Agent-based modeling of human-environment interactions in a smallholder agricultural system in the Atlantic Forest (Ribeira Valley, SP, Brazil)

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Summary

Shifting cultivation systems (SCSs) have been practiced all over the tropics for centuries as the primary subsistence strategy for smallholders. However, since the mid-20th century, SCSs have been submitted to changes, driven by a combination of geographic, economic, socio-political, and demographic factors. Consequently, land use changes lead to agricultural intensification and the replacement of more profitable and permanent practices. The implementation of forest conservation policies (FCPs) is one of the changing drivers to SCSs. They have been designed to reduce or eliminate it, criminalize traditional practices, restrict resources access, displace locals, and increase inequalities and land conflicts.

In Brazil, SCSs have been practiced by smallholders and indigenous groups, including *Quilombolas*, descendants of African enslaved who rebelled against the Portuguese regime. After the abolition of slavery, they remained spread over the country without any state legitimation. Their recognition and rights to ancestors' land were possible only in 1988, with the Brazilian Constitution. The Ribeira Valley (Southeastern Brazil) is home to dozens of *Quilombos*, one of the most significant Atlantic Forest remnants, and high biodiversity. Its first *Quilombos* were formed in the 18th century and relied on SCS to survive, relatively isolated, up to the 1950s. However, in the context of SCS changes, *Quilombos* are under a transitional process in different dimensions, including constraints to their traditions by FCPs, generating conflicts. Inspired by this challenging scenario, the Thesis goals are to evaluate *Quilombolas'* socioeconomic conditions and the perception of FCPs implementation and integrate two modeling tools. The tools will model the impact of agricultural transitions on family wealth, income, landscape structure, and tree community β diversity and model the impact of FCPs over the equal economic and ecological dimensions.

Socioeconomic data were gathered in 2017 in 14 communities through interviews of 164 farmers. *Quilombolas'* perception of FCPs and constraints for agricultural practice were investigated. The modeling implementation used MPMAS (Mathematical Programming-based Multi-Agent Systems) to simulate land use change in agriculture and forestry. MPMAS was integrated (through land use maps) with a Generalized Dissimilarity Modeling tool

(GDM) to predict beta diversity as a function of environmental variation. The modeling exercise was implemented for Pedro Cubas territory, a *Quilombo* with 52 households located in Eldorado (SP). A combination of primary and secondary data from different sources was used, including a socioeconomic census of 2014 and a collection of tree data in 2016. Five economic/political scenarios were created for comparisons, with a baseline and four different counterfactual situations, varying in market access and FCPs versions. Seven yield curve scenarios and 30 Sobol' repetitions were combined, totalizing 1050 simulations. A tradeoff analysis was applied over the political scenarios. MPMAS sensitivity/uncertainty analyses revealed variation on staples consumptions among yield curve scenarios, the sensitivity of income to different parameters, and each income source relevance. The GDM calibration highlighted the importance of climate predictors for tree species, indicating vulnerability to potential climate variability.

Results revealed that only 32% of the families were practicing SCS in 2017, but it was still relevant for food security. 83% of the interviewees were unsatisfied with the FCPs, especially the timing of issuing the licenses for SCS. The political scenarios comparison indicates that agricultural intensification caused an improvement in average income. Still, it was accompanied by economic inequality, diminished rotation of plots, lower diversity of habitats, and a less permeable landscape structure (on fallows and because of the emergence of pasture and perennial areas). GDM results showed a significant change in landscape structure/tree community for at least 10% of the territory in the last decades. Regarding FCPs implementation, scenario comparison showed that well-being conditions improved when FCPs were excluded, although more ecological impacts occur. However, such effects refer to only 2.6% of the territory where 90% is covered by mature forest, and GDM indicates that the total ß diversity would not be significantly affected. The tradeoff analysis showed that FCPs are significant for conservation in the present context when perennials and pasture areas occur. In the isolated scenario case, when SCS is the only economic activity, a combination of good well-being and conservation performances was found, suggesting it is causing even lower environmental impacts. I recommend more flexible policies for SCS implementation in the *Quilombos* in general, for the potential of improving well-being conditions by impacting a small share of the territories. FCPs flexibilization would be even more relevant to the communities that don't have access to alternatives to SCS.

Zusammenfassung

Wanderfeldbau wurde jahrhundertelang von Kleinbauern im gesamten Tropengürtel als Hauptstrategie für Subsistenzlandwirtschaft ausgeübt. Seit Mitte des 20. Jahrhunderts werden Wanderfeldbausysteme durch eine Kombination geographischer, wirtschaftlicher, soziopolitischer und demografischer Faktoren stark beeinflusst. Folglich sind Veränderungen in der Landnutzung zu beobachten, welche zu landwirtschaftlicher Intensivierung und Ersatz durch rentablere, nicht-rotierende Verfahren führen. Die Umsetzung von Waldschutzmaßnahmen spielt eine große Rolle bei Veränderungen von Wanderfeldbausystemen, da diese Schutzmaßnahmen konzipiert wurden, um Wanderfeldbau einzuschränken bzw. zu eliminieren, indem sie traditionelle Methoden kriminalisieren, Ressourcenzugriff beschränken und Vertreibung erzwingen, was zu wachsender Ungleichheit sowie zu Landkonflikten führt.

In Brasilien wird Wanderfeldbaus von Kleinbauern und indigenen Bevölkerungsgruppen praktiziert, u.a. auch von den *Quilombolas*, den Nachkommen afrikanischer Sklaven die gegen die portugiesischen Kolonisatoren rebellierten. Nach der Abschaffung der Sklaverei blieben die ehemaligen Sklaven ohne staatliche Legitimation über das ganze Land verteilt. Ihre Anerkennung und ihre Rechte an den Ländern ihrer Vorfahren wurden erst 1988 mit der brasilianischen Verfassung ermöglicht. Das Ribeira-Tal (Südosten Brasiliens) beherbergt Dutzende von Quilombos sowie die größten verbleibenden Reste Atlantischen Regenwaldes mit hoher Biodiversität. Die ersten *Quilombos* dort wurden im 18. Jahrhundert gegründet und sie überlebten auf Basis von Wanderfeldbau in relativer Abgeschiedenheit bis in die 1950er Jahren Im Kontext der Veränderungen der Wanderfeldbausysteme befinden sich die *Quilombos* in einem multidimensionalen Übergangsprozess. Hierzu gehört auch die Einschränkung ihrer Traditionen durch die Waldschutzmaßnahmen, die Konflikte erzeugen. Vor diesem anspruchsvollen Hintergrund hat sich die vorliegende Arbeit zum Ziel gesetzt, sowohl die sozioökonomischen Bedingungen und die Wahrnehmung der Implementierung solcher Waldschutzmaßnahmen aus Sicht der *Quilombolas* zu evaluieren, als auch die Auswirkung der landwirtschaftlichen

Intensivierung und der Waldschutzmaßnahmen auf Familieneinkommen, und vermögen, Landschaftsstruktur und Beta-Diversität der Baumgemeinschaft zu modellieren.

Sozioökonomische Daten wurden im Jahr 2017 durch Interviews mit 164 Bauern aus 14 Gemeinschaften erfasst. Damit wurden die Wahrnehmung der Waldschutzmaßnahmen durch Quilombolas und die Einschränkungen der Landwirtschaftsmethoden untersucht. Als Werkzeug für die Simulation der Landnutzungsänderungen in der Land- und Forstwirtschaft wurde MPMAS (Mathematical Programming-based Multi-Agent-Systems) verwendet. Die Ergebnisse von MPMAS sind dann als Landnutzungskarten in das Generalized Dissimilarity Modeling Tool (GDM) integriert worden, um die Beta-Diversität als Funktion der Umweltvariation abzuschätzen. Die Modellierung wurde für das Pedro Cubas Gebiet durchgeführt, ein *Quilombo* mit 52 Haushalten in Eldorado, im Bundesstaat São Paulo. Dafür wurde eine Kombination primärer und sekundärer Daten aus verschieden Quellen gesammelt, u.a aus dem sozioökonomischen Zensus von 2014 und Daten einer Baumerhebung von 2016. Fünf wirtschaftliche bzw. politische Szenarien wurden dann zum Vergleich erstellt, davon eines als Referenz und vier als kontrafaktische Szenarien angelegt wurden, die vor allem Unterschiede im Marktzugang und den Fassungen der Waldschutzordnungen abbilden. Um mit Unsicherheit umzugehen, wurden sieben Pflanzenertragskurvenszenarien und 30 Sobol-Wiederholungen kombiniert, was insgesamt 1050 Simulationen ergab. Auf die politischen Szenarien wurde eine Trade-off-Analyse angewandt. Unsicherheitsanalysen für MPMAS-Simulationen zeigten Schwankungen sowohl im Konsum von Grundnahrungsmitteln zwischen den verschiedenen Szenarien, als auch in der Empfindlichkeit der Einkommen gegen die unterschiedlichen Parameter sowie in der Relevanz der unterschiedlichen Einkommensquellen. Die GDM-Kalibrierung hob die Bedeutung von Klimavorhersagen für die Baumarten und die Anfälligkeit für potenzielle Klimavariabilität hervor.

Die Ergebnisse zeigten, dass 2017 nur 32% der Familien Wanderfeldbausysteme praktizierten, dies jedoch weiterhin für die Ernährungssicherheit relevant war. 83% der Befragten waren mit den Waldschutzmaßnahmen unzufrieden, insbesondere mit dem Zeitpunkt der Erteilung der Lizenzen für den Wanderfeldbau. Dier Vergleich der politischen Szenarien zeigt an, dass die Intensivierung der Landwirtschaft zu einer Verbesserung der durchschnittlichen Einkommen führt, dies ging jedoch einher mit wirtschaftlicher Ungleichheit, verminderter Rotation der Parzellen, geringerer Vielfalt der Lebensräume und einer weniger durchlässigen Landschaftsstruktur (auf Brachflächen und aufgrund der Entstehung von Weiden und Dauergrünland). Die GDM-Ergebnisse zeigten in den letzten Jahrzehnten für mindestens 10% des Territoriums eine große Veränderung der Landschaftsstruktur bzw. Baumgemeinschaft. In Bezug auf die Umsetzung von Waldschutzmaßnahmen zeigte ein Szenarienvergleich, dass sich die Bedingungen für die Wohlfahrt der Quilombolas verbesserten, wenn diese Maßnahmen abgeschafft würden, das würde gleichzeitig aber die ökologischen Auswirkungen verstärken. Diese Auswirkungen betreffen jedoch nur auf 2,6% des Gebiets, in dem 90% von altem Wald bedeckt sind, und die GDM Simulationen weisen darauf hin, dass die gesamte Beta-Diversität nicht sehr betroffen wäre. Die Trade-Off-Analyse ergab, dass Waldschutzmaßnahmen im gegenwärtigen Kontext mit Dauerkulturen und Weideflächen für die Walderhaltung wichtig sind. Für das Szenario einer wirtschaftlichen Isolation wie bis Anfang der 1950er Jahre, in dem Wanderfeldbau die einzige wirtschaftliche Aktivität ist, haben wir eine Kombination aus gutem wirtschaftlichem Auskommen und Waldschutz festgestellt, was darauf hindeutet, dass dies noch geringere Umweltauswirkungen verursacht. Wir empfehlen flexiblere Richtlinien für die Implementierung solcher Systeme in Quilombos im Allgemeinen, um die wirtschaftliche Wohlfahrt zu verbessern, bei Beeinflussung nur eines kleinen Teils der Gebiete. Die Flexibilisierung von Waldschutzmaßnahmen wäre für die Gemeinschaften, die keine Alternativen zum Wanderfeldbau haben, noch relevanter.

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List of Acronyms

ABM	Agent-based model
APA-SM	Serra do Mar Environmental Protection Area
CBRN	Coordination Body for Biodiversity and Natural Resources
CCA	Constrained Cellular Automata’
CETESB	São Paulo State Agency for the Environment
CFA	Environmental Inspection Coordination body
CIBIO	Research Center in Biodiversity and Genetic Resources, University of Porto, Portugal
DCA	Detrended Correspondence Analysis
DEPRN	State Department for the Protection of Natural Resources
EMBRAPA	Brazilian Agricultural Research Corporation, Ministry of Agriculture
ESAE	Efficiency based on standardized absolute error analysis
FCP	Forest conservation policy
FF	Forest Foundation
FPA	Forested protected areas
GDM	Generalized dissimilarity model
HDI	Human Development Index
IBGE	Brazilian Institute of Geography and Statistics
IPHAN	National Historical and Artistic Patrimony Institute
ISA	Socioenvironmental Institute
ITESP	Foundation for Land Tenure of the State of São Paulo
LUCC	Land use/land cover changes
MAS	Multi-Agent System
ME	Model efficiency
MP	Mathematical programming
MPMAS	Mathematical Programming-based Multi-Agent System
NSE	Nash-Sutcliffe model efficiency coefficient
PAA	National Food Acquisition Program
PAM	Partitioning Around Medoids
PBF	Programa Bolsa Familia
PCA	Principal Component Analysis
PECB	Carlos Botelho State Park

PEI	Intervales State Park
PEJ	Jacupiranga State Park
PETAR	Upper Ribeira Valley Touristic State Park
PRONAF	National Program for the Improvement of Family Agriculture
SC	Shifting cultivation
SCS	Shifting cultivation system
SESs	Social-ecological system
SMA	São Paulo State Environment Secretariat

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THESIS SECTION I – RESEARCH BACKGROUND AND CONTEXT

Chapter 1: Introduction

Shifting cultivation systems (SCSs) have been practiced for thousands of years all over the world. These systems are characterized by shifting cultivation plots in the landscape to take advantage of soil nutrients available after the natural vegetation has been cut. Currently, they are typically practiced in tropical areas by smallholders. Despite the fact SCSs assure subsistence to many farmers, they have been blamed for deforestation by policy-makers and local actors and are prohibited from practicing agriculture in many places (Heinimann et al., 2017; Schmidt-Vogt et al., 2009; van Vliet et al., 2012). In Brazil, SCSs are practiced by smallholders, Amerindians, and other indigenous groups in the Amazon and the Atlantic Forests, including descendants of African enslaved - the *Quilombolas*. *Quilombolas* are the inhabitants of *Quilombo* territories (Thorkildsen and Kaarhus, 2017).

Brazil was the last American country to abolish the slavery regime in 1888. Many Afro-Brazilian enslaved resisted and escaped to the hinterlands during the regime to survive in isolated communities known as *Quilombos*. Even after slavery was abolished, the Afro-Brazilian population remained largely marginalized and poor. Up to the 1950s, racial diversity wasn't accounted for by the government censuses, and it was legal to exclude people from job opportunities for their skin color (Nascimento, 1978). In 2016, 55% of the Brazilian population identified itself as black or brown ("pardo")[1], representing 76% of the people living in extreme poverty. Only 13% had managed to access university, compared to 27% of the white population. Besides, black and brown people represent more than 60% of the imprisoned population (IBGE, 2016).

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[1] https://agenciadenoticias.ibge.gov.br/agencia-noticias/2012-agencia-de-noticias/noticias/18282-pnad-c-moradores, (2017).

The 1988 Brazilian Constitution was the first law to guarantee property rights of ancestral territories to afro-descendant groups, which became the only indigenous group to own legal claim to their ancestral lands beside the Amerindians. “Traditional” or “Indigenous” populations is an umbrella category for Brazilian social groups with specific territorialities, forms of land occupation, and appropriation of natural resources (Barretto Filho, 2009). Only after the Constitution's approval did social policies and food security programs become available for these groups.

Quilombo territories are spread in Brazil, primarily as smallholders and many of which in forested protected areas (FPAs). Presently, there are 2847 certified *Quilombos* in the country, plus 1533 communities under recognition procedures[2]. In Southeastern Brazil, there are 88 communities situated in the Ribeira Valley. Since the XVI Century, *Quilombolas* survived there in relative isolation, through the implementation of SCSs. This scenario changed in the 1950s, when the government began infrastructure projects in the region, reducing isolation. These changes affected their livelihoods in multiple aspects, culminating with the intensification of their traditional agricultural system. Among the different drivers of change, forest conservation policies (FCPs) have been considered the major constraint to SCSs.

The Ribeira Valley is the largest remnant of Atlantic Forest in Brazil, hosting high levels of biodiversity. Most of Ribeira *Quilombos* are located in protected areas, meaning that cultivation is only allowed provided the Environmental Secretariat issues a license. Bureaucratic and political issues prevented shifting cultivation licenses issued between 2007 and 2013, and law enforcement generated conflicts among farmers and state organizations. Since 2014, licenses are being provided, but they are usually late, arriving after the annual agricultural calendar has started, compromising productivity.

My research group[3] in Brazil has observed and participated in this conflict arena since the 2000s. It became clear to us the urge for territorial planning, combining local development and forest preservation. This fact was the point of departure for this research.

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[2] CONAQ (National coordination of Rural Black *Quilombola* Communities Articulation) website: http://conaq.org.br/quem-somos/.

[3] Research Group in the Human Ecology of Neotropical Forests, coordinated by Dr. Cristina Adams (University of São Paulo).

Our main goals were: investigate the impacts of the FCPs over family wealth and the *Quilombola* SCS in the Ribeira Valley (São Paulo, Brazil), contributing to land use planning, improving household income, and preserving the forest landscape. The questions raised at that time were:

- Is SCS still relevant for *Quilombolas'* subsistence? What is the farmers' perception regarding FCPs implementation?
- What are the consequences of SCSs implementation on the forest landscape (structure and diversity)?
- What are the consequences of the SCS intensification on farmers' wealth, forest landscape structure, and local tree communities' distribution?
- What are the consequences of FCPs application on farmers' wealth, forest landscape structure, and local tree communities' distribution?
- Is it possible to improve family wealth and minimize the ecological impacts of land use simultaneously? What are the best strategies for that?

Proposed framework

In this Thesis, I contribute to answering these questions using Multiagent Models (MAS), which can analyze agricultural systems, integrating agents, landscape, and dynamic relations. To accomplish this goal, I applied for the PhD program at the Institute of Agricultural Sciences in the Tropics and Subtropics (Hans-Ruthenberg-Institute) at the University of Hohenheim, under the supervision of Prof. Dr. Thomas Berger.

MAS are appropriate for evaluating the effects of policy implementation and sustainable development, considering the system's heterogeneity. I decided to use MPMAS (Mathematical Programming-based Multi-Agent Systems) among the existing models developed at the Hans-Ruthenberg-Institute. MPMAS is a software application for simulating land use change in agriculture and forestry by farm household decision-making modeling.

In addition, I chose to investigate how the *Quilombo* territories tree community responds to SCS implementation and the effects of land use changes on its distribution. So, MPMAS was integrated into a Generalized Dissimilarity Modeling (GDM), a biological community-level tool. The GDM consists of a statistical technique to predict beta (β) diversity - the difference in species composition between sites - as a function of environmental variation between the same pairs of geographical locations.

To complement the modeling framework, I investigated FCPs in Ribeira Valley and the related processes and consequences. First, I assessed the historical creation of conservation laws and policies and how they have restrained SC, combing literature review and interviews. Next, I gathered primary socioeconomic and agricultural data from *Quilombola* households in 2017, in collaboration with a local NGO (Socioenvironmental Institute – ISA) and *Quilombola* communities. Finally, *Quilombolas*' perception towards FCPs and SCSs, constraints for practicing agriculture, and aspects that could be improved were also investigated, giving us a picture of the present *Quilombola* context in the Ribeira Valley.

Therefore, I expect that the results presented in this Thesis will contribute to future land use planning by *Quilombola* communities and their partners, aiming at local development and conservation of the Atlantic Forest. I also hope that the results can benefit other shifting cultivator groups living in tropical forests in Brazil and elsewhere.

Aims

The aims of the Thesis were:

- Evaluate farmers' present socioeconomic and technical conditions and the perception of FCPs implementation in different *Quilombola* communities.
- Integrate MPMAS and GDM to model the impact of agricultural intensification and socioeconomic changes on family wealth, income, land use dynamics, landscape structure, and trees' community β diversity in a *Quilombola* community.
- Integrate MPMAS and GDM to model the impact of the implementation of recent FCPs in a *Quilombola* community, referring to family wealth and income, land use dynamics, landscape structure, and trees' community β diversity.

Hypothesis

- In most *Quilombola* communities, only a small share of households is still practicing SC, mainly for keeping cultural traditions alive. Farmers have negative perceptions towards FCPs implementation for various reasons, especially for the delays in receiving licenses for SC.
- Under low population densities and using traditional practices, the *Quilombola* SCS promotes a diversity of habitats, potentially stimulating higher flora diversity.
- The transitional processes experienced by the *Quilombolas* have caused an improvement of family well-being but deteriorated local flora diversity conditions.
- FCPs implementation affects farmers' wealth by limiting SCSs practice.
- FCPs have the same effect as agricultural intensification, diminishing landscape heterogeneity, and deteriorating conditions for the local flora diversity.
- In a counterfactual scenario, in which FCPs do not constrain SC, it will not assure farmers' food security and minimum wealth conditions alone. *Quilombola* families need to rely on government subsidies, forest extraction, producer organizations, and perennial crops.
- The analysis of different political and socioeconomic scenarios simulations will explain the underlying processes and dynamics at multiple levels, indicating the best land use strategies towards achieving sustainable development.

Thesis structure

The Thesis is organized as follows: section one, with three chapters, presents the research's theoretical background and contextualizes the studied area. The present chapter introduces the problem studied in the Thesis, the chosen framework and established goals. Next, the second chapter is a literature review showing the discussion regarding SCSs, their sustainability, drivers of change (especially conservation policies), and future scenarios. I contextualize SCSs in Brazil, as well as the agricultural practices of the Ribeira Valley *Quilombos*. Besides, I justify the motivations behind the choice to model FCPs impact and present the modeling framework. The third chapter presents the literature review and fieldwork results in *Quilombola* communities, giving a recent picture of motivations, benefits, and problems faced by *Quilombola* shifting cultivators.

Section two contains the fourth and fifth chapters, describing the research methods. The former describes the two modeling tools used in this Thesis, emphasizing each model's characteristics, methods, and integration. The latter starts with a characterization of the *Quilombola* community of Pedro Cubas, chosen as the case study for the modeling procedures. This characterization is followed by a description of the models' behavior, including MPMAS validation and sensitivity analysis and the GDM system biological space.

Section three contains two chapters presenting the modeling results based on different scenarios comparisons. In Chapter 6, I evaluate the consequences of agricultural intensification on families' well-being, other microeconomic aspects, landscape structure, and tree community distribution. In Chapter 7, a study of the impacts of FCP implementation on the same social and environmental elements is performed. Finally, Section four presents the eighth chapter, which concludes this Thesis.

Chapter 2: Shifting Cultivation Systems: a history of persistence in tropical forests

Shifting cultivation systems (SCSs)

The shifting cultivation system – also known as *swidden* or *slash and burn* agriculture – has been the prevailing agricultural system in tropical areas for thousands of years, typically practiced by smallholders for subsistence. SC is characterized by the shift of small cultivation plots in a forested landscape. The vegetation is slashed and burned, so that biomass nutrients are made available, competing plants are temporarily eliminated, and the soil is exposed to allow cultivation. Plots are managed for up to three years until they become unfertile or competition with weeds is too harsh. Then, they are left to fallow for the vegetation to recover through the forest successional process. After some years, a nutrient and energetic pool is formed in the soil/vegetation complex. While not applying any external inputs, crop productivity is exclusively dependent on ecological processes and limited by labor. Therefore, farmers imitate natural forest dynamics, which explains why SCSs' practices are very similar throughout the world. The fallow phase, natural or submitted to management, lasts long enough for the woody vegetation to become dominant (Heinimann et al., 2017; Mertz et al., 2009; Mukul and Herbohn, 2016; van Vliet et al., 2012, 2013b).

Wherever they are implemented, SCSs are part of a matrix of different management types, such as orchards, permanent crops, gardens, bamboo, and pasture areas. Moreover, the combination of plots with different fallow ages, permanently under transition, with various land uses, composes a diverse, complex, and dynamic landscape (Frolking et al., 2009; Padoch et al., 2007; Schmidt-Vogt et al., 2009). Estimations fall between 35 million to one billion people practicing it, over 280 Mha (Heinimann et al., 2017; Wood et al., 2016).

Ecological and economic dimensions of shifting cultivation landscapes

Secondary forest regrowth recovers the structural and functional characteristics of the original soil-vegetation system through the natural process of re-colonization by multiple biological taxa, resulting in different communities of fauna, flora, and fungi over time. Regeneration processes are site-specific: they vary according to land use history, cultivation and fallow period ratios, soil type, topography, biome, climate, soil seed bank, and the age of fallow. Moreover, secondary forests may also be a source of food, firewood, artisanal material, and medicines (Arroyo-Rodríguez et al., 2017; Fantini et al., 2017; McNicol et al., 2015; van Vliet et al., 2013b).

SCSs have been blamed for biodiversity loss and climate change. For most local governments, resource managers, national and international environmental conservation organizations, SCSs are responsible for tropical deforestation, degradation, and rural poverty. In addition, SCSs are seen as accountable for greenhouse gas emissions due to the use of fire, soil erosion on hilly slopes, negative impacts on forest's biodiversity, affecting natural hydrological systems, promoting CO_2 emissions from the soil and the low productivity of staple crops (Mukul and Herbohn, 2016; Padoch and Pinedo-Vasquez, 2010; Sarkar et al., 2015; Ziegler et al., 2009). On the other hand, specialists have claimed that SC causes lower impacts on the forest landscape, wildlife, soil nutrients, and soil physical and hydraulic properties than other agricultural systems. Moreover, when practiced under low population densities, allowing enough fallow length, surrounded by a matrix of intact/mature forest, using low input technologies and little land use intensity, SCSs may even contribute to biodiversity conservation and ecosystem services (Pérez-García and del Castillo, 2017; van Vliet et al., 2012; Wood et al., 2017).

The impacts of SCSs are diverse and depend on landscape structure, which is related to the size, form, and spatial distribution of fragments and the type of surrounding matrix. Fallow forests can fully recover tree basal area and density, plant species richness, and diversity, although a long time is usually needed. Scientists also noted that fallow forests could exhibit a similar tree species diversity compared to more mature forests (Gomes et al., 2020; Piotto et al., 2009; Teegalapalli and Datta, 2016). Impacts on plant diversity and species composition are generally negative, although not on species richness. Forest structure is considered to recover slowly in SCSs, while stand density recovers fast. Biomass, in turn, exhibits fast growth in the early stages of forest succession (Mukul and Herbohn, 2016; Sarkar et al., 2015).

There is no consensus on whether the impact is harmful or not over soils. SCSs soils tend to show reduced erosion and maintain various ecosystem services such as carbon sequestration, hydrological aspects, and biodiversity protection compared to other land use types. The fallow period will allow the recovery of soil chemical nutrients, organic matter and other minerals, biodiversity, biomass, and fauna if long enough. There are cases where it was possible to recover and maintain soil characteristics in the long term, such as soil formation, aggregate stability, porosity (Ribeiro Filho et al., 2018; Sarkar et al., 2015; Suryanto et al., 2017; Ziegler et al., 2009).

