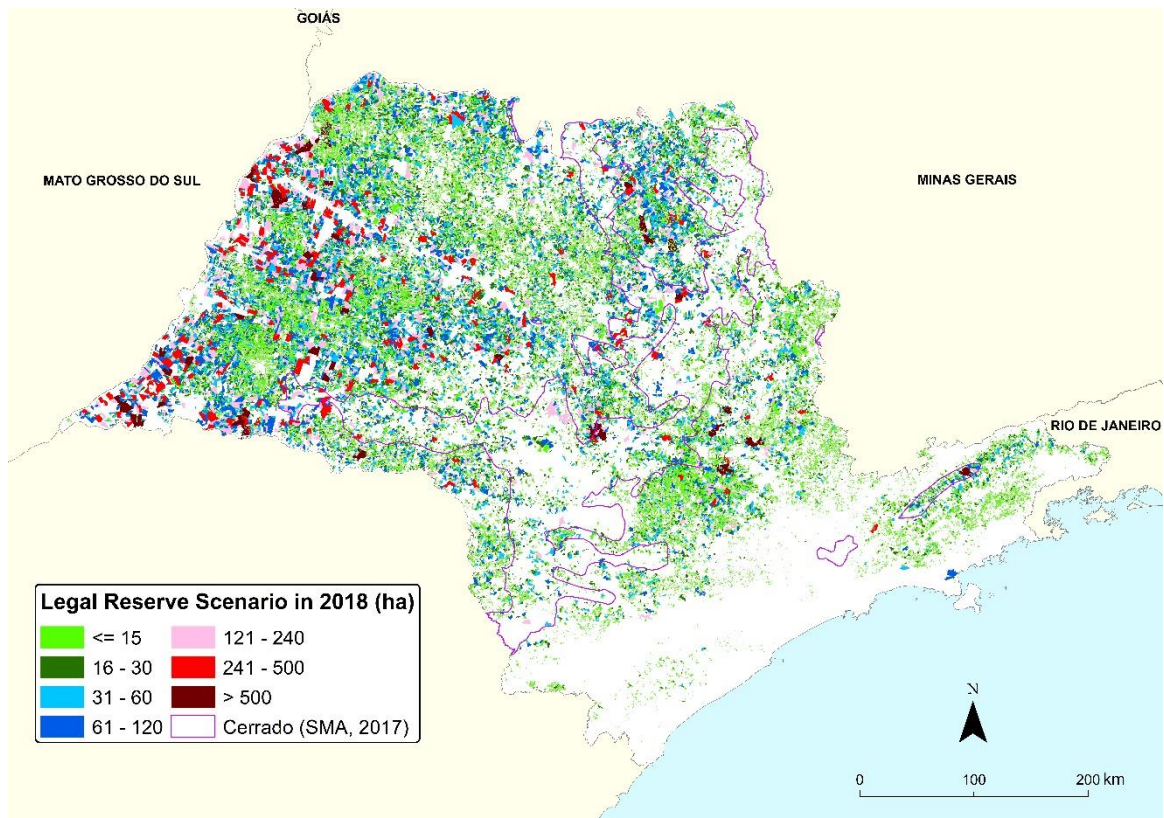


Figure S3. Distribution of farms that constitute 936 kha Legal Reserve deficits estimated for São Paulo State in 2018, with article 67 and 68 application, considering the Forest Act of 1934 as initial benchmark.