Fire use is frequently seen as harmful to the environment. In SCSs, farmers employ a series of techniques to manage and prevent wildfires. However, by having a unique view of fire use, policy-makers hinder a better understanding of fire and neglect local knowledge, experimentation, and importance. Consequently, they hamper alternative technologies and policy solutions that could improve traditional management and avoid accidental fire escapes (Carmenta et al., 2018; Sorrensen, 2009).

SCSs forest landscapes are characterized by heterogeneous mosaics, composed of spatial units of historically managed areas, fallows in different stages of maturity, and primary forests. Such a landscape is structurally heterogeneous, complex and dynamic, due to space and time variation (Dalle and de Blois, 2006; Rerkasem et al., 2009). These conditions foster different combinations of biophysical and natural resources that supply local biological populations, stimulating a wealth of species on a regional scale. Therefore, spatiotemporal variability is perceived as a key to maintaining an ecosystem’s long-term sustainability and resilience, with corresponding benefits for local demographic, genetic and environmental stability (Fischer et al., 2008; Frolking et al., 2009; Metzger, 2009).

Finally, many specialists see SCSs as a rational choice for farmers since they are well adapted to forest restrictions and limitations. They are efficient in terms of labor and nutrients input when practiced under low population densities and poor soils. Farmers are autonomous in the decision-making process and constantly innovate their management strategies to meet economic and social needs in a constantly transforming environment. Besides, SCSs are responsible for driving local and regional markets and frequently are the only source of income in places where farmers have unequal access to markets. Thanks to a great diversity of folk crop varieties (i.e., agrobiodiversity), SCSs are also able to provide dietary variability, increase crop production stability and minimize the risk of plagues and diseases (Junqueira et al., 2016a; McNicol et al., 2015; Rerkasem et al., 2009; van Vliet et al., 2012).

Systems in transition due to global changes

The mid-20th century was marked by rapid changes all over the globe, especially in regions where SCSs are implemented. These changes result from a combination of geographic, economic, socio-political, and demographic factors. Among observed drivers of change, the most relevant for SCSs are: large-scale infrastructural progress and decreased farmers' isolation, urbanization, increased access to markets and new technologies, government policies to restrain SCSs, land reforms, population pressure, diminished labor availability, and forest conservation policies (FCPs) (Chan and Takeda, 2016; Coomes et al., 2017; Grogan et al., 2013; Mertz et al., 2009; Schmook et al., 2013; van Vliet et al., 2012).

SCSs have undergone land use changes, leading, on their majority, to agricultural intensification (AI) and the diversification of traditional practices. By AI, I mean spatiotemporal changes on SCSs landscapes: diminished plots rotation, shortened fallow length, and extended cultivation periods. In addition, new management techniques include greater use of external inputs and replacement of SCSs plots by more profitable and permanent practices (Jakovac et al., 2016; Schmidt-Vogt et al., 2009; van Vliet et al., 2012; Wood et al., 2016).

Smallholders' are constantly adapting their livelihoods to ensure their production and reproduction and improve living standards (McCusker and Carr, 2006). Chosen strategies diversify according to the combination of different environmental and socioeconomic contexts, leading to different trajectories and levels of intensification worldwide. SCSs have been central to the social organization of farmers' societies and cultural identities. As the importance of SCSs declines, local institutions, cultural norms, household labor, and food security are potentially impacted, together with the arrival of new aspirations and cultural identity redefinition. Although one could expect that such a multiplicity of factors would cause the demise of SCSs, in most cases, they are being transformed and are still relevant for farmers' livelihoods and resilience (Cramb et al., 2009; Padoch et al., 2007).

Measured impacts of SCS intensification

There is vast literature on the consequences of AI in SCSs. van Vliet et al. (2012) concluded that AI has, in general, improved household income, although the presence of permanent crops leads to inequities and land conflicts. Dressler et al. (2016) showed that, after SC intensification in Southeast Asia, most households experienced an income increase. Still, it came with increased labor input and at the cost of socio-economic well-being, traditional practices, and staples production.

Different types of environmental impacts have been measured in SCSs AI processes. For example, the replacement of annuals by perennials causes the landscape to lose its mosaic pattern of rotating patches, losing the continuous state of diversity and flux and habitats for wild plants and animals. Also, the replacement causes evapotranspiration change, surface impermeabilization, greater risk of rainfall-induced landslides, accelerated surface erosion, and pollution by pesticide/fertilizer use (Rerkasem et al., 2009; Ziegler et al., 2009). Another observed effect is the reduction of agrobiodiversity, impacting local subsistence and food security (Delang et al., 2016; Pérez-García and del Castillo, 2017).

The decrease in fallow cycles reduces soil nutrients and biomass recovery, carbon stocks, vegetation regeneration, plant diversity, density, composition, and has transformed landscapes into more homogeneous matrices, dominated by young secondary forests (Dalle and de Blois, 2006; Fantini et al., 2017; Jakovac et al., 2016; Schneibel et al., 2017; Wood et al., 2016). Land use/land cover changes also impact forest regulating services that depend on diversity, such as pollination, seed dispersion, and nutrient cycling, crucial for species recovery (Wood et al., 2016). In some cases, SCS intensity (the number and duration of fallowing cycles per agricultural plot) are more significant predictors of biodiversity changes than fallow duration. The regular use of the same plot reinforces plant richness and abundance loss due to a reduction in seedling establishment and competition with pioneer species (Jakovac et al., 2015; Mukul and Herbohn, 2016; Wood et al., 2017).

Implementation of conservation policies & shifting cultivators

One of the most contradictory and conflicting drivers of change is the implementation of forest conservation policies (FCPs) and laws. FCPs are reported as potentially impacting SCSs dynamics everywhere in the tropics. Because a negative perception towards SCSs guides governments and policy-makers, FCPs typically do not incorporate farmers' needs or participation. However, farmers engagement in conservation agendas is essential for territorial land use planning, sustainable management, local development, and nature conservation (Carmenta et al., 2018; Coomes et al., 2017; Cramb et al., 2009; Fox et al., 2000; Mukul and Herbohn, 2016; van Vliet et al., 2012). Regulations on FCPs generally include one or a combination of the following restrictions: fire use control, control of land available for planting crops (e.g., older fallow and mature forest patches), or even the total obstruction of SCS activities. To improve ecosystem services, reduce deforestation, and conserve biodiversity, these policies have been designed to minimize or eliminate SCSs strongly (Rerkasem et al., 2009; Ribeiro Filho et al., 2018, 2013; van Vliet et al., 2012).

Measured impacts of FCPs implementation

There is a vast literature evaluating the effectiveness of forest's strictly protected areas (FPAs) on biodiversity conservation compared to other categories, like community managed forests (CMFs). The efficiency of each type depends on the context: under low population pressure, CMFS may be equally effective or better than FPAs; under colonization pressure, both are ineffective. Possible factors influencing the efficiency of FPAs biodiversity conservation include remoteness that avoids land occupation, illegal resource extraction and fragmentation, tourism activities, and the ability to reduce clearing, hunting, and logging pressures inside their boundaries (Armenteras et al., 2009; Bray et al., 2008; Hayes, 2006; Porter-Bolland et al., 2012). Moreover, some attempts to create FPAs have led to negative impacts such as higher deforestation pressure on surrounding areas and have implications on local biodiversity. Besides, there is no solid evidence of the effectiveness of complete exclusion of local groups on FPAs conservation, and conservation hotspots are frequently inhabited and managed by traditional and indigenous local people (Lele et al., 2010; Porter-Bolland et al., 2012; van Vliet et al., 2012).

In general, groups that occupy areas under conservation interest are politically marginalized, poor, and isolated. FPAs creation in the surrounding or overlapping traditional territories may cause the criminalization of traditional practices, restriction of resources access, displacement, the increase of elite control of resources, social differentiation over the poorest, increased inequality, land conflicts, reduction in food security and resilience. For instance, the criminalization of activities that are essential to farmers' survival has motivated illegal practices. Therefore, it has produced weak results in conservation efforts and social outcomes, turning conservation actions into unethical and undemocratic (Carmenta et al., 2018; Lele et al., 2010; Porter-Bolland et al., 2012; Rantala et al., 2013; West et al., 2006).

The future of shifting cultivation

The transition scenario presented above shows that the future of SCSs, especially regarding land use, is uncertain. Many factors are combined with local specificities (historical and political contexts, socio-environmental complexities), and, as a result, multiple trajectories can follow. Land use changes do not tail a fixed pattern but are unstable and undetermined, making environmental impacts even worse (Lambin and Meyfroidt, 2010; van Vliet et al., 2012).

According to Heinimann et al. (2017) study, SCSs will drastically decrease in the next 20 years and disappear by the 2090s. Asia is estimated to be the first continent to eliminate SCSs, due to local policies and the high-speed changes in economic structure and development. The Americas and the African continent will follow Asia. Central and South America show a mixed picture: countries like Brazil and Mexico are expected to experience a faster trend in the disappearance of SCSs, which will be gone by the 2060s. Overall, the authors expect SCSs to persist where population density is low, and options for agricultural development and livelihoods do not exist. A similar conclusion was reached by van Vliet et al. (2012) meta-analysis in 157 sites. In most cases (55%), SC areas are diminishing, while in 32%, they were increasing, and in 13%, they remained unchanged. Reduction in the SC area was related to mechanically establishment plantations. At the same time, the resilience of SCSs was explained by low access to credit, high transaction costs, the absence of policies promoting AI, and survival in environments characterized by uncertainty and risk.

SCSs are still relevant for smallholders' subsistence; thus, they will persist for the next decades. Understanding SCSs transition dynamics is essential to their management and persistence of the rapidly changing landscapes of the 21st century (van Vliet et al., 2012). Specialists have insisted that scientists and policy-makers could try to find the benefits and costs of secondary forests, such as ecosystem services and socio-cultural values. Also, governments could stimulate research for increasing productivity while keeping acceptable biodiversity levels and preserving forested landscapes for farmers' livelihoods and well-being (Fox et al., 2000; Mandal and Shankar Raman, 2016; Mukul and Herbohn, 2016).

Shifting cultivation systems in Brazil

Brazil has a long-term history of SC practice. Most of the Amerindian populations relied on these activities for survival before the colonial period. During the first centuries of colonization (16th and 17th Centuries), SCSs were incorporated by Europeans and Afro-Brazilians, probably because they represented the best and most adapted strategy for survival in tropical environments. Nowadays, SCSs are mainly implemented by smallholders and indigenous groups, which are among the country's poorest and marginalized people (Leonel, 2000). The most recent governmental rural census revealed that 77% of productive farms are owned by smallholders (average area of 18.37 ha), despite the fact they occupy only 23% of the area under production. More critical, smallholders' agriculture is responsible for 70% of the cassava consumed internally, 34% of beans, 12,5% of maize, 36% of coffee, 10% of rice, and 64% of milk. Additionally, smallholders' agriculture employs 67% of rural workers (IBGE, 2017).

Brazilian SCSs can be found mainly in tropical forests: the Amazonian and the Atlantic Forest Biomes. The cultural, socioeconomic, and environmental contexts of Brazilian SCSs are diverse, holding different levels of intensification and outcomes. Amazonia, for example, represents 40% of all the remaining tropical forests in the world, although it is a forest agricultural frontier under rapid expansion. Amazonian SCSs are practiced by some 600 thousand families, including Amerindians, *caboclos*[4], and smallholders, and are responsible for producing the more significant share of the food consumed in the region. Most important, SCSs are critical in shaping these agricultural frontiers (Junqueira et al., 2016a; van Vliet et al., 2013a).

Before the colonization period, the Atlantic Forest was the second-largest rainforest in the Americas. Nowadays, only 10 to 15% of the original cover remains due to the expansion of the agricultural frontier, industrialization, and urban development. Sixty percent of the present-day population of Brazil lives on former Atlantic Forest territory, which means 110 million people spread over more than 3000 municipalities (Ribeiro et al., 2009; Tabarelli, 2010). Most remnants are found in the Ribeira Valley, occupying 2,830,666 ha in Southeastern Brazil. Though located between the most industrialized hubs in Latin America, it is characterized by low levels of economic development due to geographical isolation (Martins, 2017; Valentin, 2006). The majority of its population spread over small rural neighborhoods, with their survival based on SCSs, since the colonial period. Nowadays, smallholder farmers relying on SCSs in the Ribeira Valley include *caiçaras*[5], Amerindians, and 88 *Quilombola* communities (Adams et al., 2013; Ribeiro Filho et al., 2018).

The *Quilombola's* Shifting Cultivation System:

Until 1888, the expression *Quilombo* designated an autonomous community territory, composed mainly of Afro-Brazilian runaway enslaved rebelling against the Portuguese regime. After the official abolition of slavery in Brazil (1888), these communities remained spread over the country, without any state legitimation and under the condition of labor surplus, surviving mainly of small jobs and subsistence agriculture. In the following decades, government policies pursued national development through population "whitening", discriminating and excluding the Afro-descendent population from political participation, and stimulating European immigration. This context rendered them to be one of the most

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[4] Caboclos are groups spread all over Amazonian Basin, at which the main characteristic is the miscegenation between local Amerindians and migrants from other parts of Brazil (Junqueira et al., 2016b)

[5] The *Caiçaras* are, according to Adams (2000), indigenous people inhabiting Southeastern Brazilian coastal zones. They originated from the miscegenation of Europeans, Amerindians and Afro-Brazilian groups, in the first decades of colonization.

marginalized groups in the country. The circumstances changed in 1988, after the end of military rule (1964–1985), with the promulgation of the new Brazilian Federal Constitution. Article 68 of the Constitution identifies *Quilombos* as social groups whose history is bound up with the former Afro-Brazilians enslaved and closely associated with the territories they traditionally occupied. It constitutes an attempt to guarantee enslaved descendants the property rights of their ancestors land through communal use and is a compensatory policy (Coelho et al., 2005; Leite, 1999; Penna-Firme and Brondizio, 2007; Schmitt et al., 2002; Theodoro, 2008; Thorkildsen and Kaarhus, 2017).

The first settlements in the Ribeira Valley were established during the 16th Century by European colonizers searching for gold. Gold mining was possible thanks to large numbers of Afro-Brazilian and Amerindians enslaved. In the 18th century, the discovery of gold in another region led to the miners' migration, leaving behind abandoned lands and freed or runaway enslaved. In the following decades, the smallholders returned to subsistence activities and SC. Access to the region was still hindered by the lack of roads and steep slopes, and transport occurred only by boat. By that time, subsistence activities included rice, maize, beans, cassava, legumes, potherbs, and fruits production. Animal protein came from swine and poultry. Part of the production was sold to local merchants in exchange for salt and fuel. Agricultural activity was performed through collective work, and SC was central to *Quilombola* social organization. The largest plots measured 4 ha per household and could be managed for up to two cropping periods (two years) and left to fallow for 10 to 25 years (Adams et al., 2013; Coelho et al., 2005; Futemma et al., 2015; Queiroz, 2006).

Transitional processes

These circumstances didn’t change until the 1960s when different drivers of change were put in place. Infrastructure projects held by the federal government, such as regional and local highways, decreased regional isolation. During the 1970s, rural schools were constructed, and incentives to cash crops were given (e.g., banana and tea plantations and cattle ranching). Gradually, integration into the market led to agricultural intensification in the *Quilombola* villages, resulting in the substitution of SC plots by cash crop production. The accessibility improvement also attracted land grabbers and professional palm heart extractors, generating land conflicts. In the 1980s, the Ribeira Valley was marked by the arrival of social and environmental movements, which encouraged the *Quilombolas* to demand infrastructure services and land titles to remain in their homelands. However, the implementation of FCPs has highly restricted most subsistence activities in the region (Adams et al., 2013; Futemma et al., 2015).

Quilombolas have passed through a complex process of rethinking their cultural identity, values, and social practices with the possibility of land title acquisition. These groups gained visibility from smallholder farmers and were transformed into new actors in policy negotiation arenas, including environmental ones. They have organized at multiple levels and created a network of institutional support that includes social movements, non-governmental and governmental organizations. Nevertheless, *Quilombolas* are expected to exist under low environmental impact with the new status and be culturally, economically, and demographically frozen in time. Combining this rationale with the negative perception towards SCSs has generated adverse circumstances (better described in Chapter 03) (Futemma et al., 2015; Penna-Firme and Brondizio, 2007; Raimbert, 2012).

Social policies and food security programs have been implemented in the region since the 1990s. The *National Program for the Improvement of Family Agriculture* (PRONAF), set in 1996, has offered credits to smallholders. Additionally, the *National Food Acquisition Program* (PAA) assured that the government directly acquired agricultural production and delivered it to families under food insecurity and public institutions. The social program *Programa Bolsa Familia* (PBF) was established from 2002 to 2006. PBF is a monthly payment to low-income families, provided children are attending school and vaccinated. Together with agricultural activities, these programs became the primary income source, contributing to its increase. However, most household expenditure has been used for food acquisition from supermarkets, revealing an increased market dependency and decreased food security (Adams et al., 2013).

Land use/land cover changes and SCSs present scenario

The intensification of market relations and access to credit for agriculture caused an increase in cash crop production (mainly perennials) to the detriment of staple crops. During the 1980s, there was an increase in banana production, followed by passion fruit in the 2000s and pupunha peach-palm in the 2010s. As large agricultural plots clearings gave way to perennial commercial crop plantations, fallow periods shortened from 10–25 to 0–6 years, and the plot area decreased from 2.0 to 0.5 ha.

Access to a range of services and amenities, such as transport, electricity, and education, made the families abandon the distant households/agricultural areas, increasing population densities in small neighborhoods. The clustering of houses reduced homegardens which ended up curbing livestock activities. Areas under management were concentrated around the villages. Schooling was improved, and women were responsible for children's attendance and no longer available for agriculture, transforming household organization. High levels of outmigration reduced the local population. These changes were responsible for diminishing available labor capital for SCSs (Adams et al., 2013).

Environmental policies also contributed to constrain farming and animal husbandry activities, according to *Quilombola* farmers. In addition to environmental policies, Juçara-palm (*Euterpe edulis* Mart.) illegal extraction became one of the most lucrative activities in the region, despite the risk of prison and paying penalties, drastically reducing the initially dominant population of Juçara-palm in Atlantic Forest undergrowth. Together with the spatial concentration of activities, FCPs have decreased young fallow areas and increased old fallow areas. Furthermore, extensive pasture areas appeared with the arrival of land grabbers. Besides, nowadays, the *Quilombolas* have to rely on fertilizers and other agricultural techniques. Additionally, my research group have observed a significant reduction in crop varieties, reinforcing the food security decrease (Adams et al., 2013; Pedroso Júnior et al., 2009).

Until the 2010s, social and environmental policies affecting the *Quilombos* were contradictory, FCPs were hard to be enforced, and the implementation of SCSs was still a priority for farmers. This confrontational context was the one to motivate this research.

Although my research group did unveil multiple aspects of Quilombolas' livelihoods in previous studies, we could not recognize all the processes involved in the dynamic relations between the farmers and the landscape and did not understand how the agricultural transitions affected the economic and biological dimensions. Furthermore, we felt the need to evaluate how the implementation of FCPs affected these dimensions and what type of policies would assure a better future for *Quilombola*'s territories.

Chapter 3: *Quilombos* and FCPs: a history of conflict

In the following pages, I will describe the intricate – and conflicting – scenario on the implementation of Forest Conservation Policies (FCPs) for constraining shifting cultivation systems (SCSs) in *Quilombola* territories in the Ribeira Valley. The present chapter begins with the research methods, followed by a brief historical description of FCP implementation in the Ribeira Valley region, related government organizations, and the latest events regarding FCPs and SCS practice on *Quilombola* communities.

Research methods

Figure 1 shows the location of most of the studied *Quilombola* communities in the Ribeira Valley region, between the urban centers of Eldorado and Iporanga. Access to each of the communities is depicted in Table 1.

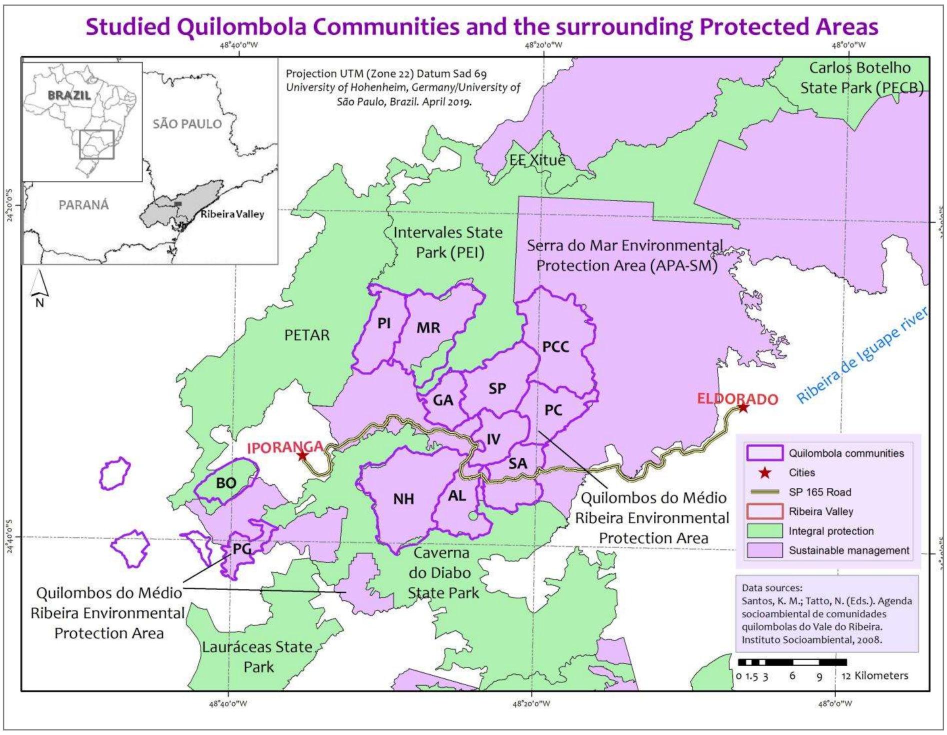

Figure 1: Map of *Quilombola* communities, protected areas, the road, and the cities of Eldorado and Iporanga.

Table 1: List of studied communities in 2017, distinguishing their municipalities, political status, access to facilities, number of farmers who acquired the license, and the number of farmers interviewed.

Community	Area (ha)*	Political Status**	Access ***	N of households *	N of households that obtained the license	N of farmers interviewed
Eldorado						
Sapatu (SA)	3,711.62	RE	PR	82	3 (3.65%)	3
Ivaporunduva (IV)	2,754.36	LT	PR	98	35 (35.71%)	33
Pedro Cubas (PC)	3,806.23	LT	FB/UR	52	19 (36.5%)	15
Pedro Cubas de Cima (PCC)	6,875.22	RE	FB/UR	22	7 (31.81%)	6
Engenho (EN)	534.11	RE	PR	15	4 (26.66%)	4
Abobral Margem Esquerda (AB)	3,459.23		PR	38	4 (10.53%)	1
Eldorado/Iporanga						
Galvão (GA)	2,234.34	LT	FB/UR	34	7 (20.58%)	7
São Pedro (SP)	4,688.26	LT	FB/UR	39	17 (43.58%)	14
Nhunguara (NH)	8,100.98	RE	UR	91	34 (37.36%)	29
Iporanga						
Praia Grande (PG)	1,584.83	RE	BO	34	12 (35.29%)	10
Piririca(PIR)	1,441.64	UR	PR	14	1 (7.14%)	1
Maria Rosa (MR)	3,375.66	LT	FB/UR	25	16 (64%)	15
Pilões (PI)	6,222.30	LT	FB/UR	63	21 (33.33%)	18
Bombas (BO)	2,512.73	UR	TR	16	13 (81.25%)	8
TOTAL				611	193 (31.58%)	164 (85%)

* Information provided by ITESP[6] from September 2016.

** LT - already obtained land title; RE - recognized but waiting for the land title; and UR - under recognition process (source: Pasinato et al., 2017).

***Access to the communities is through PR – paved road; UR – unpaved road; FB – ferry boat; TR – walking track; and BO – boat.

The history of conservation policies implemented in the Ribeira Valley was based on a literature review and complemented by interviews with local actors between 2015 and 2017. Additionally, my research group attended meetings with *Quilombola* farmers, partners, and government institutions between 2010 and 2018. Most were organized to discuss the

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[6] ITESP: Foundation for Land Tenure of the State of São Paulo. Under the Justice and Citizenship Secretariat, it is responsible for planning and executing land policies, as well as for the legal recognition of *Quilombola* territories.

conflicts between *Quilombolas* and the State Government Environmental Secretariat (SMA) and were crucial for our understanding of the process.

In 2003, our team carried out a socioeconomic and demographic survey in 11 *Quilombola* communities and 479 households as a first effort to characterize their livelihoods (AL, GA, SP, IV, PC, PCC, MR, NH, PI, and SA). Dataset consists of the household's main characteristics, from demographic to socioeconomic aspects (such as the number of members, occupation, income sources). In 2010, 33 households in SA, PC, and PCC were surveyed to assess *Quilombolas'* perception of how their management practices were changing and the drivers of change [7].

In 2017, we surveyed 14 communities from Ribeira in a partnership with ISA[8] (GA, SP, IV, PC, PCC, MR, NH, PI, SA, PG, BO, PIR, EN, and AB). It was performed to gather information on the households that obtained a license for SC in 2015 by ISA (explained below) and my doctoral research to update data and inform modeling with MPMAS. Our survey was carried out between June and August 2017, after two cropping seasons since 2015. I interviewed Eighty-five percent of the households that received the licenses (164 of 193 households). The survey consisted of structured interviews with a member of each household. The interview consisted of three topics:

- Household: Socioeconomic information, including income.
- License issuing process: perception about FCP requirements and possible problems faced for selecting the plot.
- Licensed plots: land use history; previous and future use; production obtained in the period.

Furthermore, I used secondary data from a socio-environmental survey of 14 *Quilombola* communities in the Ribeira Valley region, performed by ISA. The published dataset refers to the year 2006 (Santos and Tatto, 2008). Despite the differences in sample

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[7] This was part of the research coordinated by the University of Kopenhagen. Funding support was provided by the Danish Research Council for Social Science to Cristina Adams and Nathalie Van Vliet ("Transition of shifting cultivation systems at the agriculture/forest frontiers—sustainability or demise" project).

[8] ISA: Socioenvironmental Institute.

size and selection method, their comparison gave us a recent historical perspective. Table 2 summarizes the samples.

Table 2: Sample sizes of the different surveys.

	2003	2008	2010	2017
Number of studied communities	11	14	3	14
Was every household included in the research?	Yes	No	No	No
Number of studied households	479	421	33	164
The proportion of studied households in their communities (%)	100	75.7	19.3	26.9

The obtained data were analyzed using descriptive statistics. Here I present and discuss the results *vis a vis* in the same communities.

FCPs and conflicts in the Ribeira Valley

Quilombolas have been involved in conflicts with governmental agencies for decades. They began with the creation of restrictive protected areas (PAs) in the Ribeira Valley that overlapped *Quilombo* territories in 1958 and 1969[9]to protect the limestone cave complex and the Atlantic Forest. After the end of the military government (1984), there was an increase in PAs, encouraged by the environmentalist movement in Brazil and worldwide. Three protected areas (FPAs[10]) were created, and non-timber forest products (NFTPs) extraction, SC, and hunting were restricted, increasing conflicts. Juçara-palm extraction was also forbidden. The Atlantic Forest Biosphere Reserve was created in 1991 to solve land conflicts, was transformed into a mosaic of 16 FPAs and sustainable use areas in 2008, allowing indigenous peoples' occupation in Sustainable Development Reserves (Adams et al., 2013; Coelho et al., 2005). The creation of the Environmental Protected Area (APA): *APA[11] dos Quilombos do Médio Ribeira*, which overlapped most communities in 2008,

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[9] FPAs: 1958 - Upper Ribeira Valley Touristic State Park (PETAR, 35,712 ha); 1969 - Jacupiranga State Park (PEJ, 150,000 ha).

[10] FPAs: Carlos Botelho State Park (PECB, 37,644 ha, 1982), Serra do Mar Environmental Protection Area (APA-SM, 569,450 ha, 1984), and Intervales State Park (PEI, 49,000 ha, 1995).'

[11] APA is a category of FPA created by the Federal Law 6902/1981 for sustainable use, aiming at the conservation of biodiversity and natural processes in territories dominated by private properties. PEs are defined by the Federal Law 9985/2000 as public areas destined exclusively to conservation, scientific research and tourism.

helped to diminish the conflicts, changing the goal from biodiversity conservation to *Quilombolas'* sustainable development.

SC activities in the Ribeira Valley were restricted by the Federal Decree 750 in 1993, and later by the Atlantic Forest Law in 2006 (Federal Law 11.428/2006, Federal Decree 6.660/2008) (BRASIL, 2008, 2006, 1993). Fire use was forbidden, and agriculture was allowed only in very young secondary forests, causing harvests to be low. In São Paulo state, the monitoring of agricultural activities in forested areas is subordinated to the São Paulo State Agency for the Environment (CETESB)[12], part of SMA[13], and issues cultivation licenses. Between 2006 and 2013, CETESB did not deliver any license to the *Quilombos* for political and bureaucratic reasons. The lack of licenses left the *Quilombola* farmers with two options: to illegally grow staples or not to grow any crops (Adams et al., 2013; Aurico Dias, pers. com. 2009; Raquel Pasinato, pers. com. 2017). The combination of problems and conflicts culminated in a process of negotiation headed by the *Quilombolas* in 2009. They threatened not to allow NGOs and research groups to work in the *Quilombola* territories unless regulations were changed. As a result, Resolution SMA 027/2010 (SÃO PAULO, 2010) was issued by CETESB in 2010 (Futemma et al., 2015).

The request for a license required providing a georeferenced map and a technical assessment report. In addition, the license could take months to be released; delays could cause that year's crop to be lost. The combination of the compulsory and bureaucratic license and the fire impediment sustained the conflict between the State and *Quilombolas*. The last event to happen before the beginning of this project, in 2012, was the delivery of a formal petition to CETESB by the *Quilombolas*, demanding changes in Resolution 27/2010 (Adams et al., 2013; Futemma et al., 2015).

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[12] CETESB (São Paulo State Agency for Environment): a division of SMA, with the duty of controlling, monitoring, inspecting and licensing activities that generate pollution and other impacts.

[13] SMA (State Environment Secretariat): created in 1986, it is the higher government instance responsible for the environment in the state of São Paulo.

Political Scenario after Resolution SMA 027

Since the creation of SMA 027/2010, little has been written about the problems it created for *Quilombolas'* livelihoods. The following narrative is based mainly on the interview with Raquel Pasinato, ISA's local office coordinator.

Resolution SMA 027 was promulgated by the former DEPRN[14]. Improvements in regulations included the amount of two hectares of forest plot allowed per family/year and collective licenses valid for five to ten years. Its formulation had the contribution of local farmers. Still, the final version had to be negotiated with CETESB, which imposed the same restrictions as the Atlantic Forest Law (Federal Law 11.428/2006 and Federal Decree 6.660/2008): avoiding the top of mountains and steep slopes, riparian forests, and medium to late-stage fallow areas. Additionally, each plot needed to be inspected by technicians (ITESP or FF), which was very labor demanding. As a result, *Quilombolas* and partner organizations perceived the resolution as being more demanding than before.

Although SMA 027 was promulgated in 2010, no license was issued for a few years due to the complicated process. An articulation between communities, ISA, our researcher team, CETESB, and ITESP was necessary to simplify issuing licenses strategies. Our group was invited to present research findings on the impacts of *Quilombola* SCS to *Quilombola* and state organization representatives in a seminar held in August 2012. The presentation convinced SMA technicians, and after a break of seven years, the *Quilombolas* received their licenses in 2013. However, they were issued for two years only, meaning that in 2015 the *Quilombolas* had to request new licenses. The new licenses were again issued for two years (2015 to 2017) and, in many cases, were late for the agricultural calendar, as before. Environmental inspection and license enforcement have been under the supervision of CFA[15] since 2012. If any illegal activity is spotted, an infraction is issued, and the farmer is condemned to pay a fine.

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[14] DEPRN (State Department for the Protection of Natural Resources): under SMA administration, it was created to control and guide natural resource exploitation through license issuing, extinct in 2009.

[15] CFA (Environmental Inspection Coordination body): Connected to SMA, this departmentwas created to inspect environmental crimes;

To replace Resolution 027, CBRN[16] opened the possibility of including SCSs in a new regulation under formulation in 2016 (SMA 189) for the sustainable management of native species. This possibility was a turning point since the system would come to be considered by the government as natural resource management instead of a forest suppression activity. Motivated by this scenario, ISA organized a working group and a series of meetings between *Quilombolas* and all organizations involved in environmental licensing in 2017. Our research group was invited to participate and carry out a short survey with the *Quilombola* farmers to identify SMA 027 implementation constraints. I participated in five meetings from June 2017 to February 2018. I surveyed between June and August 2017 and presented results in November 2017.

Field research results

In 2015, 193 farmers from the 14 communities received a two-year license from CETESB and FF[17], representing 32% of the total number of households and almost the totality of farmers who intended to implement SC. The communities with the more significant percentage of families planning to implement SC plots were BO and MR (81% and 64%), but most were situated between 30-40% (PC, SP, IV, PCC, NH, PG, and PI). The communities with lower percentages were SA (4%) and PIR (7%).

1. Household characteristics

Regarding profession, 73.7% of the interviewees declared themselves as farmers in 2003, compared to 41% in 2008, 100% in 2010, and 90% in 2017 (Table 3). Other occupations mentioned were gardener, bricklayer, driver, housewife, and touristic guide. In 2003, 53.7% were practicing SC to some degree for their consumption, 71.3% in 2008, and

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[16] CBRN (Coordination Body for Biodiversity and Natural Resources): under SMA administration, it was responsible for planning, coordinating and implementation control of norms and policies, and programs related to natural resource restoration, sustainable use, and biodiversity conservation.

[17] Forest Foundation: another division of SMA, created to stimulate conservation, management, creation and expansion of FPAs

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76% in 2017. Thus, perennials production and social benefits have been the primary income sources for *Quilombolas* since the beginning of the 2000s.

Table 3: Proportion of self-declared farmers, reliance on SCS for subsistence, and primary income sources from the different surveys.

	2003	2008	2010	2017
Self-declared farmers (%)	73.7	41.4*	100	90
Producing staple crops for consumption (%)	53.7	71.3		76
Only subsistence agriculture (%)			0.03	11.66
Perennials as income source (%)	34.2	23.75	53	33
Social benefits as an income source (%)	**	**	78	38

*Data refers to individuals, not households.

**In 2003, 33% of families relied on *Programa Bolsa Família* (PBF), and 40.5% relied on rural retirement, but we don't know how these families intersect. In 2008, 40.4% of families relied on PBF, and 33.25% relied on rural pension.

Table 4 shows the primary income sources in 2017. Approximately half of the families declared they depended on SC for household income: 40% relied on a combination of SC and other activities and more than 11% relied exclusively on SC.

Table 4: Proportion of families relying on each type of income source in 2017.

Economic Activity	%
Subsistence agr. + other activities	40.49
Combination of activities without subsistence agriculture	14.11
Only subsistence agriculture	11.66
Only rural retirement	10.43
Only pupunha	6.75
Only salary	4.29
Only rural labor hired out	3.68
Only banana	3.68
Retirement + Salary	3.07
Only PBF	1.84
Total with subsistence agr.	52.15
Total without subsistence agr.	47.85

The importance of social benefits in 2017 is described in more detail in Table 5, though. Social benefits are paid to 38% of households. Rural retirement complements household income with other activities on more than 17% of the families, and it is the only source on more than 10%. PBF, in its turn, is relevant for more than 10% of families.

Table 5: Proportion of families relying on social benefits in 2017.

Social Benefits	%
Retirement + other activities	17.18
Only rural retirement	10.43
PBF + other activities	9.20
Only PBF	1.84
Total	38.65

Perennial crop production was relevant for 33% of the families in 2017 (Table 6). Banana production is more significant than pupunha (20.24% compared to 12.88% of the families), although more families rely only on pupunha (6.75%) than on banana (3.68%).

Table 6: Proportion of families relying on perennial cash crops production in 2017.

Perennial Crops	%
Pupunha + other activities	6.13
Banana + other activities	16.56
Only pupunha	6.75
Only banana	3.68
Total	33.12

2. Farmers’ perception towards Resolution SMA 027 (in 2017)

We asked farmers if they faced problems during the licensing process in 2015; 96% stated they did not. Besides, 90% confirmed that they were able to choose the area they wished for growing crops. When asked if the license arrived on time for the crop calendar, 45% of the interviewees replied it did not.

I asked the interviewees to pinpoint the main problem with SMA 027 implementation, according to their experience in 2017 (Table 7). A total of 83% perceived some kind of problem, while 17% did not face any problem. The great amount of time needed for obtaining the license was the main problem. However, there were also complaints about the bureaucracy, the need for obtaining a license, the absence of technical assistance, the fear of punishment, and the lack of information regarding the issuing process.

Table 7: Main problems faced by farmers with SMA 027 in 2017.

Main problems	%
The time needed for license issuing	38
It was not possible to use the desired plot	22
A lot of bureaucracy involved	11
The need for the license for cropping	7
Absence of technical assistance	2
Fear of being punished	2
Absence of precise information on the issuing process	1
No problems encountered	17
Total	100

3. Description of licensed plots

We calculated the proportion of the territory that corresponded to the licensed areas for SC in 2006 and 2017. Table 8 shows that in all cases, the ratio is minimal and does not reach 2%.

Table 8: Percentage of the territory licensed to SCS in 2017 and used for SCS in 2006.

Quilombola community	2017 (%)	2006 (%)
Praia Grande	1.24	
Ivaporunduva	1.07	1.86
Engenho	0.93	
Maria Rosa	0.85	
Pedro Cubas	0.58	0.02
Nhunguara	0.42	0.21
Pilões	0.40	
Galvão	0.38	0.17

Abobral Margem esquerda	0.16	
Pedro Cubas de Cima	0.14	0.21
Sapatu	0.04	0.58

Table 9 shows the proportion of licensed plots that were managed. Sixty percent were entirely or partially used. *Quilombolas* expressed interest in using all the plots partially or not (totalizing 75% of all plots).

Table 9: Proportion of licensed plots used or not and the intentions of using plots in the future.

What happened to the plot?	%
No used	39.18
Partially used	36.48
Used	24.32

I asked *Quilombolas* about the reasons for not using the plots after almost two years of obtaining the license (2015-2017). The main reason appointed was the lack of labor provision in the household (Table 10). They mentioned the delay in receiving the licenses was often, and family health, unforeseen and financial problems were also impeditive.

Table 10: Reasons appointed by farmers for not using agricultural plots between 2015 and 2017.

Why was the plot not used?	%
Lack of labor provision	42
License issuing was late	28
Health problems in the family	15
Unforeseen problems	9
The license didn't arrive	4
Financial problems	2

For the cases where the licensed plots were used, the great majority was dedicated to the original purpose of growing staples using SC. Only 6% of the areas were used for different purposes between 2015 and 2017, including kitchen garden, cash crops plantation, and livestock raising

Agricultural production was mainly destined for household consumption between 2015 and 2017 (Table 11). 49% of the areas presented the expected productivity, although not necessarily the desired productivity. 33% of plots were less productive than expected, and 18% were more productive than expected.

Table 11: Use of agricultural production in the licensed plots between 2015 and 2017.

Household use of production	%
Own consumption	76
Own consumption and selling the surplus	16
Sell	7
Exchange	1

Finally, I asked farmers if they had other areas under cultivation besides the licensed plots (2015 to 2017). Table 12 shows that one-fourth of the farmers had other plots, but only 3% had to cut the forest to do so (possibly indicating illegal deforestation). The other plots were being used for perennials and livestock or for maintaining staple crops seeds.

Table 12: Use of non-licensed plots between 2015 and 2017.

Did you grow crops in a different plot in the same period?	%
No	76
Yes	24
Did you slash the vegetation in the other area?	**%**
No	21
Yes	3

Discussion

1. Household characteristics

The proportion of interviewees declaring themselves as farmers has varied among the different data collection periods, from 41.4% in 2006 to 100% in 2010 and 90% in 2017. Also, 53.7% of the households were growing crops exclusively for their consumption in 2003, against 71.6% in 2006 and 76.0% in 2017. Despite the differences, results indicate the declining relevance of SCS, as described above. Results also show this was an already ongoing process at the beginning of the 2000s. A typical path in the transition from SCS to more intensive systems is the adoption of new technologies. In the case of *Quilombos,* the adoption of cash crop production was responsible for the income of one-third of the interviewed households in 2017. Following the same path, social benefits have also continually gained importance to *Quilombolas'* livelihoods, and nowadays, almost 40% of families rely on them.

2. Farmers' perception towards SMA 027

The great majority of interviewees (83%) reported problems with SMA 027. In 2003, 35.3% described the existence of FCPs as a problem for agricultural practice. Although most interviewees declared they received the license for the plot they desired in 2015, I believe this does not reflect the reality. Throughout our years in the field, one of the main complaints our team heard was not being allowed to choose the most productive plots. The plots allowed by SMA 027 are not as fertile as the areas that were traditionally selected in the past, due mainly to fallow age. Farmers would rather choose plots around 15 years or older. Besides, some farmers spontaneously told us they followed the legislation rules when selecting the plots for licensing; otherwise, they would consider other plots. There is no doubt that the farmers have perceived the Resolution as negatively impacting their livelihoods. This perception is an ongoing process, as we have observed conflicts for at least 20 years.

3. Description of licensed plots

One of the main features of the licensed plots was the small proportion of the territories dedicated to SC, which are mainly covered with mature forests. Aerial photographs from 2000 revealed that Pedro Cubas had 94.3% of its territory under mature forest, Pedro Cubas de Cima 86.8%, São Pedro 81.34%, and Sapatu 82.66% (Adams et al., 2013). In 2010, Bombas had 79% of the territory covered by mature forest (Thorkildsen, 2014). Other territories were not analyzed but may follow the same pattern, except for those that are very close to the conurbation area of Eldorado.

When I surveyed in 2017, the licensed period was close to ending, but one more cropping season was still possible. Nevertheless, 53% of plots were unused due to workforce absence, unforeseen, and financial problems. The combination of facts shows how vulnerable *Quilombolas'* livelihoods have become. SCS has decreased and is replaced by non-farm activities or full-time cash crop production, as noticed for other regions. Staple crop production has become a spare time activity. The fact that licensed plots were managed for their original purpose and different plots (without a license) were used for the same reason shows that farmers implement SC if they have a chance and are allowed. Additionally, a significant proportion of families were using crops for their subsistence, showing SC importance and potential role for food security. Food security is gaining relevance due to the economic crisis the country is going through since 2014 and could be aggravated by the coronavirus pandemic.

What are the expectations for the future?

Quilombola communities are characterized by socioeconomic differences that include household assets, the share of families involved in cash crop production, average family income, market access, access to education and electric power, and political organization. More important, they differ in the degree of SC practice. Many of these differences were generated and accentuated by the mid 20th century drivers of change. BO was the community with the most significant share of families requesting licenses to implement SCS and the one with the most precarious socioeconomic conditions, lacking access to facilities such as markets, education, household assets, and electric power. On the other hand, SA is the community with a lower share of farmers aiming at growing subsistence crops with SCS. SA is located along a paved state road, with better opportunities to sell cash crops and get involved in non-farm activities such as tourism. Facilities are more accessible, and living standards are relatively higher.

Data from the 2017 survey was used in the political mobilization aiming to change Resolution SMA 027. They were showed to convince state organizations that SCS was still crucial for food security, especially in more isolated communities, and that farmers were eager to and will implement it. As a result, CBRN decided to include *Quilombola* SCS in the new resolution as a forest management activity. As a result, resolution SMA 189/2018 was published in December 2018, including SCS as sustainable agroforestry management. The changes from SMA 027 and SMA 189 were:

- Licenses are issued for forest management instead of forest suppression;
- Individual licenses may last up to five years;
- Each plot must measure up to one hectare, although families are allowed to request for more than one plot;
- The creation of a working group for elaborating and implementing technical reports for plots is required. It is composed of representatives from the state, civil society, and indigenous groups.
- SMA 189 opens the possibility for the establishment of agreements between each *Quilombo* territory and the government. Such arrangements would allow communities to explore their territories for 20 years without the need for periodic licensing.

What remains unchanged:

- Visits from technicians are still necessary;
- The need for vegetation evaluation and plot demarcation with a GPS;
- It is still possible that new licenses can arrive late.

Deliberations about the conflict

The establishment of PAs has been used as the most crucial strategy for nature conservation around the world. However, it is not uncommon to find conflicts related to FPAs implementation and management. Socio-environmental conflicts include not only the problem of biological conservation, but different interests and institutions, the perspectives of political-economic structures, institutional histories, and adaptation of human societies have also to be considered (Thorkildsen, 2014). Also, such conflicts typically engage three spheres of transformation: the economic, the ecological, and the cultural ones. Ribeira Valley is not an exception, as I was able to show. Although regulations for forest use seem necessary, they could be less restrictive for SCS, maybe limiting areas that are susceptible to erosion but allowing farmers to use more fertile plots (e.g., intermediate fallow forests).

Conclusion

This survey revealed why the *Quilombola* farmers are unsatisfied with the legal constraints to SC implementation and emphasized the importance of SCS to their livelihoods. Conflicts with the State caused by FCPs are not new to them, but this is the first time *Quilombolas'* perception was considered in detail. The results showed that the main problems include the timing in issuing the licenses by the government, not relying on traditional *Quilombola* knowledge regarding the soil-vegetation dynamics of the SC system, and the amount of bureaucracy involved in the process. Overall, the results showed a conflicting situation where no one wins because governmental environmental organizations cannot accomplish their regulatory requirements for nature conservation. By recognizing the described process as a socio-environmental conflict and addressing the related historical, economic, and political dimensions, elements for an adequate policy and management implementation are provided.

This research also confirms our previous findings (Adams et al. 2013) that the *Quilombola* agricultural system is under transition. However, I revealed that the socioeconomic scenario has not significantly changed in the last two decades. Thus, even though SC has become a spare time activity, it is still relevant for food security, at similar levels twenty years ago. This relevance suggests that SC is not following the path to its complete demise, where agriculture will be exclusively market-oriented and mixed with other economic activities. Instead, drivers of change and local trends probably lead to a scenario where SC will resist as a safety component against risk and uncertainty.

Moreover, it has been clear that the *Quilombolas* have gradually acquired more political autonomy. This phenomenon is inserted in the context of social and environmental movements rise in Brazil at the end of the 20th century, when development agencies started to stimulate decentralized forms of governance through the empowerment of citizens and participatory approaches implementation (Futemma et al., 2015; Hayama, 2017). Such a process has been crucial to SCS persistence. The fact that state institutional structure is changing may cause some insecurity in the short-term future, but political empowerment and alliances might compensate for it.

THESIS SECTION II – MODELS METHODS & BEHAVIOR

Chapter 4: Model integration: description of methods

Introduction: theoretical background

This chapter mainly focuses on the modeling methods implemented in this Thesis: MPMAS (Mathematical Programming-based Multi-Agent Systems) and GDM (Generalized Dissimilarity Modeling). First, I start with the theory behind the modeling tools choice, followed by a literature review of the models implemented to represent shifting cultivation and conservation policies. Then, I describe the data collection methods, models running, scenario settings and conclude the chapter describing the methods implemented on models' integration. Validation results and the study area are presented in the next chapter.

Modeling approach

For all complexities involved in reproducing livelihoods, in a process that is, at the same time, multi-level, nonlinear, systemic, and dynamic, the *Quilombola* SCS may be described as a social-ecological system (SES). In SESs, individuals relate to each other and the natural systems through dynamic and complex interactions, according to institutional rules. SESs are composed of different variables (biophysical, political, and socioeconomic) and various interdependent processes (ecological, historical, demographic, and others), which interact with each other in multiple spatiotemporal levels (Desouza and Lin, 2011).

Multi-agent system models – (MAS) have been implemented to study these systems. MAS are composed of decision-making agents – as autonomous entities –, and an environment: a shared space over which they make decisions, communicate, interact and depend on each other. The agent component is an agent-based model (ABM), representing the actors' decision-making structure under study. Decision-making is an autonomous, heterogeneous, and decentralized process. The cellular component, on its turn, is represented by layers of grid cells, placing agents over a diverse space where decisions are taken. Agent and cellular components are integrated through interdependencies and feedbacks, influenced simultaneously by each other. Complex micro/macro linkages are captured because of their bottom-up structure, reflecting connections between different production options, farm resources, and household objectives to macro-phenomena (Robinson et al., 2007; Schreinemachers et al., 2007). For their flexibility, MAS are appropriate tools for representing complex spatial systems and the interactions between heterogeneous socioeconomic and biophysical environments, the processes shaping the landscape, and the dynamic feedbacks across levels/scale. Moreover, they can perform realistic representations, being recognized as helpful simulation tools for interdisciplinary modeling, policy evaluation on sustainable development, and climate mitigation and adaptation (Jepsen et al., 2006; Nolan et al., 2009; Schreinemachers et al., 2010).

Models integration

Policies designed for large-scale processes may impact ecologies, economies, and societies but are usually modeled with a disciplinary perspective and neglect the interactions and feedbacks among the systems. To overcome this constraint, models should represent economic, environmental, and social dimensions. For this purpose, MAS can supply a platform for collaboration and learn among scientists, policy-makers, and farmers (Schreinemachers and Berger, 2011). With that in mind, the framework proposed in this project is based on the integration of two modeling tools: MPMAS (Mathematical Programming-based Multi-Agent Systems) and the Generalized Dissimilarity Modeling (GDM), a community-level modeling tool. Figure 2 shows the interactions between the two models and the factors included and produced outputs. For readers' assistance, each of the dotted line boxes represents the different method steps described in this chapter. The numbers on the boxes indicate the various steps taken on the methodological procedures.

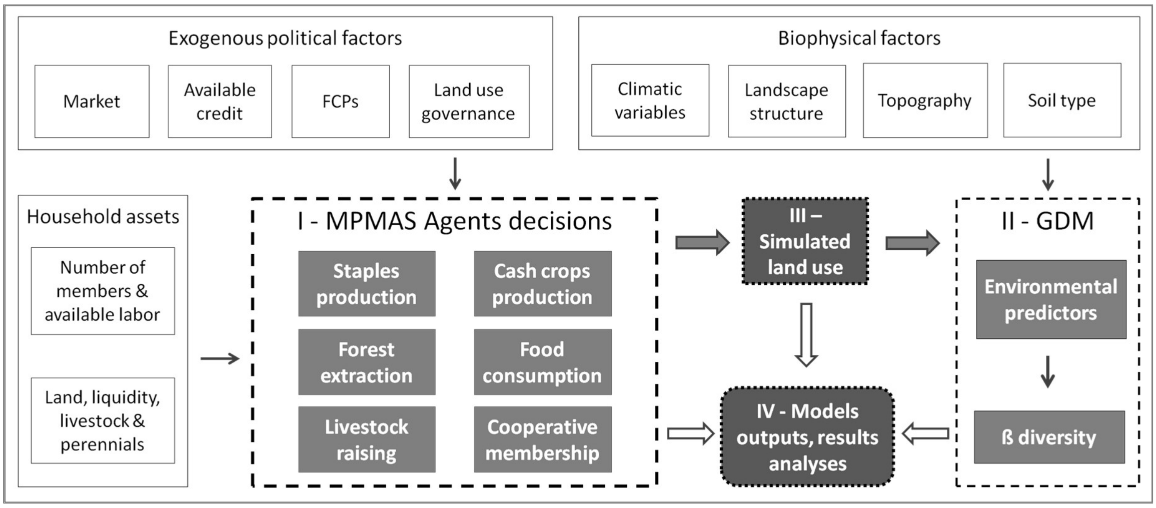

Figure 2: Diagram of the whole model and the factors that influence agents' decisions and tree communities distribution.

MPMAS - Mathematical Programming-based Multi-Agent Systems

MPMAS is an agent-based software package for simulating land use change in agriculture and forestry (Schreinemachers and Berger, 2011). It was first designed by Berger (2001) and has been developed ever since at the Institute of Agricultural Sciences in the Tropics and Subtropics (Hans-Ruthenberg-Institute) at the University of Hohenheim (available at *mp-mas.uni-hohenheim.de*). MPMAS is founded in microeconomics and farm management theory, and it can combine economic models of farm household decision-making with a range of biophysical models.

MPMAS uses mathematical programming (MP) to simulate individual decisions on investment, production, and consumption, a suitable technique to represent decision rules for rural activities. The MP determines the choice among the set of production activities offered for the agents' decision in the problem, while constraint equations connect and constrain activities, ensuring feasible solutions according to agents' resources. Resources include available land and labor in the household, cash reserves, off-farm labor markets, and production credit options. Agents' characteristics comprise the household demographic composition, land ownership, and location in the spatial context. Each farm problem is solved individually to achieve income or utility maximization by choosing the optimal combination of several production activities. Agents make decisions on farm investment, food consumption, and crop production. By individually including agents, MPMAS explicitly considers high degrees of heterogeneity, nonlinearity, interaction, feedback, and emergence (Berger et al., 2017; Troost and Berger, 2015; Wossen and Berger, 2015).

The cellular model represents the spatial context, focusing on landscape dynamics and transitions. The landscape is where agents are spatially distributed and contextualized regarding resource quality and ownership and available production options (i.e., land owned by the farmer, soil types, land use, or land cover). Thus, the cellular module enables the coupling and integration with spatially explicit biophysical models at a disaggregated level and simulation of the system's ecological aspects and environmental changes (Berger et al., 2006; Wossen and Berger, 2015).

MPMAS structure is used to implement different scenarios representing exogenous changes to the system, either environmental, economic, or political ones. Results might be analyzed both at the aggregate or disaggregate level. Both perspectives are essential for policy impact analysis, referring to their effectiveness, efficiency, and equity (Wossen and Berger, 2015). With the use of MPMAS, it is possible to simulate complex interactions between agents and the environment and to assess ex-ante farmers' adaptation to drivers of change (Schreinemachers and Berger, 2011). When together, these interactions can reveal the sustainability of collective or individual management strategies.

Tree community beta diversity

The vegetation is known to be a robust indicator of environmental integrity and biodiversity status. Hence, forest composition and forest cover were selected as proxies of structural diversity. Therefore, I opted to model a group of tree species that represents the fallow forests chronosequence. In nature, a variety of factors promotes compositional and structural changes in biological communities, depending on the mechanisms involved in species individual responses to endogenous or exogenous drivers. They correspond to variations in demographic rates, compensatory mechanisms related to environmental changes, and genetic restructurings. Some of the most popular tools to map biodiversity patterns and model species richness are the species distribution models (SDMs). These tools require only species occurrence data and related environmental conditions to be implemented for understanding how ecological factors limit species distribution, species responses to climatic events or other environmental impacts, or to assess threats to species persistence. However, these tools are generally limited to common or well-sampled species and give an incomplete understanding of biodiversity at regional scales. Also, analyzing individual models for many species can be increasingly time-consuming (Fitzpatrick et al., 2011; Latombe et al., 2017).

Together with the team from CIBIO[18], I opted for a tool that can model the group of all species at once without excluding any taxa. We preferred it instead of combining individual models of many species and excluding the rarely recorded ones (which might be the majority of cases). Compositional and structural reorganization of biological communities in response to environmental change is known as beta (β) diversity. We used generalized dissimilarity modeling (GDM) to predict β diversity - the difference in species composition between sites - as a function of environmental variation between the same pairs of geographical locations. In GDM, the variation (or compositional dissimilarity) of a given biological group is measured directly from lists of biological entities. Such variation is translated as the proportion of species that occurs at one location and does not occur at the other. Thus, the more significant the environmental difference, the greater is the dissimilarity. In summary, GDM is a good solution when one intends to predict the spatial distribution of large numbers of species and cannot do so with little records. GDM statistical procedure is based on the presence or absence of the species group, observed at sampled sites in the studied region (Latombe and McGeoch, 2017; Rosauer et al., 2014; Williams et al., 2010).

GDM is based on spatial layers for different environmental variables that provide ecological conditions to determine compositional dissimilarity between all possible pairs of sites, depending on their environmental conditions and geographical distances. It follows a generalized linear approach based on the Bray–Curtis Index. It permits rapid analysis of large numbers of species, enabling the detection of shared biological patterns where multiple biotic

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[18] Research Center in Biodiversity and Genetic Resources, University of Porto, Portugal.

interactions occur. Moreover, it is possible to extrapolate compositional turnover beyond the sampled communities to the whole landscape.

GDM has been implemented to visualize community composition spatial patterns and in biodiversity assessment activities and conservation planning, extrapolating distributions of community types, as well as the potential impacts of climate change (Fitzpatrick et al., 2011; Fitzpatrick and Keller, 2015; Latombe et al., 2017). However, as it has been recently developed (Ferrier et al., 2002), GDM has not been widely implemented, although it is possible to find various applications. For example, Ashcroft et al. (2010) used GDM to divide a region into units of homogenous landscapes, based on the species turnover along environmental gradients of different groups of invertebrates. Fitzpatrick et al. (2011), in their turn, used the model to forecast climate changes on ants. Lomba et al. (2011) implemented this tool to estimate dissimilarity levels of a community of plants in the landscape, in northwest Portugal, according to climate and landscape structure variables. Additionally, Fitzpatrick et al. (2013) implemented GDM to compare compositional and structural variations between floras of Australia and Europe in terms of seed dispersal adaptations. Moreover, Fitzpatrick and Keller (2015) used GDM to map the genomic variation of a tree species related to geography and climate. Here, the GDM was used to evaluate the impacts of different management strategies and current nature conservation policies on targeted biodiversity parameters of the *Quilombola* forested landscape.

Modeling shifting cultivation

The first simulation models created to study SCSs were developed in the 1980s, including spatial and environmental contexts. Wilkie and Finn (1988) simulated the effects of SCS on forest regeneration processes in Zaire and found that population pressure, land tenure systems and fallow length were impacting landscape structure. Dvorak (1992) modeled the relationship between fallow and labor in SCSs in West Africa to find that environmental and economic factors affect soil fertility variation. Gilruth et al. (1995) simulated the location of SCS plots in the Republic of Guinea, including forest structure, productivity, and elevation. In the same year, Hall et al. (1995) used GEOMOD to study land use changes in Southeast Asia and tropical Africa. Later, SCSs were modeled by Angelsen

(1999) to examine the effects of the labor market and property regime on the expansion of agricultural frontiers and deforestation in Indonesia, based on microeconomic theories. In parallel, Walker (1999) used an ABM in Brazil to simulate the dynamics between SCS and forest structure, including the role of the market, farmers' groups, staples production, consumption, and forest transition.

The first two decades of modeling SCSs were marked by uncertainty due to the significant simplification of the decision-making processes (Ngo et al., 2012). These circumstances changed from the 2000s when more elaborated decision-makings were implemented in the models, and economic factors were considered in more detail. Deadman et al. (2004) applied an ABM to a SCS in the Brazilian Amazon, addressing social, environmental, and spatial issues. Subsistence, soil quality, household composition, and endowment were used for decision-making. Sulistyawati et al. (2005) modeled SCS in Indonesia to compare different land use strategies, integrating demographic, socio-cultural, economic, and ecological factors. Bi et al. (2007) studied SCS intensification in China by implementing an ecological model (FORECAST). During the same period, Jepsen et al. (2006) estimated the choice of agricultural plots based on yields and labor, according to the fallow age and slope, in Vietnam. Wada et al. (2007) implemented ABM to SCSs in Laos, including market crop demand and supply, prices, and production costs. Additionally, Brown (2008) used a resource extraction model to simulate SCS and forest dynamics in Cameroon through utility maximization, combining spatial and household modeling.

Wickramasuriya et al. (2009) implemented a Constrained Cellular Automata (CCA) land use model to simulate SCS spatial dynamics in Sri Lanka. to capture the dynamics of agricultural intensification and the resulting reduction in soil fertility. Later, Evans et al. (2011) ran an ABM for land use/land cover change in China to explain rates of cash crop adoption and evaluate the consequent emergence of household inequalities. The relationship between SCSs and ecosystem services (ES) was studied by Wickramasuriya et al. (2009), who applied a CCA to SCS in Sri Lanka. Klemick (2011) aimed to quantify ES in an Amazonian SCS, such as hydrological externalities and fallow contribution to crop productivity. The measures included soil quality controls, instrumental variables, and spatial econometric approaches. On the same reasoning, Jourdain et al. (2014) applied a MP method to compare the implementation of two different ES payment programs in Vietnam. Since 2014, no other papers were published using modeling to investigate SCSs.

The presented studies differ in numerous aspects, such as implemented tools, the accuracy of outputs, efficient validation, real-world data, factors considered, and research goals. However, there is a prevalence of simulations to access SCS's environmental impacts, and ABMs are found in the minority of presented cases. Additionally, I did not see many examples of the combination of different models to assess SCSs' diverse dimensions and, up to this moment, no work integrating ABM and GDM tools.

Modeling conservation policies

Most of ABM implementations so far have been developed to perform impact assessments in an ex-ante process to prospect the effects of possible agricultural and conservation policies that can affect land use decision-making. Therefore, such implementations seek more sustainable options by assessing policy versions' economic, social, and environmental impacts (Reidsma et al., 2018). The first studies performed impact assessments of abstract and generic policies. Weisbuch and Boudjema (1999) tested models of environmental policies to find the most appropriate one in a high uncertainty context, where a spatially explicit model represented European farmers. Janssen et al. (2000) tested different policy models over a pastoralist society, covering the environment and economic characteristics, finding patterns and emergent properties from the interaction between farmers and policymakers. In their turn, Sengupta et al. (2005) implemented an ABM based on real farmers' data, including their specificities and territory, to anticipate a conservation policy in the USA and evaluate environmental impacts.

Later on, Brady et al. (2009) aimed to understand the possible impacts of three different EU standard agricultural policy models (EU CAP) over farm structure, landscape mosaic, and biodiversity. Le et al. (2010) used the LUDAS model to assess the impacts of land use policies over an SES in Vietnam. Represented farmers were under transition from more traditional SCS towards an intensive farming system. One year later, Gimona and Polhill (2011) published their coupled model of agricultural land use change and species metacommunity in Europe. They were able to indicate the most appropriate rural policies to achieve target species conservation. In Vietnam, Ngo et al. (2012) used an ABM model to improve a SCS's impacts over the forest ecosystem. The authors concluded that an ABM could fully represent the relationship between SCSs and FCPs implementation. In 2013, Smajgl and Bohensky published their ABM implementation to assess the impacts of payment for ES in China, where they encountered conflicts between farmers (including SCSs) and conservation goals. On the other hand, Daloğlu et al. (2014) coupled an ABM with the SWAT tool to simulate the consequences of different policy and land tenure scenarios for the landscape structure and water quality in the USA. Finally, Troost et al. (2015) used ABM to simulate farmers' decisions on biogas investment and participation in agri-environmental measures in South-West Germany. They helped to evaluate future policy schemes in the region. At the same time, Guillem et al. (2015) coupled ABM with an individual-based model of skylark populations in Scotland to evaluate the consequences of food and bioenergy production to skylark numbers.

In sum, there are various ABM implementations in policy evaluation procedures, focusing on environmental and economic outcomes, using fictitious scenarios or real farmers' data, through ABM only or coupling with other tools. Most of the models used European agricultural systems, although some authors studied tropical areas where SCSs are practiced. Overall, the majority of papers demonstrated ABM's great potential for policy evaluation and impact assessment. Still, our model will contribute to the literature for investigating the impacts of FCPs' through an analysis of economic and environmental outcomes, from simulations integrating MPMAS with GDM, using real farmers' data.

Data collection

Ethnographic data

The first research project, "Social memory and historical ecology: the shifting cultivation system practiced by *Quilombola* populations from Ribeira Valley and its relationship to the local Atlantic Rainforest formation,"[19] had its fieldwork conducted between 2006 to 2010. Visited communities were Pedro Cubas (PC), Pedro Cubas de Cima (PCC), São Pedro (SP), and Sapatu (SA). I combined ethnographic and oral history methods to identify drivers of change in the SCS and to understand this system´s role in shaping the local forest's landscape. Sixty-six individuals were interviewed, aged between 36 and 75, focusing on their family lives and the agricultural system and associated landscape elements. The ethnographic data was crucial for constructing the system to be modeled and provided some parameters.

Botanical data: first data collection

Another research was conducted in parallel in 2008. The "Forest succession in SCSs plots under fallowing[20]" project aimed at identifying and quantifying tree species richness and diversity in a SCS fallow chronosequence. It was conducted in the community of São Pedro (SP). Three secondary forest age groups were selected for sampling: from 2 to 4 years, 10 to 15, and 40 to 60 years; three samples were made for each age group. Fallow plots measured around one hectare and were located on slopes 25° to 30°, connected to a mature/pristine forest area on the top sideline. Only trees measuring more than 2 cm at DBH (diameter at breast height) were sampled. The trees sampling design was based on Gentry (1982), meaning that eight parallel transects were positioned perpendicularly to the top sideline, measuring 50 meters of length downslope against 2 meters of width (Gomes et al., 2020, 2013) - check Figure 3. The position of each transect on the top sideline was defined by raffle. Each transect was partitioned into five sections of ten meters (*a* to *e*), where the location of trees was registered, being section *a* closer to the mature forest area. In total, 3.898 individuals and more than 170 species were sampled and identified.

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[19] Coordinated by Dr. Rui S. S. Murrieta (University of São Paulo) and funded by FAPESP (São Paulo Research Foundation), process number 2008/52446-4

[20] Coordinated by Dr. Eduardo Pereira Cabral Gomes (Institute of Botany of the State of São Paulo) and funded by CNPq (National Council of Technological and Scientific Development) Process 478.520/2007-7, and by the Institute of Botany of the state of São Paulo, project 01.07.

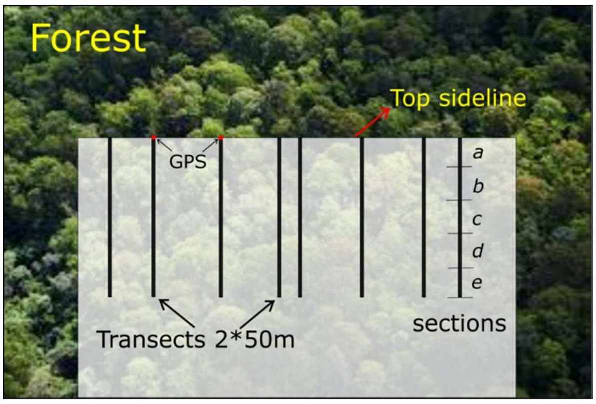

Figure 3: Sampling design implemented on the botanical data collection.

Socioeconomic census

A socioeconomic census was conducted in Pedro Cubas (PC), in 2014, by the "Multi-agent systems modeling as a tool for evaluating technology adoption and diffusion in *Quilombola* communities of Ribeira Valley, SP"[21] research project. Its goal was to understand the process of adoption and abandonment of agricultural innovations in the *Quilombola* communities. Household heads of all of the community's 52 participated in the survey. Information on household structure (number, age, gender, and profession of members), agricultural production (annual and perennial crops species, number and area of plots and fallows), household income sources (government pensions, rural retirement, salary), household expenditures, goods and accumulated wealth were gathered[22].

Botanical data: second data collection

One of this study's goals was to evaluate the impact of SCS practice on trees' community β diversity under different socioeconomic and political scenarios. I used the data collected in 2008 to save the effort of sampling ten new plots. Unfortunately, it was not feasible to use the same methods due to the quantity of sampled species that would need to

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[21] Research project: "Multi-agent systems modelling as a tool for evaluating technology adoption and diffusion in *Quilombola* communities of Ribeira Valley, SP "; coordinated by Dr. Cristina Adams (University of São Paulo), funded by FAPESP (Process number: 2011/10666-0).

[22] The short research carried out in partnership with ISA (Chapter 3), in 2017, complemented the ethnographic research and socioeconomic census.

be identified. Instead, supported by the Institute of Botany researchers, I chose a representative group of species without collecting or identifying individuals, diminishing the effort. A Twinspan tool analysis was used to find the most abundant species in each age group as ecological indicators of the forest succession process (Figure 4). The list was further discussed with local farmers, which helped to define the final group based on ethnoecological knowledge and easiness of recognition in the field. We chose 19 indicator species, and the Juçara palm was also added to this group because of its relevance for the Atlantic rainforest ecology, its original great abundance, risk of extinction, and economic importance (Table 13).

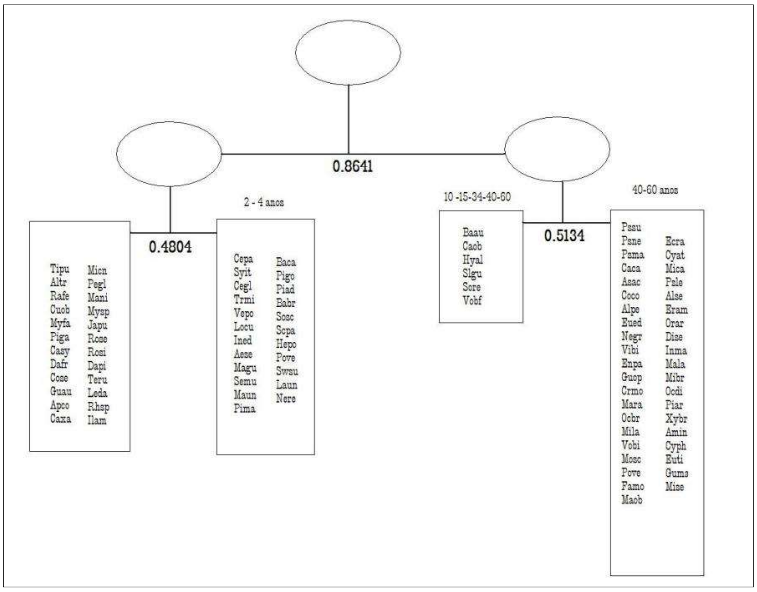

Figure 4: TwinSpan analysis results.

Table 13: Groups of ecological indicator tree species, pollination, and dispersion modes.

Fallow phase	Species	Pollination mode*	Dispersion mode**
2 to 4 years	*Cecropia glaziovii* Snethl	Anemophily	Zoochory
	Cecropia pachystachya Trécul	Anemophily /Melittophily	Zoochory
	Schizolobium parahyba (Vell.) Blake	Melittophily	Anemochory
	Nectandra reticulata (Ruiz & Pav.) Mez	Insects	Zoochory
	Vernonia polyanthes (Spreng.) Less.	Melittophily	Anemochory

	Aegiphylla sellowiana Cham.	Melittophily/Psychophily/Ornitophily	Zoochory
	Inga edulis Martius	Melittophily/Ants	Zoochory
10 to 15 years	*Tibouchina pulchra* Cogn.	Melittophily	Anemochory
	Alchornea triplinervia (Spreng.) Müll.Arg.	Anemophily	Zoochory
	Rapanea ferruginea (Ruiz & Pav.) Mez.	Anemophily	Zoochory
	Myrcia fallax (Rich.) DC.	Insects	Zoochory
	Piper gaudichaudianum Kuntze	Insects/Anemophily	Zoochory
	Campomanesia xanthocarpa O. Berg	Melittophily	Zoochory
40 to 60 years	*Astrocaryum aculeatissimum* (Schott) melittophily urret.	Cantharophily/Melittophily/Myophily	Zoochory
	Guapira opposita (Vell.) Reitz.	Melittophily/Anemophily	Zoochory
	Psychotria mapourioides DC.	Insects	Zoochory
	Cabralea canjerana (Vell.) Mart.	Melittophily	Zoochory
	Allophyllus petiolulatus Radlk.	Insects	Zoochory
	Euterpe edulis Mart.	Melittophily	Zoochory
	Virola bicuhyba (Schott ex Spreng.) Warb.	Melittophily	Zoochory

*Tress can be pollinated by wind (Anemophily), by insects in general, by bees (Melittophily), butterflies (Psychophily), birds (Ornitophily), beetles (Cantharophily), and flies (Myophily).
** Seeds can be dispersed by wind (Anemochory) or animals (Zoochory).
*** Based on: Kinoshita et al., 2006; Montoya-Pfeiffer, 2018; Silva et al., 2012.

I sampled seven fallow plots in each of the previous age groups (21 fallow areas), located in Pedro Cubas (PC) or Pedro Cubas de Cima (PCC) (Figure 5). All plot visits were accompanied by locals, who assisted on transects opening. In addition, I hired one of the older farmers in Pedro Cubas to help us with plant identification and recorded the presence data of each species in all the transects. Fallow age and history of each plot were also recorded. The community leader signed a consent form before fieldwork started (Appendix A).

Figure 5: Plots where we collected data on tree species. The circled area shows plots surveyed in 2008 in São Pedro. The other plots represented the visited areas in 2016.

4.I - MPMAS

MPMAS documentation

The ODD protocol (Overview, Design Concepts, and Details) is a well-recognized method for ABM documentation, bringing the underlying theoretical concepts and details, including equations, objects, and algorithms implemented (Grimm et al., 2006; Müller et al., 2013). One can find MPMAS ODD protocol in Schreinemachers and Berger (2011), so I report below the information related to the application of MPMAS in this Thesis.

Overview

a. Purpose

To achieve the goals of this study and supported by the MPMAS developer team, I designed MPMAS to answer the following questions: What are the consequences of SCS intensification on *Quilombola* farmers' wealth and forest landscape structure? What are the consequences of FCPs application on farmers' wealth and forest landscape structure? The model also aims at assessing the sustainability of the SCS.

Scenarios with different FCP models and market access were compared, including counterfactual scenarios of the present *Quilombola* context. For unveiling the consequences of agricultural intensification, we compared three scenarios: one representing the historical past, with no market access or FCP implementation; a recent past scenario, representing the decade of the 2000s, with market access and the previous version of FCP; and the present-day scenario representing actual conditions of market access and FCP. To evaluate the impact of FCP implementation, we compared the current present-day scenario with the two counterfactual ones. The model refers to a subsistence system: staple crops production and fallow areas of different ages are central to this project.

By implementing MPMAS as a descriptive tool, we expect to reveal unforeseen consequences of the interactions between local processes and identify better economic sustainability and forest conservation strategies. By implementing MPMAS as a predictive tool, on the other hand, we aim to assess possible future conditions of SCS practices.

Entities, state variables, and scales

The model comprises 52 agents representing all the households in Pedro Cubas (PC). The household state is related to its composition, engagement in SC or other agricultural activities, access to social benefits, land, and livestock assets. Agents are specified by the number of individuals, gender, age, job, mortality/fertility rates, agricultural labor capabilities, cooperative[23] membership, food consumption rates, the existence of salary and cash transfer programs[24]. Liquidity info was calculated from each agent's income minus expenditure values obtained from the census. Household income includes profit with crops, livestock, hiring out farm labor, salary, and social benefits. Expenditure is composed of expenses on the local market, mainly on food items. Land assets are represented by areas

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[23] The cooperative named Cooperquivale (Cooperative of the *Quilombola* farmers from Ribeira Valley) was created in 2012, aiming at stimulating and facilitating quilombola agricultural products flow and promoting income generation (Pasinato et al., 2017).

[24] The previous ethnographic researches had indicated that remittances are relevant to *Quilombola* communities, especially in the present context. They should have been included in the model, but no interviewe farmer declared to have received them in the period of data collection.

dedicated to all possible productive activities (annuals, perennials, pasture) and farmsteads and the fallow areas of different ages. Livestock assets include chicken, pork, and cattle, raised for selling or feeding the family.

Together with the MPMAS developer team, I run all scenarios for four simulation periods. One simulation period is the set of equations containing all activities and constraints to support agents' decisions in a linear programming (LP) matrix. Once the model is run for one period, parameters are updated in the LP, and the agent can take decisions of the subsequent period. The simulation period is equivalent to one year, but it is split into months on equations to take crop calendar labor into account and distribute it properly. Agents' decisions are made twice a year: in the pre-harvest and the post-harvest periods. Annual crop production decisions are taken once a year, based on farmers' yield expectations. Still, decisions referring to investment, maintenance, and the selling of perennials, as well as household consumption, are taken twice a year.

The present scenario refers to 2014, but other FCPs and market access designs refer to the 1960s and the 2000s. Households' detailed dataset refers to 2014, but the landscape dataset used for different scenarios is from 1962, 2007, and 2014. The biophysical module represented in the cellular component of MPMAS corresponds to the whole Pedro Cubas territory (3,806.23 ha).

Cell grid sides measure 25 m, accounting for small SCS areas. The cellular component combines layers of land use, farmstead location, and farm property. The land use map consists of the combination between land use classes (6 classes: perennials, farmstead, pasture, current annual cultivation, fallow with 60 ages) and soil types (2 main types of soil in this territory, distinguishing hilly areas from those that are closer to rivers and the flat regions), totalizing 130 classes. The variation of soil types is expressed as yields variation in the model, especially for annual crops. Farmland property is fixed through time because we represent a collective territory based on a hereditary property transfer.

b. Process overview and scheduling

Land use decisions consider the amount of land in different ages of forest succession. Since agents have limited access to fallow areas (held by the household), the current choice of a plot affects the availability of plots with a minimum recovery age in the future. To find the best way to represent this situation, the MPMAS developer team delivered an LP matrix where agents could base their decision on several years of planning into the future. In this way, agents can account for the future age of household areas, depending on the decisions they make today (all other factors included), and assuring the benefits of fallow in the future.

Therefore, the implemented model contains intertemporal planning, providing a multi-period horizon for the agent to take the future into account, adding planning periods to the simulation one. I included 40 planning periods, meaning the farmer is considering 40 years ahead when making decisions. In other words, decisions are taken for one period, but they include a horizon of 40 years, providing the agent more flexibility in planning. The plan will be run for the immediate period only, and its outcomes will influence the agent to adapt its decision and change the plans if necessary. Another multi-year plan is created on the subsequent simulation period, again for the same number of planning periods. The multi-period matrix allows the agent to consider all land uses in the household's properties, especially fallow age, to decide where and how to produce staples. Perennials and other assets are also considered. On the other hand, the recursive dynamics help the agent deal with uncertainties involved in agricultural production.

The planning period is divided into pre and post-harvest stages. The model is centered on the SCS: the pre-harvest starts right before the annuals calendar and the decision on annuals production. At this moment, agents decide which crop to plant, how much and where it will be planted. The post-harvest stage refers to the marketing and consumption of agricultural and livestock products, followed by the farmer's investments to start, keep, or abandon the perennials and livestock production. However, agents' decisions are taken for both periods simultaneously, right after the harvest, when the yield is known. So, decisions include actions for the post-harvest period of year one and the pre-harvest period of year 2. Decisions are based on the expectations over annuals yields and prices. Some decisions are taken for both stages, such as forest extraction, selling off-farm labor, hiring in extra work, and household consumption (from the household's production or bought in the market). Income and cash flow are calculated by the model and the total area dedicated to agriculture and the penalties paid for not consuming the minimum food required. Once the calculations are made, the agent can plan for the next simulation period.

Design concepts

a. Theoretical and empirical background

MPMAS theoretical framework is based on microeconomics and farm management theory. It uses mathematical programming to capture farming systems heterogeneity by optimizing modeling agents' decisions individually. Economic optimization of farm problems sustains the decision rules implemented and includes agents' specific capabilities and limitations (Schreinemachers and Berger, 2011). Recursive-dynamic simulations consist of learning and adaptation processes on the decision of land use strategies throughout the simulated periods.

Agents' decisions are based on a combination of previous researches, data collected for this research, and farmers' and local actors' knowledge. The modeled system simulates an SCS based on subsistence farming submitted to changes imposed by a set of external drivers. Since forest dynamics play an essential role in the system, more emphasis was given to the choice of agricultural plots among different fallow ages (representing variation on crop productivity) and the provision of household food consumption. I applied empirical parameterization with parameters from the census (2014) to capture the system's heterogeneity and fully represent farmers. Four submodels were implemented: decision module, demographics, asset evolution, and plot evolution, all described below.

b. Individual decision-making

The decision-making process is disaggregated at the household level. Aggregate results can be extracted from the outputs' analysis. MPMAS uses mixed-integer programming to find optimal solutions to farm problems. Through economic optimization, the agent maximizes the net present value of the cash flow of its production plan after ensuring primary objectives (minimum food and cash consumption) have been fulfilled. Consumption decision variables are considered in the optimization values, and crop consumption is added to income due to their great importance. Economic activities include cash crops (annuals and perennials), livestock, forest extraction, and selling off-farm labor. Decisions concern buying seeds; acquiring perennials and livestock inputs; starting, eliminating, or keeping livestock and perennials investments; cooperative membership; purchasing food and hiring in labor. Available cash constrains these decisions, and the household's available labor and land constrain production activities. Production balance equations limit the selling of the total production, which can be used for household consumption and keep seeds and offspring. Agricultural activities are represented in monthly balances that influence other activities' temporality due to labor demand. Moreover, a minimum food consumption requirement was established, forcing agents to consume their production using reward and penalty variables in the equations. Figure 6 illustrates the decision model, including endogenous and exogenous factors that influence the modeled system.

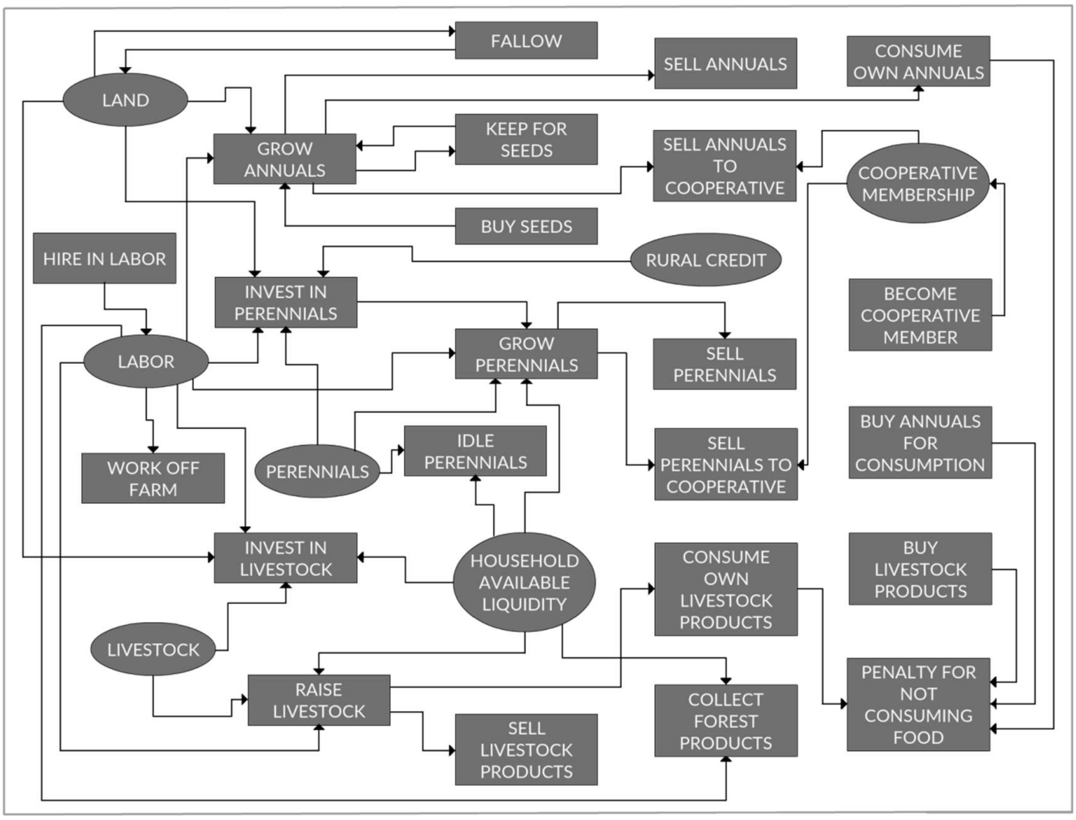

Figure 6: Diagram of the decision model implemented in MPMAS. Decisions are presented in rectangles, and assets are shown in circles.

Exogenous variables that impact agents' decisions are: the implementation of FCPs, access to the market, and the cooperative. FCPs representation consists of blocking areas on the land use map referring to old fallow patches, riparian forests, hilltops, and steep slopes. Market access is represented by the possibility of selling the household's production or not. No economic values were established for social norms, meaning that social rules won't interfere in the decision-making process. The model is spatially explicit, and spatial layers were created from primary data. The most critical temporal aspect of the model is the chronosequence of fallow ages that influences crop productivity expectations. Fallow ages allow the farmer to calculate the amount of available fertile land in the future and are represented accordingly in the multi-period matrix. Uncertain parameters in the model include crop yields; labor demanded by each production activity, hired and provided by the household; initial liquidity values; food prices for buying or selling their production; the amount of food consumed; community's fertility and mortality rates; livestock weight; and the number of forest extraction trips.

c. Learning and Individual Prediction

Being a recursive dynamic model, MPMAS enables periodic adaptation to initial production plans. When plans are put into practice, actual yields and prices are included. Each agent can learn with the outcomes – meaning they adjust their expectations – and remake plans for the next period. However, in all the scenarios simulated in the present study, external conditions were constant over time. Therefore, there is no learning included in simulations.

d. Individual Sensing

All variables are sensed by all individuals in the same way, as LPs are the same for every agent. The individual space is perceived only in the agents' property areas, who owns different resources/land uses. An individual gets access only to its assets. In reality, farmers sell or hire labor among households, but exchanges between neighboring villages are frequent. In the model, one agent's decision of selling/hiring labor does not affect the other. I assume agents are all leveled on knowledge of land use practices, and there are no costs involved in information gathering.

e. Interaction and Collectives

The *Quilombola* producer cooperative has a great potential to impact economic standards and decision-making, as it allows smallholders to sell their crops for higher prices. Here I modeled the cooperative to choose for the farmer to pay a membership tax and sell higher prices. I don't model the actions of the cooperative itself.

f. Heterogeneity

Heterogeneity is introduced into decisions by differences in the state variables: agents' properties, household composition, household's available capital and labor. All of them define the starting conditions in the model. The household structure expresses available labor, consumption requirements, and household income sources. The agents' heterogeneity is responsible for defining heterogenic land use strategies.

g. Stochasticity

The present model is primarily deterministic, although stochastic transitions were included (e.g., household composition and livestock submodels).

h. Observation

All decision values are easily accessed from the model's outputs. Results can be individually taken or collectively calculated and are compared among all different scenarios. I was interested in the total population and household income to measure agents' economic class and poverty position. I was also interested in the entire area dedicated to each land use class, including fallow ages and mature forests. Food consumption was analyzed regarding their source (produced or bought) and penalties for the cases when minimum levels were not reached. Additionally, I calculated the number of crops and animal protein production and application (consumption, marketing, seeds, etc.).

Details

a. Implementation Details

The present study uses a new version of the MPMAS framework (MPMAS/mpmasql4) that allows for multi-period planning problems. It is implemented on Linux OS and requires different components to run. Mpmasql4 processes input files by extracting information from a SQL database. MPMAS component is the agent-based simulation tool itself, responsible for the recursive dynamic multi-period modeling. It includes solving optimization problems for each agent, using exogenous variables, calculating outcomes, adapting farmers' decisions at each period, and updating assets and land classes susceptible to aging. The mqlmatrix is a tool created to read static decision problems generated by mpmasql4 so that the model can be inspected and corrected if necessary. Finally, an IBM CPLEX library is used to solve the LP problems by being linked to the executables. The model files are available with the Thesis' additional material.

b. Initialization

When the model starts running, an initial state for agents is established, including all their assets, population (household members), and land use classes. There is also an initial state for the land use map to be changed at every simulation period. Agents' expectations are also included in the initial state, coming from collected data. Each of the modeled scenarios contains a different initialization, with variations in the parameters.

Agents' initial state is originated from the census dataset, including information on the household structure, agricultural production, household income sources, and expenditures. Information regarding the participation of local organizations and actors was gathered in the 2016 fieldwork, together with data on yields expectations, perennials production, and rural credit acquisition. I obtained food and crop regular market prices from national secondary data (IBGE and EMBRAPA)[25].

The initial soil maps representing the present are based on information provided by farmers (census), the rural extension services institution (ITESP-Foundation for Land Tenure of the State of São Paulo), and maps prepared by ISA (Santos and Tatto, 2008). The initial soil map specifies the type of agriculture implemented, together with the areas dedicated to

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[25] EMBRAPA: Brazilian Agricultural Research Corporation, Ministry of Agriculture, Livestock, and Food Supply; IBGE: Brazilian Institute of Geography and Statistics.

fallowing and their specific ages. Maps for past scenarios were based mainly on aerial photographs (from 1962 and 2000) and info provided by farmers. I produced the map with farmsteads' location by combining institutional maps (from ITESP) and GPS data collection. I created the property map by combining institutional maps (from ITESP and ISA) and data from the census interviews. In the lab, I put together mosaics of aerial photographs taken in 1962 ("Baixada Santista & Planalto" - GEGRAN/SACS scale 1:40.000) and 2000 (flight PPMA/SMA 2001/2002, scale 1:35.000; Instituto Florestal - SP); over which classifications were performed (ArcGIS 10.2.1).

Annual crops are the same as the staples that have always been planted in the *Quilombos*: rice (*Oryza sativa* L.), maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz.), and beans (*Phaseolus vulgaris* L.). These are not the only staples traditionally produced by *Quilombolas*, but they occupy the larger areas on the landscape and need a more significant share of available labor. Whenever implemented, traditional techniques are used, and no chemical inputs are required. Perennials are represented by cash crops: banana (*Musa paradisiaca* L.) and the pupunha heart of palm (*Bactris gasipaes* Kunth). Perennials production is stimulated by agricultural agencies and enabled by credit, used for buying seedlings and all necessary inputs. They are consistently implemented under the same model, relying on a significant volume of fertilizers and pesticides for their yields and labor inputs.

c. Input data

Three main aspects are varied among the scenarios: sociopolitical conditions, uncertain parameters, and yield curves. They are all combined by multiplying the number of simulations. The sociopolitical scenarios differ in the initial year, reflecting prices, land property, land use map variation; the presence/absence of the different FCPs version; the cooperative, market access, cash perennial crop production, and social benefits. Uncertain parameters were submitted to the Sobol' sequence method for uncertainty analysis (described below), meaning they are all combined with different levels of variation in quasi-random sequences in 30 different scenarios. They are the same parameters mentioned in the design concepts. Seven different yield curves for rice and maize were implemented, relating crop productivity to fallow age. In total, I run 1,050 scenarios.

Exogenous factors included prices, FCPs, market, and credit access. Prices are applied to sell crops, livestock, forest extraction products, off-farm labor, buying food, and hiring in extra work. Prices for selling to the cooperative are determined by the government) and are higher than the regular local market. FCPs are present in two different designs or absent. Market and credit access are present or absent, referring mainly to the investment and outlet of cash crops.

d. Submodels

The decision module takes care of the primary household decision problems (Figure 6). It is an ensemble of equations combining decision variables for farm production decisions and household consumption of food. Food consumption equations determine the minimum cash expenditures with food and equations establishing minimum and maximum values for the food items. Food items are staples and livestock products. I chose minimum and maximum quantities according to the population sector (separated by gender, age, and career). Values of calories and protein for food consumption were obtained from the national research on family budgets, distinguished by age and gender (IBGE, 2011).

The demographic submodel is responsible for tracking and simulating the household life cycle (i.e., the birth of new members, aging, or dying). It updates household members' ages every year, reflecting on the member's labor capacity and the probability of giving birth or passing. It also models birth and death events from probabilities. Fertility and death probabilities were obtained from IBGE, distinguished by age[26]. Labor provision is based on our previous knowledge from ethnographic work and surveys. MPMAS treats these changes as non-economic and stochastic events, that however, can impact economic activities.

The assets evolution submodel is responsible for aging perennials and livestock assets and assigning proper values for perennials yields/livestock weight, inputs, costs, and available labor. For taking care of this complexity, MPMAS has a specific compound, responsible for transforming it into different model elements and creating, for each age, activities for investment, maintenance, selling at pre and post-harvest periods, and constraints

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[26] https://ww2.ibge.gov.br/home/estatistica/populacao/projecao_da_populacao/2013/default_tab.shtm

for endowment and disinvestment. During perennials lifespan, the agent can continue production, replace the plot with different land use types, or abandon production. Livestock heads can be bought, sold out, or slaughtered at any time. Additionally, the livestock module takes into account sex, fertility, and mortality rates. The dataset on perennials' initial costs, necessary inputs, productivity, and other technical requirements was provided by ITESP. I obtained labor and profitability from ethnographic research. The number of perennials assets was obtained from the socioeconomic census. The livestock dataset was obtained from technical agricultural research institutions, such as EMBRAPA[27].

Finally, the plot evolution submodel is responsible for updating the cellular component of MPMAS at every single simulation period. From one period to the next, plots used for annuals are left for fallowing. Plots under forest succession can be converted to any type of use, at any time, or get older. Perennial areas may be left idle, eliminated, get one year older, or designated to a different management option. Pasture areas remain as the same land use class, if not abandoned for fallowing. This submodel is responsible for producing MPMAS outputs to be inserted in the GDM modeling step.

MPMAS Model verification

Before I ran the scenarios, I submitted the constructed MPMAS model to a series of verification tests. The tests help identify errors in model construction and check if the structure is adequate for the study goals, and check the model performance and improve it if necessary. The tests consisted of systematic and independent variations over the initial settings for different scenarios to evaluate if the model produced outcomes as expected. For example, supported by the MPMAS developer team, I analyzed how the model responded to the absence of labor or livestock, price increases, and if it implemented the minimum food consumption. Expected and obtained results, input, and output files are presented in the Thesis supplementary material.

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[27] http://www.infobibos.com/Artigos/2008_2/Organomineral/Index.htm
https://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/Ave/SistemaAlternativoCriacaoGalinhaCaipira/Reproducao.htm ;

Creating & running scenarios

Scenarios ran on MPMAS were created in three compositions: political/economic and yield curves and Sobol’ sequence under uncertainty analysis) and were combined among each other, generating many different scenario settings. The motivations and relevance of the components will be described as follows.

Political/economic scenarios

Together with MPMAS developers, I created different political/economic scenarios that I could evaluate the impacts of FCPs, analyze agricultural intensification, and assess the future of the *Quilombola* SCS. In total, five scenarios were created, combining, among other factors, the presence or absence of FCPs, and the level of agricultural intensification. We implemented three FCP versions: the old (referring to the 2000s rules), the new (after Resolution SMA 027), and the absence of FCPs. On the MPMAS maps, we blocked the use of areas under restriction depending on the FCPs' rules. Market access was controlled through the possibility of selling farm production or not, the existence or absence of rural credit, the complete restriction of forest extraction activities, and the possibility of producing and owning perennial plantations or not (Table 14).

Present with new policy (Newpol)

This scenario represents the *Quilombola* context at the time the socioeconomic census was conducted (2014). It contains total market access, the latest version of FCPs implemented, and typical agricultural intensification practices: cash crop production, forest extraction activities, and the existence of the cooperative. Newpol is the baseline scenario, which function is to be compared to the other scenarios. Resolution SMA 027 restrictions on land use blocked primary forests and secondary forests on medium and late stages; 50 meters around mineral springs; hilltops; and steep slopes with more than 45°. Blocked Riparian forests included: 30 meters for rivers measuring up to 10 meters wide; 50 m for rivers measuring from 10 to 50 m; 100 m for rivers measuring from 50 to 200 m; 200 m for rivers measuring from 200 to 600 meters; and 500 m for rivers with more than 600 meters.

Present without policy (Nopol)

This scenario represents present *Quilombola* livelihood and territory conditions, but without FCPs implementation, allowing the evaluation of a counterfactual scenario. It has the same configurations as Newpol, but the FCP is absent.

Recent past with old policy (Oldpol)

The Federal Decree 750/93 was implemented from 1993 to 2010s. Simulating the old policy scenario was an opportunity to evaluate the possible consequences of this FCP in a slightly different socioeconomic context. By that time, farmers had already adopted cash crop production, but the only crop was banana. We simulated the year 2000 because we had more precise spatial data. Land use restrictions are similar to SMA 027, except for riparian forests: 5 meters of for rivers measuring up to 10 meters wide; rivers from 10 to 200 m wide must have a riparian forest measuring half their width; and 100 meters of riparian forests for rivers more than 200 meters wide; and 200 m around mineral springs.

Presoldpol

This scenario was also based on present-day *Quilombola* conditions, but with the older version of FCP implemented. Thus, it is a combination of Newpol and Oldpol scenarios to isolate the policy effects as a counterfactual situation to the Newpol.

Past

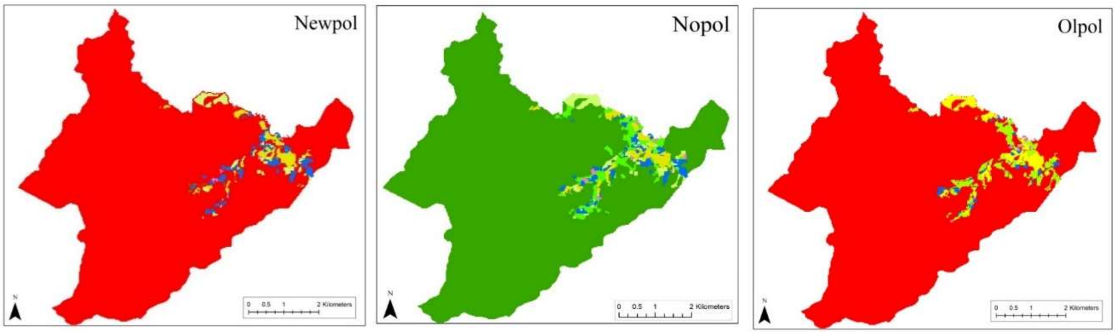
Here the *Quilombola* system was represented under its traditional conditions, before the process of changes started. We used it to compare family welfare and environmental conditions with the present context and represent the lowest level of agricultural intensification or the first stage of the process. We simulated the 1960's situation because we had the 1962 aerial photographs from the community and livelihood information based on ethnographic and oral history methods. Prices and other cash values included were the same as in the present scenarios (of 2014) because it would be tough to find reliable data on the local currency in the 1960s. Moreover, we intended to create a counterfactual situation for the present conditions, and therefore it had to be comparable.

Table 14: Parameters used on the political scenarios and their variation.

VARIABLE	Newpol	Nopol	Oldpol	Presoldpol	Past
First year	2014	2014	2000	2014	1962
Last year	2017	2017	2003	2017	1965
Price year	2014	2014	2000	2014	1962
Land use map	2014	2014	2007	2014	1962
Property map	Present	Present	Present	Present	Past
Cooperative	Present	Present	Absent	Present	Absent
Conservation policy	New version	Absent	Old version	Old version	Absent
Forest extraction	Present	Present	Present	Present	Absent
Market access	Total	Total	Total	Total	Lower (only for rice and pigs)
Perennials production	Present	Present	Present*	Present	Absent
Livestock raising	Present	Present	Present	Present	Assets for the past
Social benefits	Present	Present	Present	Present	Absent

*Perennial assets are represented only by banana plantations in this case; on the others, they are represented by banana and pupunha.

Figure 7 illustrates the soil spatial layer inserted on MPMAS, i.e., the spatial representation of land use under different scenarios. Table 15 shows the proportion of each land use type in each of the presented political scenarios. One should notice that different versions of FCPs block almost the same area, despite their differences, because the great majority of the territory is/was covered by mature/primary forests.



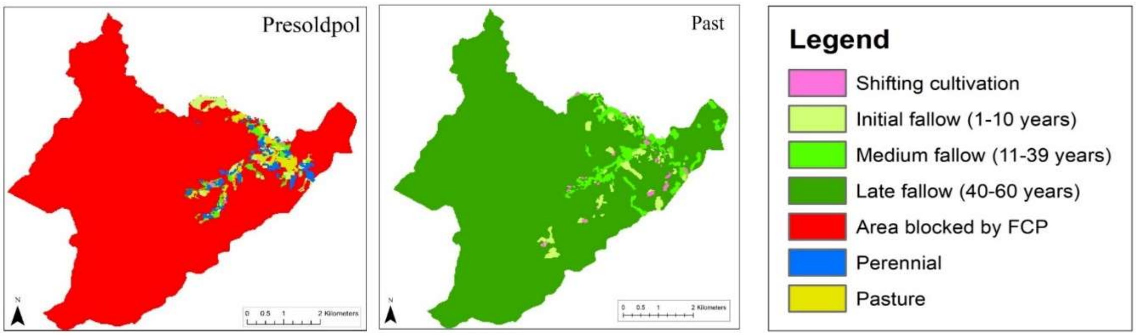


Figure 7: Spatial layers of land use inserted on each of the political scenarios.

Table 15: Proportion of different land use types in each of the political scenarios.

	Newpol (%)	Nopol (%)	Oldpol (%)	Presoldpol (%)	Past (%)
Shifting cultivation	0.12	0.22	0.34	0.13	0.53
Initial fallow	1.18	1.67	2.44	1.52	2.15
Medium fallow	0.06	2.78	0.08	1.17	3.80
Late fallow/Mature forest	0.10	91.73	0.09	0.17	93.52
Blocked by FCP	95.54	0	94.05	93.49	0
Perennial	1.56	1.79	0.58	1.79	0
Pasture	1.44	1.81	2.42	1.74	0

MPMAS Uncertainty/Sensitivity analysis

Large and complex models usually face uncertainty in their structure and parameterization, which will hardly be eliminated and might lead to inaccuracies and errors in their results. Therefore, it is necessary to evaluate model robustness and the conditions under which the study conclusions are adopted. In the present model, I dealt with epistemic uncertainty, which means our knowledge of some of the parameters was incomplete. Therefore it was not possible to find the appropriate value to be fixed in any particular analysis. Consequently, it was impossible to calibrate and validate the model with traditional methods to a single best-performing parameter combination. MPMAS was partially validated because its implemented functions, equations, and models of reference are well established in theories of economics and ecology (Berger and Troost, 2014; Helton et al., 2006). Still, validation procedures are implemented (see Chapter 5).

To deal with the uncertainty, I implemented uncertainty and sensitivity analysis as constituent procedures connected in the same process, complementing each other. When applying uncertainty analysis to a computational model, one intends to estimate how uncertain are the model outputs and the conclusions taken from them. Model results uncertainty is taken as a function of the uncertainty in the input of exogenous parameters. On the other hand, when a sensitivity analysis is used, one identifies the parameters that contribute the most to the model's uncertainty and analyzes them individually to reveal their level of importance and to quantify their impacts on the model's outcomes. This procedure is recommended when uncertainty analysis results are not well defined and vary significantly according to the combination of parameter values. By elucidating the response to the variation of key parameters, sensitivity analysis is very useful in revealing the model's behavior and identifying critical factors. The sensitivity analysis method uses the uncertainty analysis results to investigate the model's response to individual parameters that influence and contribute to its uncertainty (Helton et al., 2006; Troost and Berger, 2015). Both analyses are presented in Chapter 5.

Sobol' sequence method

Several methods are available for implementing the uncertainty analysis, but some can be expensive in labor or computation. Therefore, the MPMAS team suggested the use of a sampling-based method, using representative samples and a probability distribution. We expected to perform a representation of uncertainty and sensitivity with relatively small sample size. We chose Sobol' sequence, a quasi-random sequence to compute variance-based indices, described in Saltelli (2002). The aim was to identify a subset of input variables values to handle most of the variance in the outputs. We estimated the sample size and distributed values in the group of variables. For each model run, a different value within the chosen distributions was used as the input parameter, determining the results' uncertainty and sensitivity to the inputs. Results were presented not as individual values but as a distribution of values originated from different simulations, covering the uncertain parameter space (Oberkampf et al., 2002; Sobol', 1993; Troost and Berger, 2015).

We identified 22 uncertain and uncalibrated parameters, including yield for annuals and perennials, labor provision, hired from outside and labor demanded by agriculture and livestock, costs of investment activities, household demography dynamics, available liquidity and expenditures, food consumption, forest extraction, received governmental benefits, prices for buying food or selling production and livestock weight. We combined parameters over one thousand different samples, of which we chose the first 30 ones. Every political scenario was simulated with the same sequence and combination of uncertain parameters, making it possible to have a fully controlled experiment. Before results analysis, we implemented a convergence analysis to show that after a certain number (presented in the next chapter), the model was not sensitive to adding more repetitions (Berger et al., 2017).

Yield response curves implementation

Yield curves implementation is the third component of scenarios creation. Initially, the uncertainty regarding yield curves could be included as an additional parameter in Sobol' experimental design. However, previous research showed us that fallow age is the critical factor for land use decisions. Thus, crop productivity response to fallow aging is one of the most important dynamics of our model, connecting economic and environmental aspects. This is the reason we decided to isolate yield curves' potential effects from the conventional uncertainty analysis. This procedure made it possible to evaluate how different curve shapes influence agents' decisions in every political scenario and every Sobol' repetition, performing a sensitivity analysis over yield curves.

In general, crop yields productivity depends on various factors such as climatic, physical, ecological, socioeconomic, and cultural ones. In the *Quilombos* territories, the factors varying the most are altitude, slope, aspect (for the irregular topography), and land use history. However, we don't have enough data on yields to estimate how crop fertility responds to the combination of all factors with statistical confidence[28]. Therefore, we compared the implications of different yield curves distilled from the literature on the model outcomes. Mertz (2002) analyzed more than 300 papers to check if there was a positive correlation between fallow age and crop yield. His findings show that there are not enough empirical studies to confirm this relationship due to the complexity of the factors involved and the difficulty in collecting reliable data. No other studies with concluding remarks about the correlation were found, and only one concluded that no significant relationship existed between fallow age and soil fertility (Delang and Li, 2013). Anyway, Mertz (2002) proposed different possible scenarios that can be found on SCSs, as we can see in Figure 8. By combining inflection points ABCD on different levels, different yield curves are found.

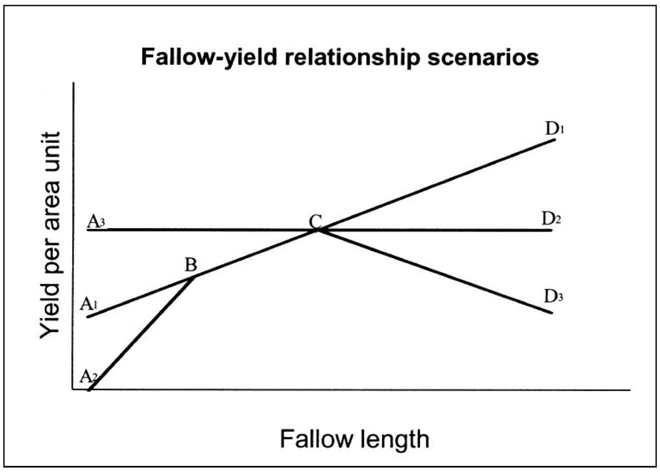


Figure 8: Possible scenarios of the fallow-yields relationship, proposed by Mertz, 2002. ABCD inflection points can have different combinations to produce different curves.

The lack of studies on the correlation between fallow age and crop productivity and the uncertainty it could cause to the model required us to use different yield curves in the simulations, based on the shapes proposed by Mertz (2002). To do so, we combined our data set (from present and former projects) to choose possible curves and establish values for the

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[28] During the time of this research, we tried to model the correlation between fallow age and crop productivity with the use of LUCIA (Land Use Change Impact Assessment tool - https://lucia.uni-hohenheim.de/en). The model was fed with data on chemical and physical soil characteristics, crops physiological information, topography, and climate data. However, specific data on crops and soil were missing, and we could not find the proper conditions to satisfactorily calibrate the model.

inflection points and therefore create production functions for the curves. A1 and A2 were defined for fallow age zero, where A2 was the minimum value obtained from sampled plots. B was defined for fallow age 12 for different yield values. C was determined for 15 years, based on the average of all sample plots. D was defined for fallows with 60 years. D1 refers to the maximum yield value recorded in the field, and D2 is the same as C.

We created a set of seven curves for rice and maize (Table 18), each of them implemented and ran in a different scenario in MPMAS. To facilitate results analyses, the curve shapes of both crops were the same in each scenario (Figure 9).

Table 16: Production functions of rice and maize implemented on different scenarios on MPMAS.

Curve - Shape	Maize	Rice
III - A_2BCD_2	y = 500+(50-500)/(1+(x/14.50917)^62.50291)	y = 825+(82.5-825)/(1+(x/14.78918)^67.50667)
IV - A_2BCD_2	y = 500+(50-500)/(1+(x/11.69042)^36.5584)	y = 825+(82.5-825)/(1+(x/11.31664)^35.46546)
VII - A_1BCD_2	y = 500+(250-500)/(1+(x/14.67163)^62.62994)	y = 825+(412.5-825)/(1+(x/15)^84.26719)
VIII - A_1BCD_2	y =500+(250-500)/(1+(x/12)^46.21639)	y = 825+(412.5-825)/(1+(x/11.53789)^35.30107)
XI - A_1CD_1	y = 250 - 9.761883*x + 1.36607*x^2 - 0.01264879*x^3	y = 412.5 - 16.10714*x + 2.254018*x^2 - 0.02087054*x^3
XII - A_2CD_1	y = 50 + 39.52381*x - 1.044643*x^2 + 0.009672621*x^3	y = 82.5 +58.14275*x – 1.25225*x^2 + 0.01006687*x^3
XIII - A_1CD_1	y = 250 + 19.04762*x - 0.4017855*x^2 + 0.003720235*x^3	y = 412.5 + 27.89275*x - 0.427225*x^2 + 0.003191875*x^3

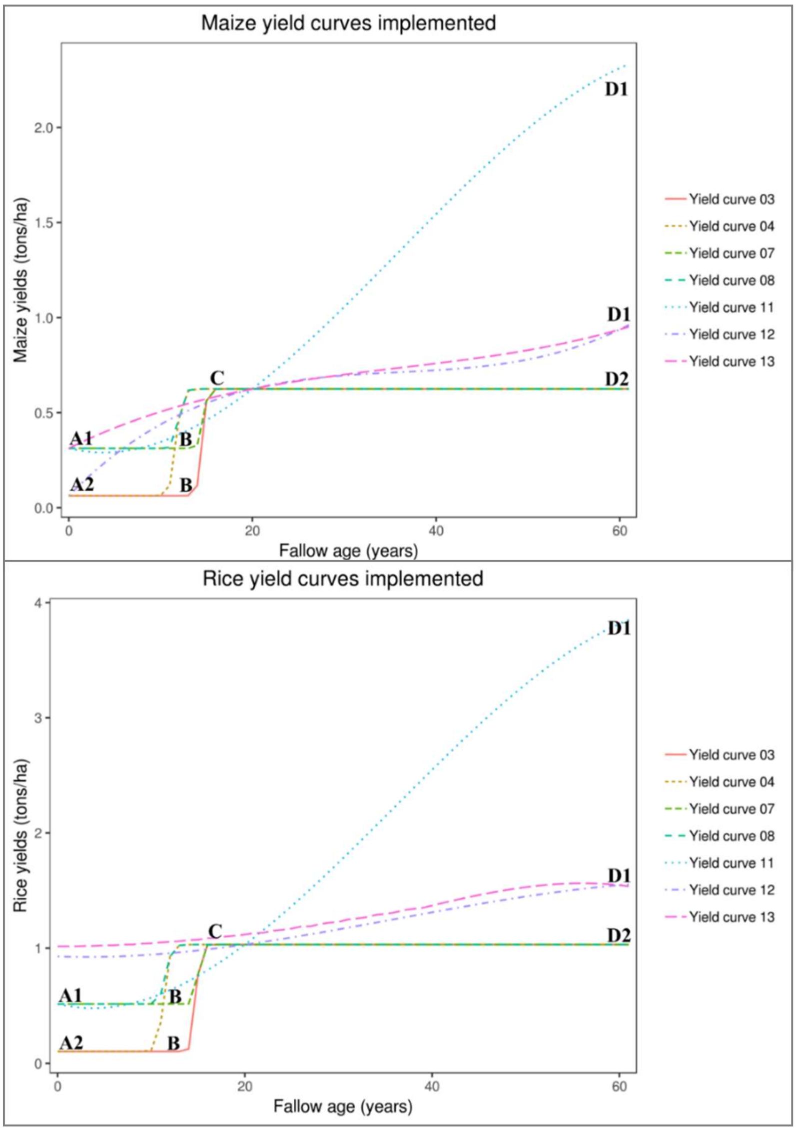

Figure 9: Yield curves implemented on MPMAS simulations for rice and maize.

We tried the same procedure for beans and cassava, but there was not enough data to create the yield curves, so we decided to implement only one yield curve for each crop. Cassava and bean curves follow the shape of A_1BCD_2 and can be visualized in Figure 10.

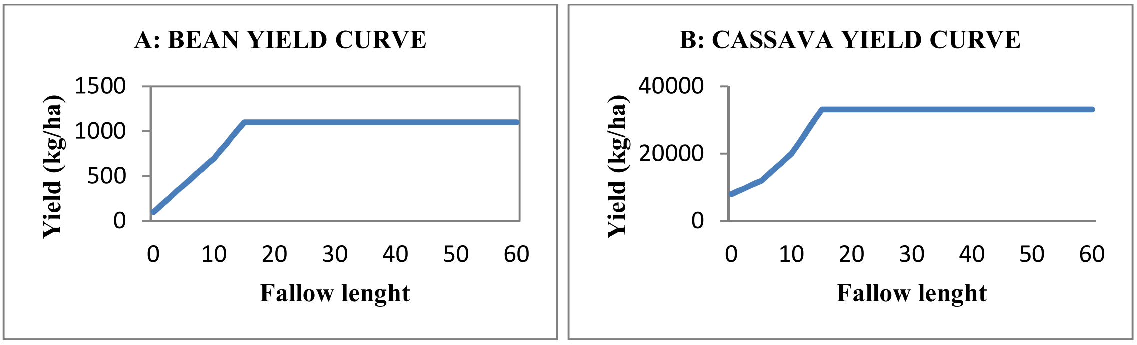

Figure 10: Yield curves implemented for bean (A) and cassava (B).

By combining the three compositions, we performed 1,050 simulations: 5 political * 7 yield curves * 30 Sobol' scenarios. For example, the Newpol scenario is combined to yield curve 03 into Newpolyi03 and combined with all Sobol' repetitions. Therefore, we have Newpolyi03sb01, Newpolyi03sb02, Newpolyi03sb03, Newpolyi03sbn, up to Newpolyi03sb30.

4.II – GDM

β diversity: exploratory analysis and calibration

Spatial dataset

Once the tree community data were collected in the field, I gathered environmental variables that could impact species distribution in the *Quilombola* landscape. I implemented all spatially explicit analyses on ArcGIS®10.2.1 software. Selected variables and their respective sources are presented in Table 17. In total, 33 predictors were chosen for further analysis. Each environmental variable corresponded to an individual spatial layer. Spatial resolution was transformed to 25 meters in all cases (without changing original resolutions), following what was defined for MPMAS. I performed all work under the geographic coordinate system Datum SAD 1969/Zone 22S.

Table 17: Variables used in the GDM exploratory analysis and their respective sources.

Variable	Source
Land use	The production of this map was described above in the "design concepts" section of MPMAS documentation. I also added Pedro Cubas de Cima and São Pedro territories.
Altitude	Provided by Topodata (http://www.dsr.inpe.br/topodata/index.php; INPE, 2008), a national project for constructing a Digital Elevation Model (DEM) for the whole Brazilian territory. The DEM was based on the SRTM mission and delivered by USGS. All layers were gathered with 1 arc-second resolution and later resampled to 25 meters raster dataset (the same procedure described for the Bioclim variables below).
Slope	
Aspect	
Rugosity	This layer was created by overlapping slope and altitude.
Soil types	A spatial layer containing the geomorphologic distribution on *Quilombolas* territory was produced by Ribeiro Filho (2015). The map originated from soil sampling, field observation, literature review, and base maps. The resulting map indicates the distribution of five soil types on the three communities' territories: 1. Litolic Neosols + Cambisol, 2. Cambisol + Gleisol + Fluvic Neossol + Quartzarenic Neossol, 3. Cambisol + Litolic Neosol, Cambisol + Claysol + Latosol, and Litolic Neossol + Cambisol. However, different soil types do not represent a gradient of variation. Therefore, each soil type was designated as one variable, and the grids contained the percentage values of occurrence. This procedure was essential for the grids where more than one soil type was encountered
Distance to mature forest	I used our spatial datasets on land use, and household locations were to create layers representing the geographic distances of any point on the landscape to roads, forests, and houses.
Distance to roads	
Distance to houses	
Distance to rivers	A spatial dataset containing the hydrological distribution was used to create this layer.
BIO1 = Annual Mean Temperature	Bioclim variables: a set of 19 spatial biologically meaningful climatic variables is provided by the WorldClim project (https://www.worldclim.org/bioclim), comprising annual trends, seasonality, and extreme or limiting environmental factors for temperature and precipitation. Unfortunately, the dataset is available at a resolution of 1 km. Nevertheless, I decided to use the Biolcim variables due to their potential impact on species distribution, despite the low resolution, and because they introduced variation in the modeled territory. To create a raster layer with 25 meters for cell size, I implemented a "resampling raster" procedure on the ArcGIS tool, which changes cell sizes from the original layer without changing the dataset extent. The former cells are replaced by a grid of smaller cells containing the same values.
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	
BIO3 = Isothermality (BIO2/BIO7) (* 100)	
BIO4 = Temperature Seasonality (standard deviation *100)	
BIO5 = Max Temperature of Warmest Month	
BIO6 = Min Temperature of Coldest Month	
BIO7 = Temperature Annual Range (BIO5-BIO6)	
BIO8 = Mean Temperature of Wettest Quarter	

Variable	Source
BIO9 = Mean Temperature of Driest Quarter	
BIO10 = Mean Temperature of Warmest Quarter	
BIO11 = Mean Temperature of Coldest Quarter	
BIO12 = Annual Precipitation	
BIO13 = Precipitation of Wettest Month	
BIO14 = Precipitation of Driest Month	
BIO15 = Precipitation Seasonality (Coefficient of Variation)	
BIO16 = Precipitation of Wettest Quarter	
BIO17 = Precipitation of Driest Quarter	
BIO18 = Precipitation of Warmest Quarter	
BIO19 = Precipitation of Coldest Quarter	

Species representation

The first step of botanical data analysis was to spatially represent tree positions, combining the presence/absence information with the different spatial biophysical layers for further modeling exercises. The analysis considered the methods applied for collecting data in the field and the desired spatial scale used by the other modeling tools. A dataset with spatial information collected for each of the 19 species was produced, indicating the pixels where they occurred (Figure 11). Next, I plotted each tree individually in the actual transects and transect subdivisions where I encountered them. Finally, I overlapped this tree position layer with the pixels' web of the other spatial layers. Each pixel where an individual tree was found had its presence marked, despite the number of individuals found in the field. In other words, species abundance was not considered. In total, 310 grids of the landscape registered at least one individual of the 19 species. This tree positioning layer was used in all subsequent analyses.

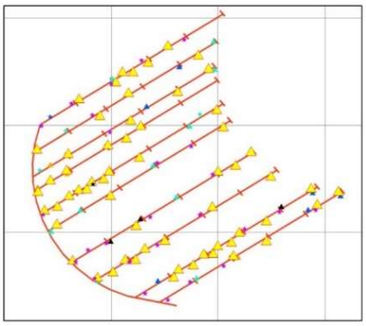

Figure 11: Representation of the investigated fallow areas, showing the transects and tree species individuals.

Variables in the model

First, I applied a Principal Component Analysis (PCA) to the tree community dataset (without the environmental variables), a multivariate technique that transforms a set of observed variables into orthogonal variables, the principal components. Through PCA, one intends to find combinations of correlated parameters to describe most of the variation in the dataset. The first principal component is the one that shows the most extensive possible variance in the dataset, followed subsequently by the component with the second-largest variation, and so on. By transforming data into a new cartesian coordinate system (X*Y), PCA enables the visualization of the patterns of similarity of all environmental variables (through their position and variance) (Einasto et al., 2011). PCA was implemented using the *vegan* package[29] on R software[30].

Next, I applied a Detrended Correspondence Analysis (DCA), a multivariate ordination technique that can be considered an indirect gradient analysis, to deduce which environmental gradients can be based on the species composition datasets created here. Rare species were down-weighted to dampen their effect on the ordination. With DCA, species and site ordination are provided in known units (standard deviation), enabling their direct interpretation of ecological turnover. Therefore, by evaluating species and site scores/graphical position and applying prior knowledge on species ecological characteristics, one can infer the environmental meaning of the axes and define the ecological space

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[29] Vegan package, version 2.5-4.

[30] RStudio: Version 1.1.463 – © 2009-2018 RStudio, Inc.

delimited by them. Furthermore, DCA can reduce the arch effect by rescaling the axes and decompressing the gradient extremes (Correa-Metrio et al., 2014). It was implemented to the ensemble of 19 species in each plot (exclusively on the grids where data was collected) and across transects. The DCA analysis was performed with the *vegan* package on R software.

Next, I implemented Spearman's correlation test to eliminate repetitive environmental information and reduce the number of variables used on GDM. It is a nonparametric rank statistic for measuring association strength between the predictors. It does not measure linear relationships between variables, but it verifies how well an arbitrary monotonic function can describe such a relationship (Hauke and Kossowski, 2011). This analysis calculated the pair-wise coefficients of linear correlation among all groups of variables, ranging from -1 (perfect anticorrelation) to +1 (perfect correlation), where zero indicates the absence of correlations. The cutting value I established for determining a strong correlation/anti-correlation was $\tau = 0.75$. Finally, I applied the test to the grids and the whole landscape. Together with PCA and DCA, results are shown in Appendix B.

After following these steps, I found correlations and the importance of variables for the dataset and decided which were the most appropriate environmental predictors to generate the GDM. Land use was one of the most crucial predictor layers in this study. It intensely determined the composition of the chosen species since they are indicators of the fallow chronosequence. More than that, land use was the main link between MPMAS and GDM. The slope was a factor with significant variation in the studied region, together with altitude and aspect. It was correlated to distance to rivers in the whole territory PCA, which was expected as the flatter areas are closer to the main rivers. Still, it also was determinant to the distribution of tree species. I chose distance to mature forests because these habitats are the only source of seedlings for many tree species, despite the fact it is correlated to land use in Spearman's analysis (not in PCA). Rivers were chosen because they can be essential plant dispersers but also restrict trees distribution. Distance to houses was selected because I deal with an anthropogenic landscape, and many tree species are being managed. Distance to houses and land use are correlated in the PCA implemented over the whole territory, which could be expected since the distant areas usually suffer less anthropic pressure, so they were kept in the GDM. Distance to houses, distance to mature forest patches, and soil type CAL are correlated in the PCA implemented over the grids, typically indicating areas under management and represented a small portion of the territory. Finally, Bioclim variables 4, 16, and 17 were chosen, even though Spearman's correlation was found only between 4 (temperature seasonality) and 17 (precipitation of driest quarter) for the whole territory. Variable 16 (precipitation of wettest quarter) was kept because it is related to temperature, and variable 17 representing different environmental factors.

GDM calibration

GDM calibration included calculating compositional dissimilarity between all pairs of sites, deriving flexible I-spline functions for all environmental predictors (and geographical distance), calculating the difference in value between sites, and fitting coefficients with maximum likelihood estimation. Next, the environmental space was transformed, keeping a flexible shape, providing the best supported relationship between environmental/geographical separation and compositional dissimilarity. Finally, the model could be used to predict compositional turnover (ß diversity) across locations lacking biological data (Ferrier et al., 2007; Fitzpatrick et al., 2013). All steps described here were implemented on R software[31].

Initially, a dataset containing species presence only (site-by-species matrix) was read into the model together with their geographical position. In parallel, each of the chosen environmental predictors was combined into a raster stack. Then, the model was ready to calculate compositional dissimilarity between any two pairs of cells by combining the matrix with the biological response, environmental predictors, geographical distance and fitting them to a site-pair table. First, dissimilarity was calculated with the Bray-Curtis index. Next, the table was transformed into a GDM model object. The object provides the I-spline turnover function for each predictor while holding the other predictors constant. The plotted splines indicate the magnitude of compositional turnover associated with the variable, while others are constant (Figure 12). Those values can be interpreted as the importance of each variable

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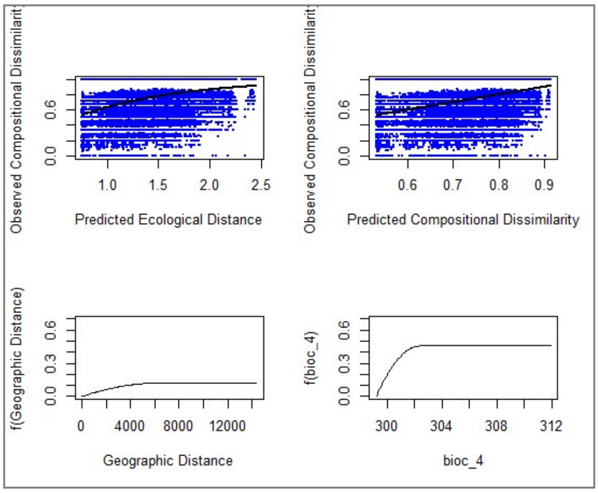
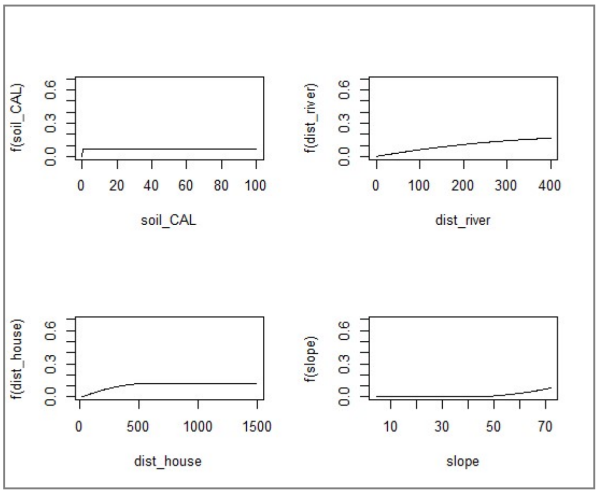
[31] GDM procedures required the use of packages *gdm* (version 1.3.11), *raster* (version 2.8-9) and *rgdal* (version 1.4-3).

in determining ß diversity patterns. Additionally, the spline's shape indicates the rate of species turnover and how the variation occurs at any point of the gradient, and where these changes are most pronounced (Fitzpatrick et al., 2013; Fitzpatrick and Keller, 2015).





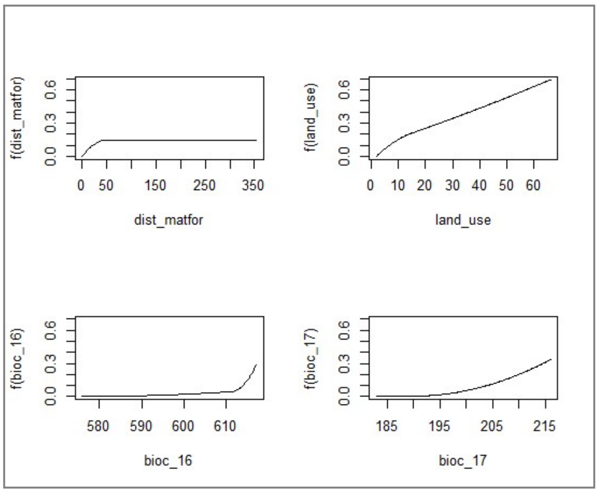


Figure 12: I-splines produced for each environmental predictor applied to the GDM.

The variable that obtained the highest I-spline value was land use (more than 0.6), followed by Bioclim 4 (Temperature Seasonality; 0,4). Land use gradient was constantly causing changes in the community, while Bioclim 4 reached its peak at the beginning of the gradient and remained constant. The variables that showed less influence over ß diversity were slope, which had a minor impact only at the end of the gradient, soil CAL and distance to houses, which showed a constant value of 0.1 from the beginning of the gradient. From the model object, I obtained the percentage of null deviance in turnover explained by the fitted GDM model. I also obtained values for variable importance (as the percent change in deviance explained by the full model) and variable significance (explained by a model fit with that variable permuted), as shown in Table 18.

Table 18: Values provided by the variable importance and significance.

Variable	Variable importance	Variable significance
Land use	28.36	0
Bioclim 4	8.69	0
Bioclim 17	2.86	0.02
Bioclim 16	2.841	0.04
Distance to mature forest	2.64	0.12
Distance to rivers	1.41	0.14
Distance to houses	0.82	0.2

Variable	Variable importance	Variable significance
Geographic	0.5	0
Slope	0.27	0.42
Soil CAL	0.19	0.4
Model deviance	16301.34	
Percent deviance explained	9.05	

4.III – Simulated land use

Integrating models through maps

Output maps of simulated land use produced by MPMAS were the primary linkage between the two models implemented in this research. Those maps were inserted on the last step of the GDM analysis when biological dissimilarities between the simulated scenario and the *Quilombola* landscape is predicted. Among all environmental predictors implemented on the GDM, I will update only the distance to mature forest from the land use map as the landscape structure changes. Figure 13 illustrates the different spatial layers used by each model and the connection between them.

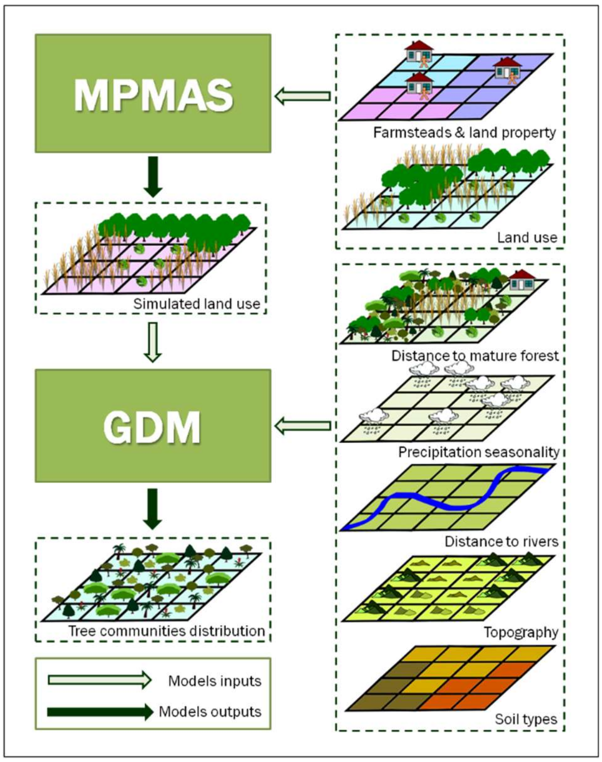


Figure 13: Diagram of the integration of MPMAS and GDM models through the use of spatial layers.

However, each of the five political scenarios produced one map for every Sobol' repetition, multiplied by the seven yield curves (1050 output maps). To avoid the laborious task of running GDM many times, the first challenge was to find a method to evaluate and group similar resulting maps, producing few combined maps to insert in the GDM model. This group of maps should reflect the variations produced by the uncertain parameter space modeled in MPMAS. A k-means cluster method was implemented, where the Silhouette index defined the number of clusters. This index indicates how well matched the object is to its group and how poorly matched it is to the other groups. The higher the average width, the better the number of clusters that fits the objects. I provided the cluster analysis of the range of groups from two to nine to choose the one with the best silhouette value. Next, I used the resulting individual output map (with the higher silhouette width value within each cluster) for the GDM analyses. As a result, I reduced the number of resulting maps processed in Step IV methods in the next chapter. The k-means cluster was run on R software, with the assistance of packages *cluster* (version 2.0.7-1) and *factoextra* (version 1.0.5). Output maps were processed with the *raster* package.

Chapter 5 – Study site and models behavior

This chapter presents a more detailed description of the Atlantic Forest ecosystem, where *Quilombola* communities are situated. Then, I describe the community of Pedro Cubas, where the modeling parameters were collected for this research project, and present the results from an exploratory data analysis. I finish by describing the models' behavior results, including MPMAS validation and sensitivity analysis and GDM's biological space.

5.I – Socioenvironmental context

Atlantic Forest

The Atlantic Forest is distributed along the eastern coast of South America, extending from 4° to 32°S and covering more than 1.5 million km^2, including Brazil, Paraguay, and Argentina. By spanning tropical and subtropical latitudes and different topographical and climatic conditions, it exhibits a significant heterogeneity of habitats, allowing high biological richness and diversity and strong seasonality. The varied environmental gradients make this biome one of the most biodiverse globally, with higher plant diversity than most Amazonian forests (Joly et al., 2014; Ribeiro et al., 2009; Tabarelli, 2010).

Another impressive characteristic of the Atlantic Forest is its very high levels of endemism (more than 8,000 species), including 40% of its vascular flora and 16–60% of its bird, mammal, reptile, and amphibian species. At the macro level, the combination of rainfall and temperature is recognized as the main factor defining tree species distribution. It is also a great source of environmental services, such as water provision for more than 100 million Brazilians, seasonal rainfall distribution, food provision, and soil stability on steep slopes (Joly et al., 2014; Tabarelli, 2010).

The high levels of fragmentation faced by the Atlantic Forest impose a big challenge for Conservation Biology and threaten present and future extinction of many species, putting it on the top list of global priority conservation hotspots (Joly et al., 2014; Rodrigues et al., 2009). Moreover, only 2.6% of its remnants are protected under FPAs, 80% of the fragments are not larger than 50 ha. Most of them are isolated in open-habitat matrices of agriculture or pastures (Sobral-Souza, 2018). For that reason, Joly et al. (2014) reinforce the importance of fragments connectivity through biological corridors and stepping stones for enabling the biological flux. In the scientists' research agendas, it is crucial to address the forest response to human disturbances and economic instruments to reach sustainability.

The *Quilombo* modeled community: Pedro Cubas

History

Pedro Cubas shares a similar history with the neighboring communities regarding territory occupation and later reduction in isolation and agricultural intensification. The first record of inhabitants is related to fugitive enslaved escaping from a gold mining farm in the region between 1849 and 1856. In the first decades of the agricultural transitional process (the 1950s), the road access improvement allowed the arrival of new actors, who settled by violent means. They established banana and rice production and cattle ranching, relying on local farmers' families' labor. Conflicts with land-grabbers resulted in the expulsion of local leaders from Pedro Cubas in 1987. These families returned in the 1990s, when the official recognition of the *Quilombo* territory process started, culminating in its legal recognition in 1998 and land titling in 2003 (Futemma et al., 2015).

Pedro Cubas has a territory of 3,806.23 ha in the rural area of Eldorado municipality. To reach the community, one has to drive 34 km from the urban area, cross a ferry boat across the Ribeira de Iguape river and drive an additional 14 km of unpaved road. In 2014, Pedro Cubas was composed of 52 households with 185 inhabitants.

Landscape structure

Pedro Cubas' land use and land cover for the year 2014 were already described in Chapter 4. Newpol scenario spatial layer represents the land use, and Nopol characterizes land cover. Table 19 shows the proportion of every land use/land cover type.

Table 19: Proportion (%) of different land use types in each political scenario in 2014.

	Newpol (%)	Nopol (%)
Shifting cultivation	0.12	0.12
Initial fallow	1.18	1.67
Medium fallow	0.06	2.78
Late fallow/Mature forest	0.10	92.43
Blocked by FCP	95.54	0
Perennial	1.56	1.56
Pasture	1.44	1.44

I performed landscape metrics measurements of each of the classes in the territory of Pedro Cubas in 2014. We calculated the number of patches, the total area, and the average size of patches for each class (Table 20).

Table 20: Pedro Cubas' landscape structure in 2014.

Fallow age	Total Patches	Total Area	Average patches size
Area under use	21	135.25	6.44
Initial Fallow (1-10 years)	22	49.88	3.18
Intermediate Fallow (11-40 years)	64	101.06	1.81
Late Fallow (41-60 years)	4	11.56	2.35
Mature Forest (>60 years)	3	3,506.81	1,168.94

The great majority of the territory was under mature or pristine forest cover, followed by intermediate fallow. This coverage indicates a vast area that won't be available for agriculture, according to the actual FCP. With approximately 50 ha of initial fallow, there was less than one hectare available for each family to implement SCS if the land was shared equally.

Exploratory analysis: evaluating the census results

The analysis of the census results complements the evaluation of the MPMAS robustness (together with uncertainty and sensitivity analyses) and provides remarks for the validation procedures. We started by developing a combination of cluster and correlation analyses, followed by an investigation of the land use changes in the agents' group between 2007 and 2014. The goal was to characterize the agents' population and the distribution of variables among agents by searching for typical aggregations.

Table 21 shows the first description of the households/agents and the variation found on the dataset among the population. I considered age and gender groups, retired and employed household members, members benefited by cash transfer programs, land property, areas dedicated to each land use type, liquidity, and the producers' organization members.

Table 21: Variation of the dataset of the agents' population.

	Land Assets						
	Annual crops (ha)	Banana (ha)	Pupunha (ha)	Young Fallow (ha)	Old Fallow (ha)	**Liquidity** (Reais – R$)	
2007	0 – 1.5	0 – 4.75	0 – 0.94	0 – 17.94	0 – 27.13	-5,810 to 67,130	
2014	0 – 2.63	0 – 4.75	0 – 6.63	0 – 31.25	0 – 28.43		
	Livestock Assets						
	Chicken	Pork	Cattle				
2014	0 – 52	0 – 11	0 – 18				
	Population						
	Boys	Girls	Man	Woman	Retired Man	Retired Woman	Agents with benefits
2014	0 – 3	0 – 3	0 – 5	0 – 3	0 – 2	0 – 1	0 – 6

Cluster analysis

Four different cluster tests were applied to the agent's database (K means, Enhanced Hierarchical Cluster (EHC), PAM clustering, and Ward Hierarchical Cluster), with different numbers of agents' groups (4 to 9). To validate the results, I used three algorithms: Silhouette, Dunn, and Davies-Bouldin. EHC with four groups reached the best results (Fig 14).

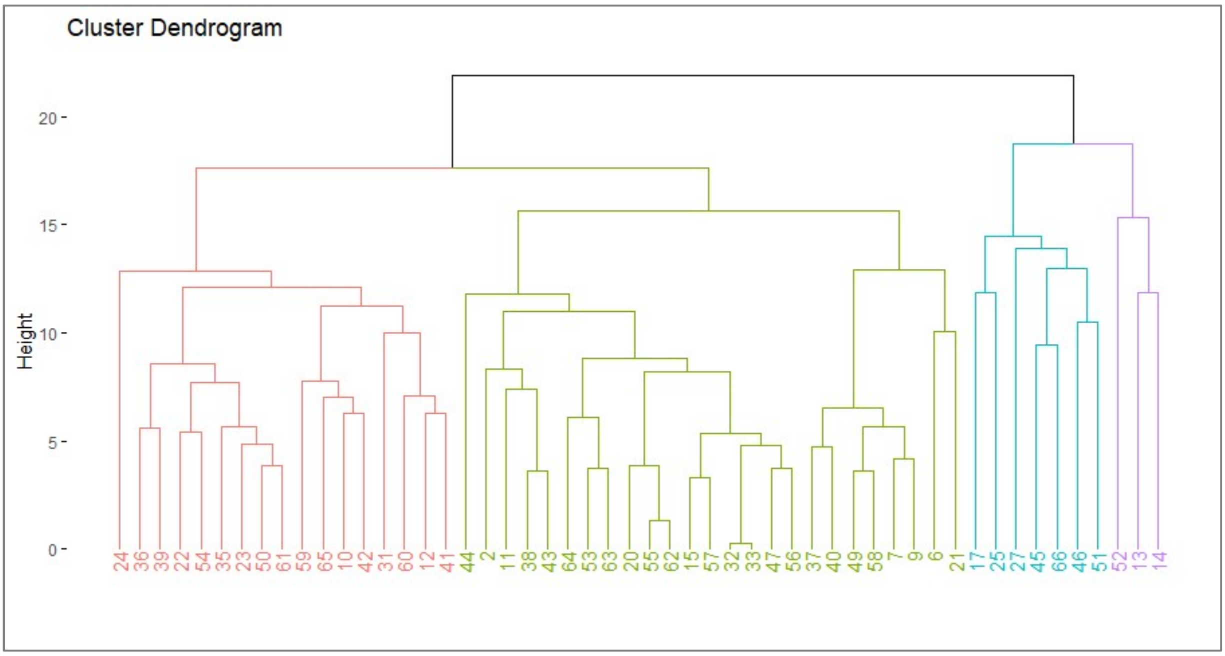


Figure 14: EHC cluster analysis for four groups of agents.

Even though this was the best option, the clustering configuration was not entirely satisfactory (groups are compact with a slight variance between members). Therefore, it did not lead us to any decisive conclusions about the agents' population. However, it was still possible to find some level of specificity in different groups. The purple group, with three agents, showed average liquidity, owned young and old fallow areas in 2014, produced banana in 2007 and 2014, and were considered good farmers by others. The blue group, with seven agents, owned old fallow and perennial plots in 2007 and 2014 and presented high liquidity values. The green group, with 25 agents, owned small land properties, were not classified as good farmers by others, had low liquidity, and did not produce staples or perennials. Finally, the red group with 17 agents did not grow perennials in 2007 but produced them in 2014 and had babies and benefits from the government.

<u>Correlations</u>

I run the correlation analysis for combinations of all variables used for cluster analysis. Results showed that the area used for pupunha in 2014 is positively correlated to the area for SC in 2014. Those who are available for perennials are also available for annuals.

The area dedicated to banana production in 2007 was correlated to young fallow areas in the same period; this could indicate that farmers planting staple crops in the 2000s decided to change to banana as a cash crop. The young fallow areas for both years are inversely correlated. The agents who had larger young fallows in 2014 had smaller old fallows in the same period. Probably when the agent is not working with agriculture, he owns old fallows plots only. When active, he has only young fallows remaining.

Unfortunately, no correlations were found among the population and economic dimensions of the assemblage of agents, suggesting the impossibility of creating definite groups of agents with cluster analysis. Moreover, it prevents any modeling effort of such a relationship.

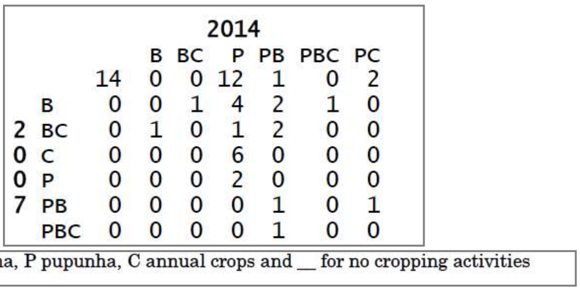
Analysis of shifts in land use

The analysis of shifts attempts to perceive processes of land use change occurring in the last decade. It includes the total number of agents changing from one land use to another between 2007 and 2014 (Table 22).

Table 22: Total number of agents enrolled in different land uses in different periods (N=52).

	Land use	Nº of agents
2007	Annual crops	11
	Banana	15
	Pupunha	5
	Young fallow	26
	Old fallow	48
2014	Annual crops	4
	Banana	10
	Pupunha	36
	Young fallow	37
	Old fallow	45

The number of agents enrolled in producing annual crops, and banana plots diminished substantially in the seven years, while the opposite happened with pupunha. Most agents preferred perennials cash crops to staple crops in both periods. Figure 15 shows there was a complete shift among agents growing annuals in 2007 and 2014. Additionally, it shows that all agents working with agriculture in 2007 were still engaged in 2014, and 15 households who were not farming in 2007 were growing pupunha in 2014 (P=12), some engaging with banana (PB=1), others with annuals (PC=2). Unlike in 2007, farmers who were cropping annuals in 2014 were also growing perennials (C appears only as PC, BC, or PBC in 2014).



```
                   2014
             B  BC   P  PB  PBC  PC
        14   0   0  12   1    0   2
  B      0   0   1   4   2    1   0
2 BC     0   1   0   1   2    0   0
0 C      0   0   0   6   0    0   0
0 P      0   0   0   2   0    0   0
7 PB     0   0   0   0   1    0   1
  PBC    0   0   0   0   1    0   0
```

**For B banana, P pupunha, C annual crops and __ for no cropping activities

Figure 15: Analysis of the shift of land uses between the years 2007 and 2014.

Comparing the amount of land under different land uses by each agent in 2007 and 2014 (Figures 16) shows that those who had crops did not have young fallow areas in 2014, a different situation from 2007. These results can be explained by the hiatus on SCS between the years 2006 and 2013. Possibly young fallow areas in 2007 became old in 2014. This assumption can be sustained by summing up fallow areas of both periods:

- Young fallows: 2007 = 117 ha; 2014 = 77 ha;
- Old fallows: 2007 = 165 ha; 2014 = 205 ha.

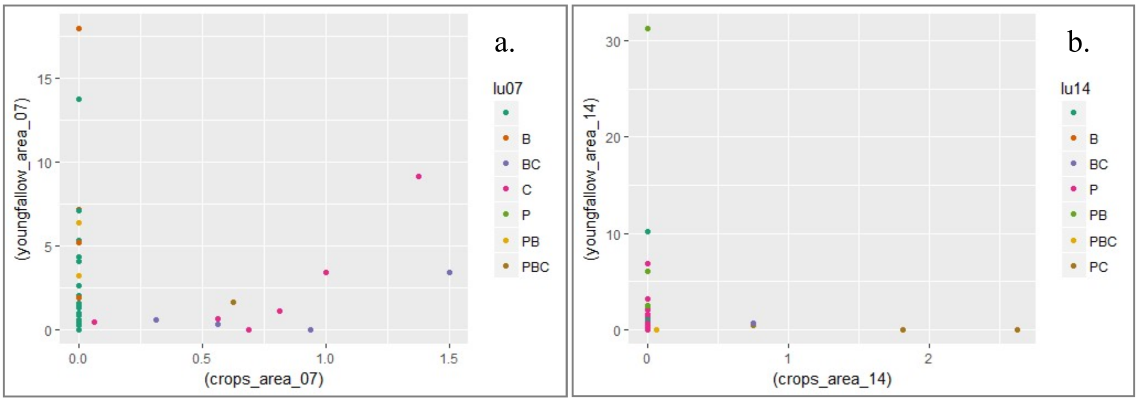


Figure 16: Amount of young fallow and crops area, by agent, in 2007 (a) and 2014 (b).

Discussion

I could find variation among the types of individuals in each household but no correlations among them. Additionally, liquidity values were not correlated to any other variable, such as livestock or the classification as a good farmer by peers. During the period analyzed, there were not many agents farming staples, making it challenging to find the particular economic dimension that could influence this. I can only affirm that in 2014 the group of factors was constraining staple/annual crop cultivation. These different dimensions significantly impact the decision-making processes over land use, but they are not directly connected to observable characteristics. In other words, the presence of varied dimensions is a confounding factor.

The analysis of shifts in land showed that a transitioning system is being represented, where adoption and diffusion of pupunha are prominent. From this perspective, the model should reflect the attractiveness of pupunha as a cash crop. Finally, the small size of the sample (although it represents the whole community) should be considered a factor that is preventing an accurate model calibration.

Concerning the calibration and the validation of the model, I conclude that taking up cultivation after a hiatus of seven years may be similar to innovation, even when connected to former tradition. People may be reluctant and wait, observe the results of others and the policy environment stability. Perennials production is a fundamental aspect of the system. I hope its validation is within reasonable limits, but SC will still be considered because of its importance, and it can reveal scenarios differences. There is little to no data to calibrate/validate the production decision for other crops. Unobserved factors (e.g., preference for tradition, connection to NGO, socio-cultural identification as *Quilombola,* and farming skills) are likely to influence whether SC is carried out. Traditional calibration/validation methods may be misleading when using a primarily economic model. Finally, we are in an ex-ante, out-of-sample, and counterfactual situation. The quality of the model has to rely on good input data, testing the sensitivity of results against uncertainties, and some rudimentary plausibility tests.

5.II – Processing models outputs

MPMAS convergence analysis

After running all scenarios, the convergence analysis of cumulative averaged results was the first to be implemented to prove that the number of Sobol' sequence repetitions was sufficient to cover the effect of input uncertainty on the model's results. This was confirmed by checking whether the relevant model outputs converged at some point over the repetitions simulated and that one thousand repetitions would be unnecessary.

Convergence was tested for the following outputs: agents' income; the area dedicated to SCS, perennials, and fallow; the number of forest extraction excursions; cooperative membership; and the number of livestock heads. Mean values and confidence intervals were calculated. Outputs were considered for each yield curve of each political scenario. A different convergence analysis was implemented to compare the baseline and the other four political scenarios for the same outputs. All analyses were run on R software[32]. The convergence of differences in the outputs was reached with 30 Sobol' repetitions, meaning that running more than 30 repetitions would not pay for its effort (Berger et al., 2017). Convergence results are presented in Appendix D; some examples are shown in Figure 17. Analysis scripts files were attached to the Thesis.

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[32] Plots were produced with the assistance of packages *ggplot2* (version 3.1.0) and *scales* (version 1.0.0)

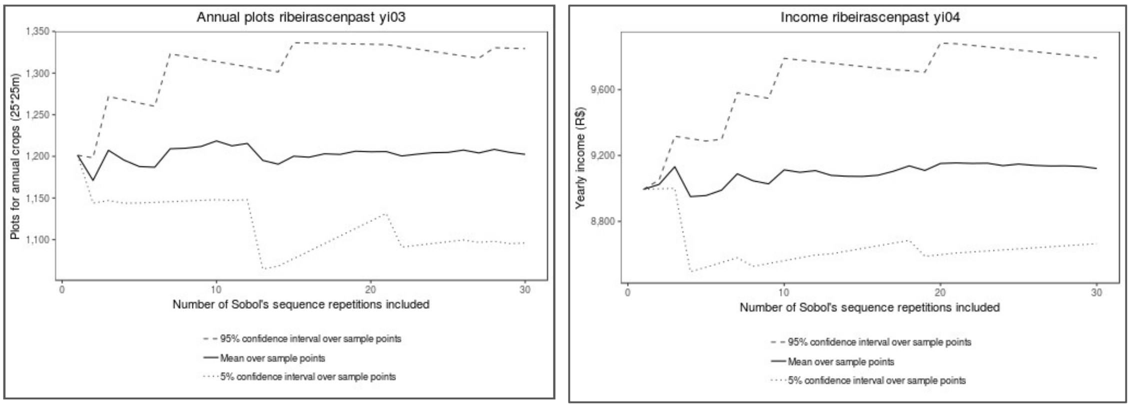


Figure 17: Example of the convergence analysis. Each graph shows one yield curve in every political scenario and the convergence of all Sobol' repetitions.

Next, different MPMAS output types were analyzed to enable political scenarios comparison under a counterfactual analysis style. This analysis was based on comparing the represented current *Quilombola* context (Newpol) and counterfactual situations for market access, FCPs, or other characteristics. I compared Newpol with the Past and Oldpol scenarios to evaluate the impact of agriculture intensification on family economic wealth and the forest landscape. The effects of FCPs on local livelihood and the landscape was assessed by comparing the Newpol, Presoldpol, and Nopol scenarios. Results analysis follows the same structure of convergence analysis. Because an uncertainty and sensitivity analysis were implemented, all MPMS results were presented as the average of the full range of Sobol' repetitions results for each political scenario, for each yield curve.

Uncertainty and sensitivity analysis results

Uncertainty/sensitivity analysis of MPMAS results is complementary here. Model responses to yield curves and to parameters variation in Sobol' repetitions are presented.

Yield curves

MPMAS outputs from the Newpol scenario were analyzed. All yield curves plots can be seen in Appendix E. Crops were produced in higher amounts on yield curve scenarios 07, 08, and 13 (Figure 18). These scenarios present higher productivity in the early fallow stages (0 to 5 years of fallow). This was an expected dynamic in the model because FCPs block later successional stages plots. Therefore, yield curves with higher productivity in the later stages did not stimulate annuals production as much.

Crop productivity impacts different aspects of the system, from crop consumption, levels of engagement to SC in the community, and landscape structure. Scenarios with higher staples production dedicate larger areas to SC (Figure 19). When the space devoted to annuals is larger (orange), the area under the initial fallow is smaller (beige).

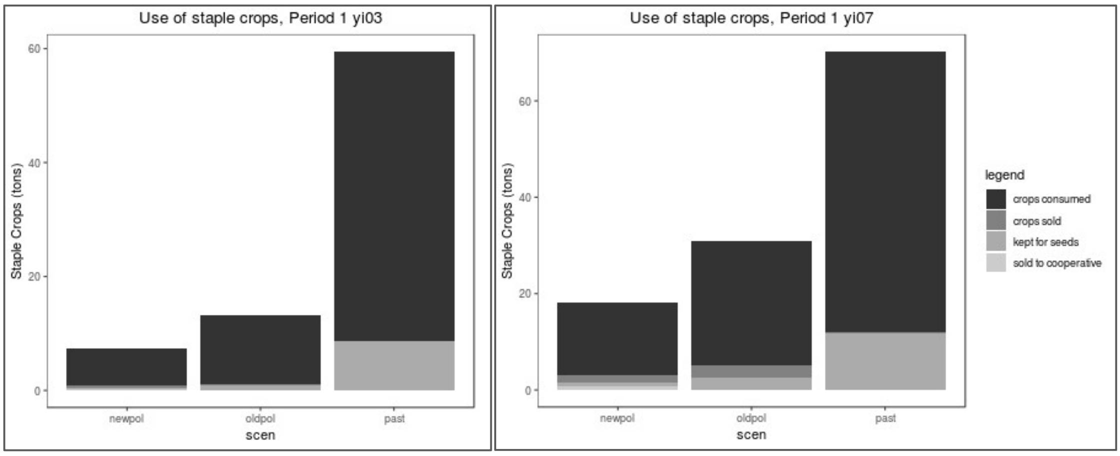


Figure 18: Samples of variation in staples consumption.

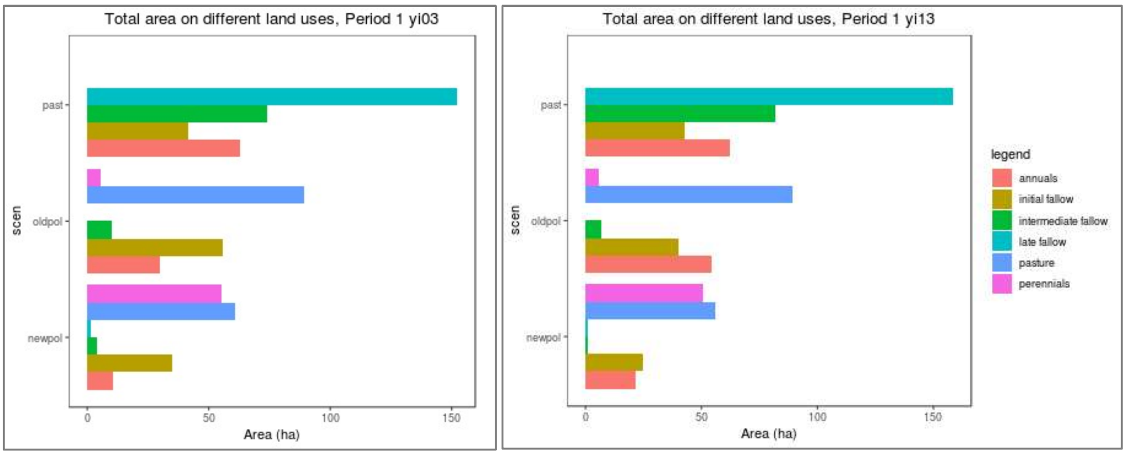


Figure 19: Samples of variation in land use types.

Consequently, the share of own staples consumed also varies between the yield curves, and the higher production scenarios are the ones to consume higher amounts of staples (Table 23). However, they are not the scenarios to consume more; the absence of production is compensated by the food from the market.

Table 23: Amount of food (tons/year) consumed by all agents, per yield curve.

Yield	Food bought	Own food consumed	Total
yi03	85.09	11.04	96.13
yi04	77.99	9.67	87.66
yi07	68.75	19.33	88.08
yi08	62.25	17.42	79.67
yi11	61.75	18.06	79.81
yi12	81.76	12.21	93.97
yi13	68.26	20.04	88.3

Also, yield curves 03, 04, and 12 have fewer agents engaged in shifting cultivation than the other curves (Table 24).

Table 24: Simulation results for the total number of agents engaged in SC.

Period	yi03	yi04	yi07	yi08	yi11	yi12	yi13
1	29	26	34	34	34	31	34

For each yield curve scenario, Sobol' repetition results were averaged.

Plots for the community average income and individual income did not differ for yield variation (Figure 20). Consequently, no differences were found for the economic class tests, headcount ratio, and poverty position evaluation, as they are all based on income.

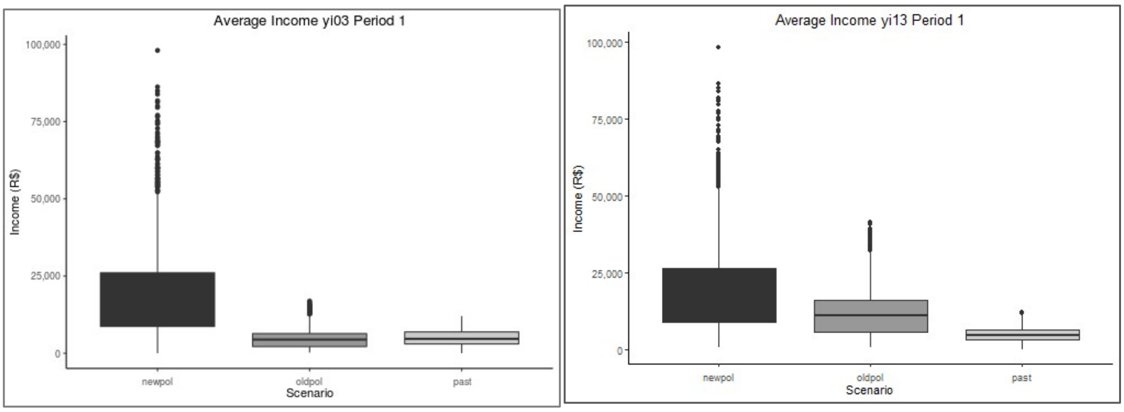
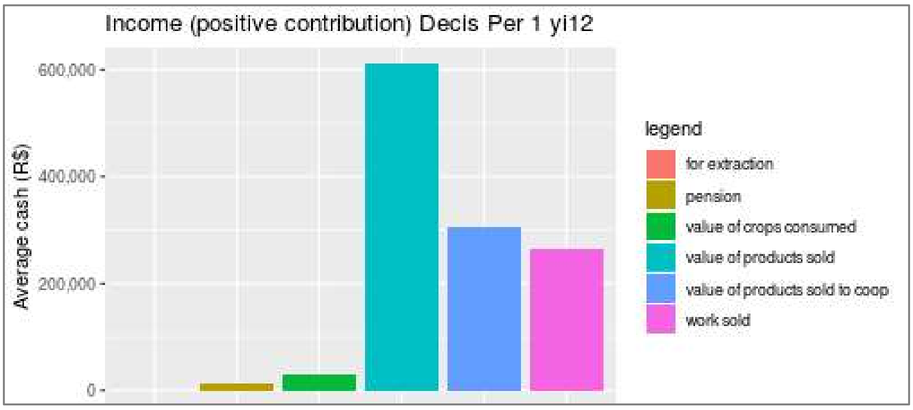


Figure 20: Average community income, yield curve 03 on the left and yield curve 13 on the right.

The comparison of household income composition between yield curves 12 and 13 – scenarios with lower and higher staples production, respectively – shows that the lower contribution to income from consumption, in green, is compensated by higher acquisition from farm product sales, in blue (Figure 21).



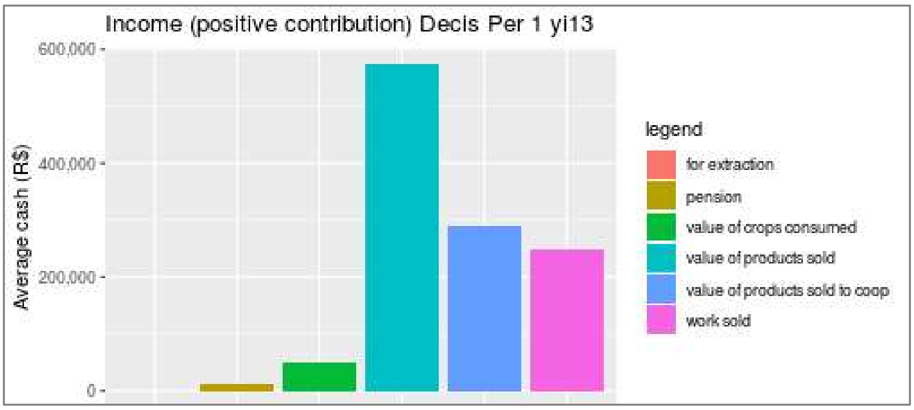
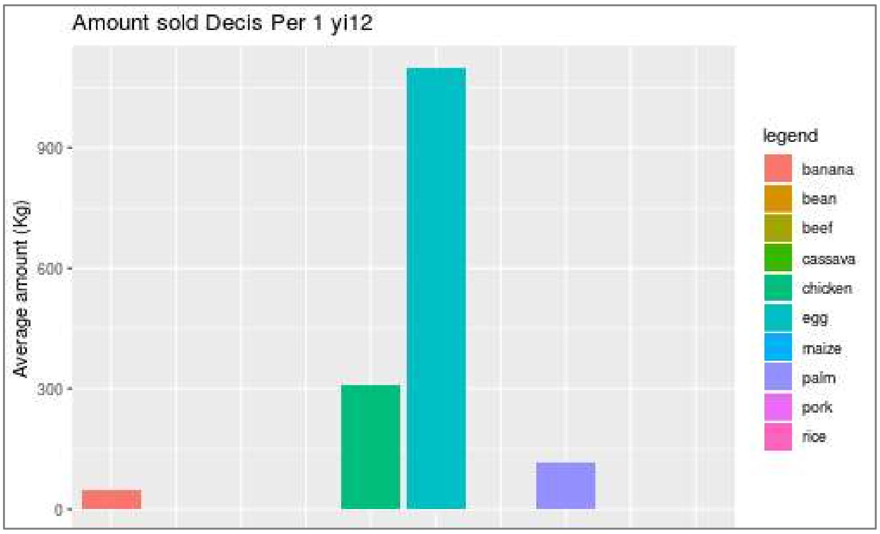


Figure 21: Samples of variation in income composition.

To investigate a little deeper, farm product sales were depicted. Figure 22 shows that sales of chicken products are higher in the less productive scenarios.



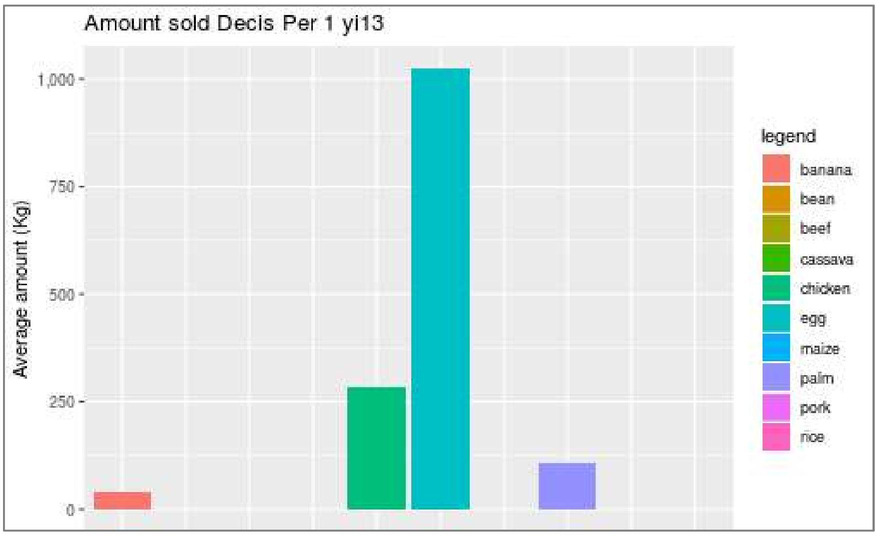


Figure 22: Depiction of farm products sold.

<u>Sobol' repetitions</u>

Multiple linear regression was performed on MPMAS Newpol scenarios outputs. The regression tests were implemented over all the uncertain parameters used in the Sobol' sequence method at once (Table 25). Staples consumption, production, and income outputs presented some level of sensitivity to parameters variation. Perennials production did not.

Table 25: Multiple linear regression results, implemented over MPMAS outputs and uncertain parameters, from Newpol scenarios yield curve 04.

Output	Residual standard error	Multiple R-squared	Adjusted R-squared	F-statistic:	p-value:
Staples consumption	0.5783 on 7 degrees of freedom	0.9193	0.6656	3.624 on 22 and 7 DF	0.04321
	Parameter	Estimate	Std. Error	t value	Pr(>|t|)
	Annuals Yield	1.124	2.347e-01	4.79	0.00199 **
Annuals area	0.6778 on 7 degrees of freedom	0.8891	0.5406	2.551 on 22 and 7 DF	0.103
	Parameter	Estimate	Std. Error	t value	Pr(>|t|)
	Annuals Yield	1.38	2.750e-01	5.03	0.00151 **
Income	0.05379 on 7 degrees of freedom	0.9993	0.9971	455.3 on 22 and 7 DF	4.898e-09
	Parameter	Estimate	Std. Error	t value	Pr(>|t|)

Prices for buying or selling staples	-8.928e-02	1.237e-02	-7.218	0.000175***
Staples consumption	-9.254e-02	2.063e-02	-4.487	0.002843**
Beef consumption	7.061e-02	2.477e-02	2.850	0.024687*
household fertility rates	-6.843e-02	2.741e-02	-2.496	0.041218*
Forest extraction	1.938e-01	1.348e-02	14.372	1.88e-06***
Household mortality rates	-3.311e-02	1.276e-02	-2.594	0.035738*
Received governmental benefits	4.037e-01	2.094e-02	19.277	2.52e-07***
Costs of perennial production	-3.143e-01	1.216e-02	-25.838	3.33e-08***
Labor demanded by agriculture and livestock	9.104e-02	2.920e-02	3.118	0.016887*
Perennial yields	6.985e-01	1.270e-02	55.019	1.72e-10***

Both staples consumption and production responded positively to the yield variation. Figure 23 illustrates these relationships, where the sensitivity of consumption is more evident than the sensitivity of staples production. In the latter, there is more sensitivity in the yield curves 03, 04, and 12.

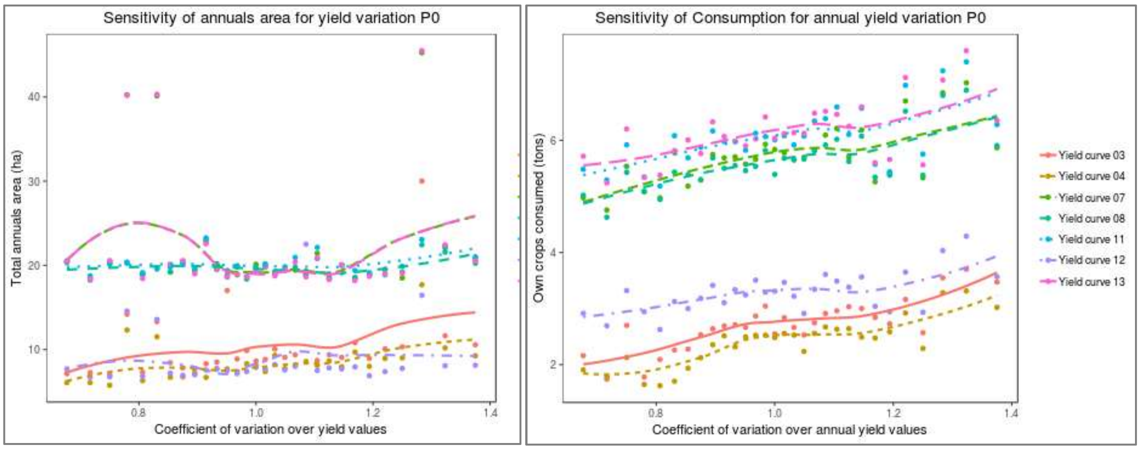


Figure 23: Correlation between yield increase and the total area dedicated to annuals production (left), and between annuals consumption to yield variation (right).

However, income was the most sensitive output to several parameters. The multiple linear regression showed the sensitivity of income, especially to buying and selling staples prices, benefits from the government, costs of perennial production, and perennial yields (Figure 24). However, the sensitivity of income is more evident to perennial yields and less noticeable to perennial costs.

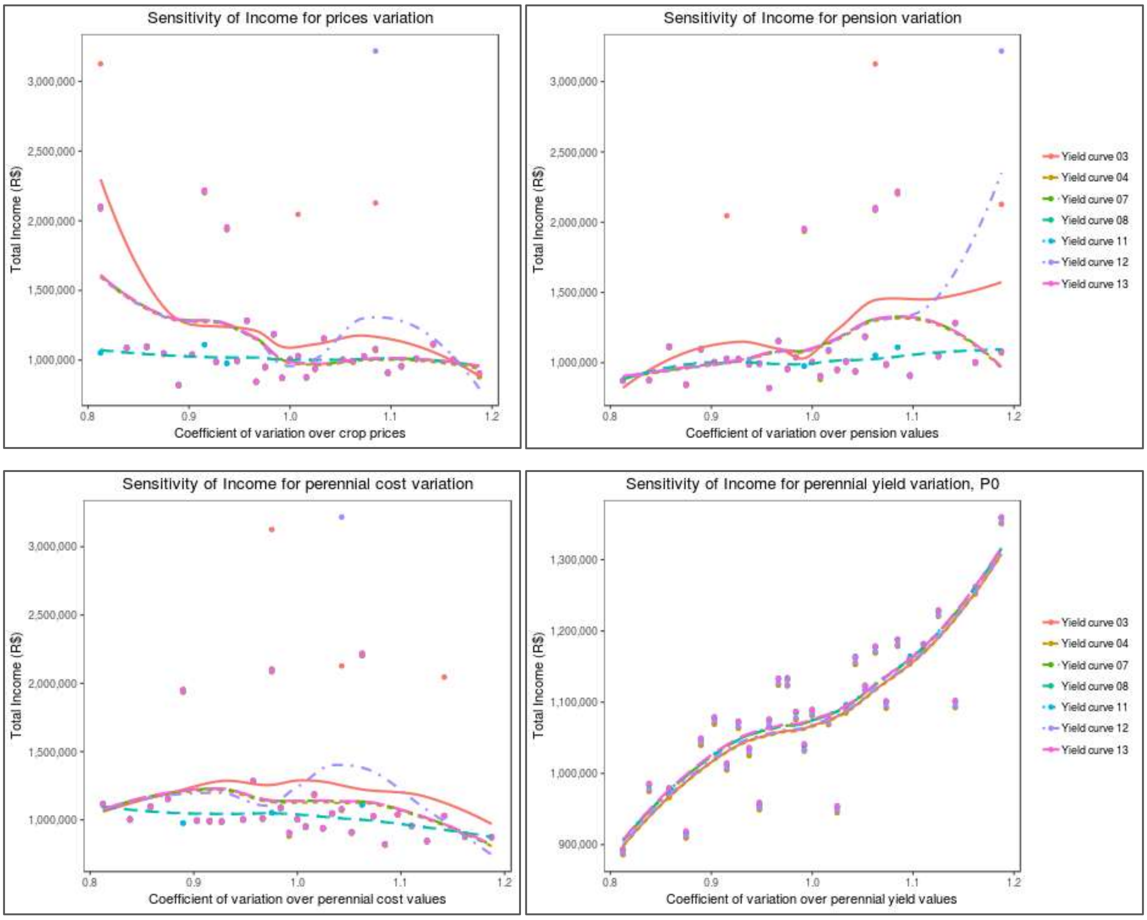


Figure 24: Sensitivity of income for the variation on staples prices, pension, perennial costs, and perennial yields.

Discussion

Finally, the observed system behavior indicates that higher annuals production is preferred when agricultural plots are fertile enough. However, MPMAS showed other possible paths to achieve income or utility maximization. Accordingly, the lower availability of productive agricultural fields, caused by the combination of agricultural intensification and FCPs constraints, was compensated by the diversification of production activities. The sensitivity of annuals area and consumption to yield reaffirms the behavior observed in the sensitivity analysis for yield curves variation. Also, the sensitivity of income to diverse parameter variations raises awareness of how interpreting this output when used for political/economic scenarios comparisons. With that, uncertainties in the model are better defined, and results analysis becomes more consistent.

MPMAS validation procedures: methods and results

Three validation procedures were applied to the model's outputs: model efficiency, efficiency based on standardized absolute error analysis, and scatter plots for the goodness of fit analysis. Traditionally, validation means comparing the model's outputs to real-world observations to evaluate how well it represents the modeled system's behavior. Thus, it is possible to separate components from the model and confront them with real-world data from the modeled system (Schreinemachers et al., 2007). All analyses were performed for the Newpol scenario, including all yield curves and Sobol' repetitions. Complete validation results are shown in Appendix C. The observed dataset was extracted from the 2014 census.

First, I executed the Nash-Sutcliffe model efficiency coefficient (NSE) to assess the predictive power of our model. It is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE was implemented through the *hydroGOF* package[33] on R software[34]. Then, comparisons were performed at the agent level. Table 26 presents NSE's best values for the mentioned indicators.

Table 26: Best values found on NSE coefficients and the respective yield curve and Sobol' repetition of Newpol.

	Annuals area	Scenarios	Perennials area	Scenarios	Initial fallow area	Scenarios
Best value P0	0.303	Yi 07, Sb 23	0.999	All	0.796	Yi 04, Sb 23
Best average value P0**	0.199	Yi 07	0.999	All	0.750	Yi 03

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[33] HydroGOF package, version 0,3-10.

[34] RStudio: Version 1.1.463 – © 2009-2018 RStudio, Inc.

Standard deviation P0**	0.049	Yi 07	0	All	0.030	Yi 03
Best value P1	0.241	Yi 13; Sb 16	0.999	All	0.71	Yi 04, Sb 23
Best average value P1**	0.191	Yi 11	0.999	All	0.639	Yi 12
Standard deviation P1**	0.04	Yi 11	0	All	0.033	Yi 12

*Yi: yield curve scenarios; Sb: Sobol' repetition.

**Average and standard deviation values within all Sobol' repetitions (30 scenarios) of the yield curve scenarios.

NSE ranges from -−∞ to 1, where NSE = 1 is the perfect match between observed and simulated data and NSE = 0 means predictions are as accurate as the mean of observed data. However, if $-\infty < \text{NSE} < 0$, the residual variance is larger than the data variance. Perennials and initial fallow areas present a good match between modeled and observed values. However, annuals area predictions are not accurate, and the model is just a little better than the average of observed data.

To complement NSE on validation procedures, I performed an efficiency based on standardized absolute error analysis (ESAE) to compare observed and simulated landscapes. ESAE is a simple descriptive statistic of deviation. The total discrepancies between simulated and observed values of different parameters – or absolute errors –, are normalized by the total expected count of values (or individual entities). Standardized absolute error performs the models' degrees of errors, where extreme values are zero for the perfect fit to two for the maximum error. To obtain a value of ESAE, it's necessary to subtract the error degree from the value of one. Efficiency values greater than 0,5 are expected (Troost, 2014; Voas and Williamson, 2001). I used R software through the following formula:

ESAE = 1- sum[i](|Simulated[i] - Observed[i]|)/sum[i](Observed[i]);

Where "i" represents the different categories of land use. All land use types were analyzed together, at once. The best ESAE results are found in Table 27, and complete results in Appendix C. Simulations can produce expected results on land use/land cover types.

Table 27: Best values found on ESAE coefficients, and the respective Yield curve and Sobol' repetition, of Newpol political scenario.

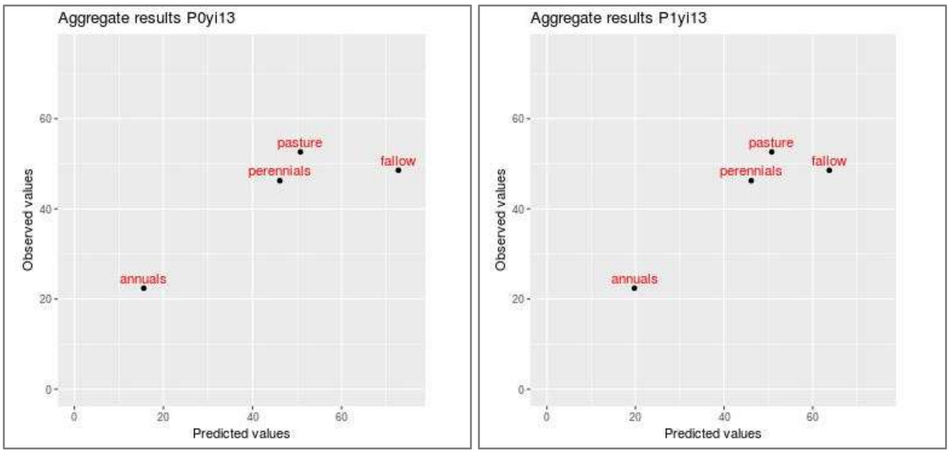
	ESAE values	Scenarios
Best value P0	0.824	Yi 07; Sb 19
Best average value P0**	0.779	Yi 07

Standard deviation P0**	0.017	Yi 07
Best value P1	0.937	Yi 11; Sb 19
Best average value P1**	0.884	Yi 11
Standard deviation P1**	0.021	Yi 11

*Yi: yield curve scenarios; Sb: Sobol' repetition.

**Average and standard deviation values within all Sobol' repetitions of the yield curve scenarios.

Finally, I produced scatter plots to perform visual comparisons between observed and simulated values of land use categories. All land use classes were aggregated in Figure 25 and presented individually and disaggregated in Figure 26. Obtained values resulted from the average of all Sobol's repetitions. Again, all analyses were accomplished with the assistance of R software and the *ggplot2* package[35].


Aggregate results P0yi13

Aggregate results P1yi13

Figure 25: Observed*Predicted values of aggregated land use types.

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[35] Ggplot2 package, version 3.1.0.

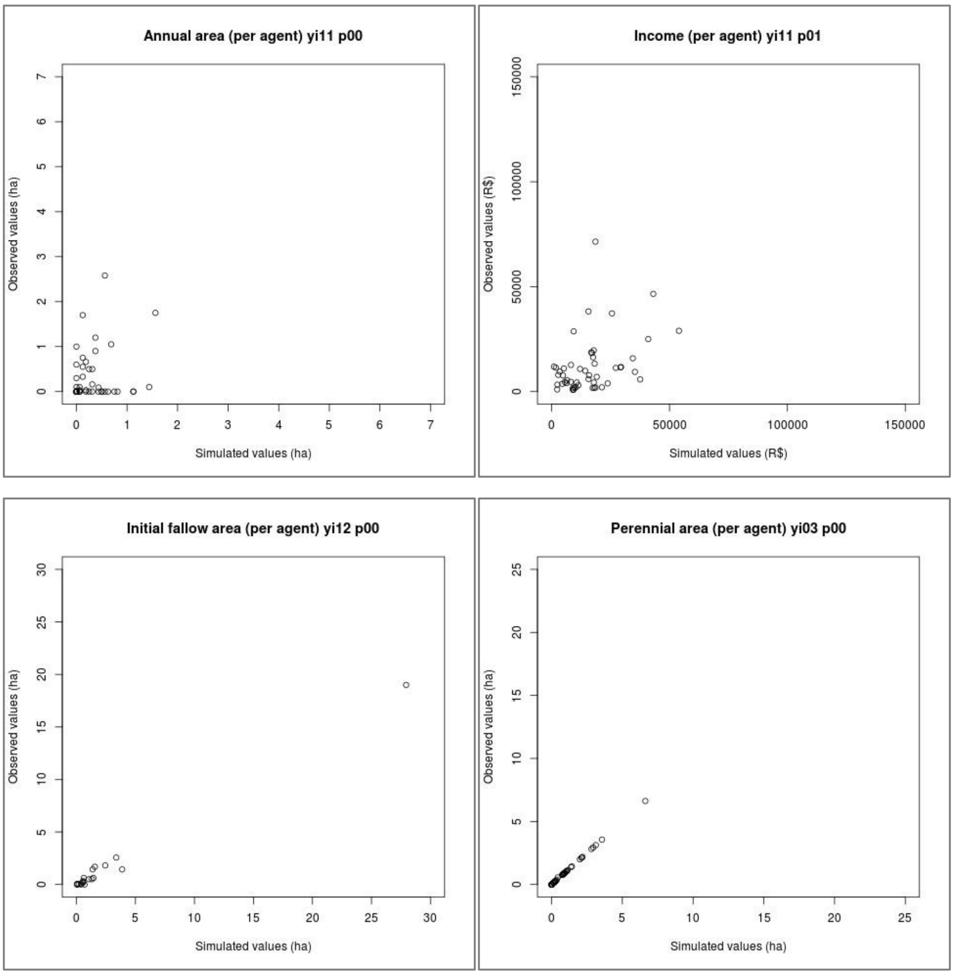

Figure 26: Observed*Predicted values of each of the land use types, disaggregated.

I concluded that the model can perform reliable predictions for the land use categories in general, as shown by ESAE results and scatter plots for aggregate areas (except for initial fallow areas). The initial fallow area has a good performance on NSE analysis, though. The perennials area has a good performance on all analysis types. It is the most profitable activity in the model; therefore, agents decide to produce them as much as possible. In this respect, the model is correct.

Regarding the annuals production area, the only consistent results are the aggregate scatter plots. The area for annuals could not explain differences between agents' and their behavior, following what was observed in our exploratory analysis above. I believe there are a few reasons for that. By comparing the model's predictions to the observed dataset, I found that 23 farmers were growing annual crops in 2014. Only eight were producing them in 2016, while 29 agents were doing so in the model (13 of them were producing in 2014 and 6 produced in 2016, while 14 were not producing in any period). Among the 52 agents in the model, 12 never grew any staple, and only five were growing crops in 2014 and 2016. Additionally, I performed a logit regression for those agents producing crops in 2014 and 2016 and the model[36]. Such a procedure was implemented to find if there were specificities regarding those still producing for subsistence. There is no strong correlation between annuals production and any characteristic of the household from the observed data. For the simulated dataset, the presence of employed man is moderately correlated to SCS implementation (0.53).

After all, I conclude that SC, in the represented context of agricultural transition, was more similar to agricultural innovation adoption than to a tradition or a main economic activity, confirming what was found in the exploratory analysis. The greater number of agents using SCS in the model, and the significant reduction observed in annuals production, are indicators of this new status of SCS in Pedro Cubas. From the model's perspective, staples production is more profitable or less work demanding than in reality. I included crop consumption in the model as part of household income to represent the traditional importance of this system. Still, I probably did not characterize the opportunity costs of this type of work for farmers. Moreover, the model could not identify the sociocultural processes behind the initiative of still producing staple crops or abandoning them entirely.

GDM biological space

GDM transforms the selected predictors into their biological space by converting each variable from its arbitrary scales to a common biological importance scale. By transforming the predictors, I obtained spatial patterns of biodiversity (Figure 27).

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[36] Performed with the *stats* package in R, version 3.5.3.

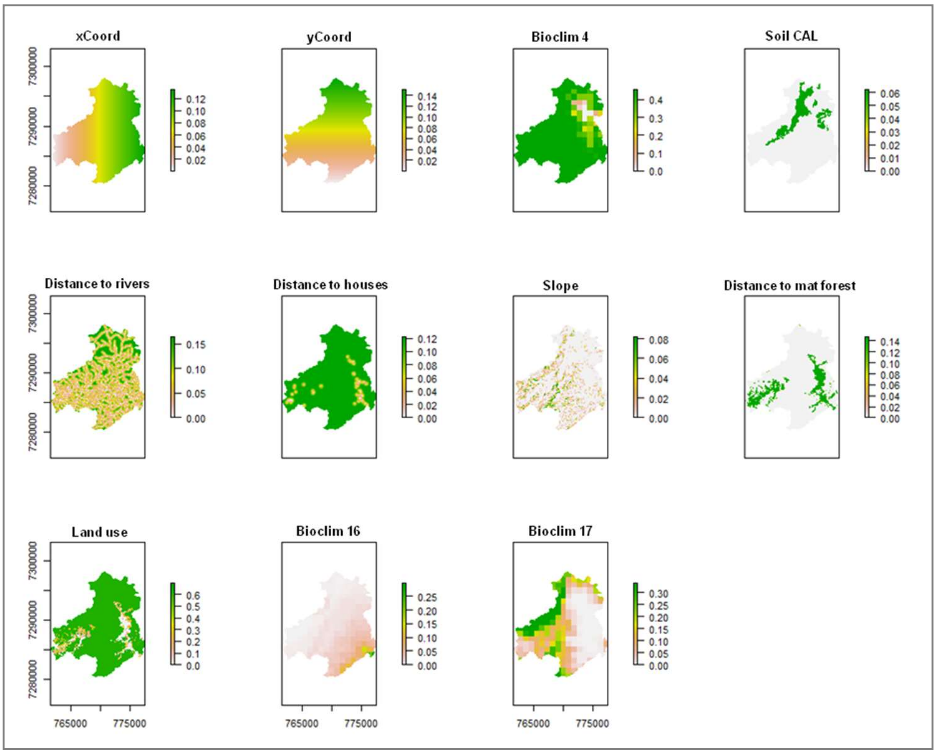


Figure 27: Spatial layers of environmental predictors transformed into the biological space.

However, it was not possible to visualize only one pattern combining all the variables. For that, I implemented a cluster analysis overlapping all layers in one. I used a k-medoids cluster algorithm (PAM - Partitioning Around Medoids) over all transformed variables in five clusters. The number of clusters was defined by the Silhouette index, following the same procedure used on methods Step III (Chapter 4). The results were mapped on the territory and checked for the patterns revealed by the combination of predictors' biological spaces (Figure 28).

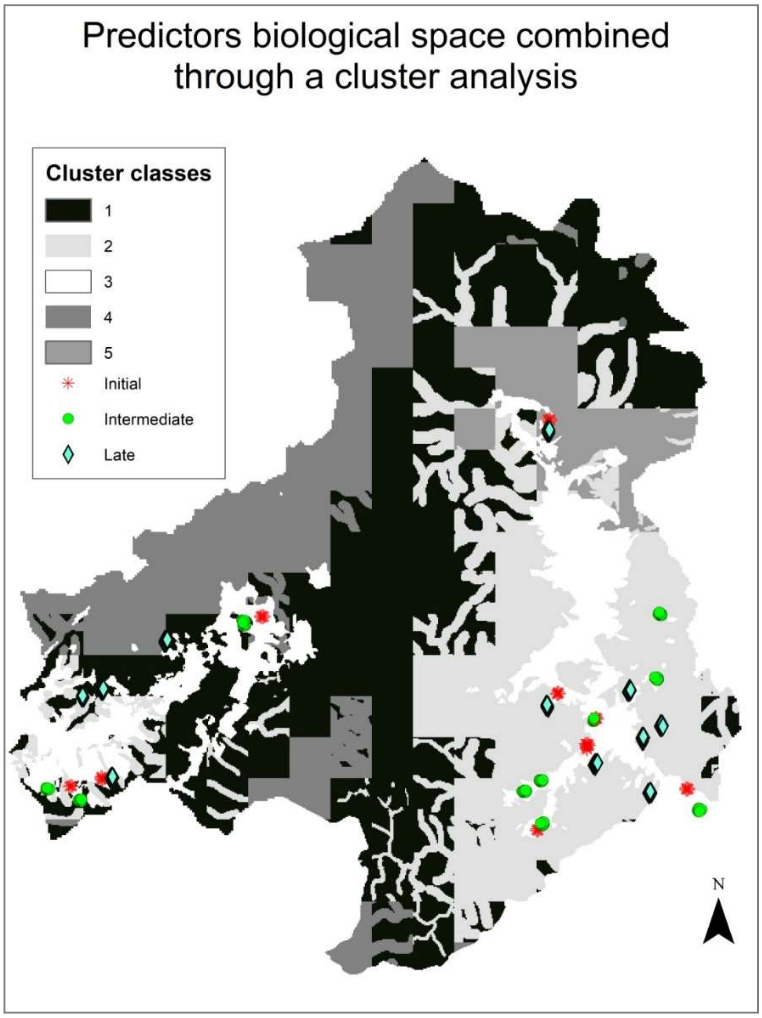


Figure 28: Clusters combining all predictors' biological spaces and the location of data collection plots.

All classes were equally influenced by the distance to houses and not influenced by soil CAL. Class 1 is influenced by fallow ages and temperature seasonality (Bioclim 4). Class 2, where most of the visited late fallow plots are located, shows the importance of temperature seasonality, distance to houses, and precipitation of the driest quarter (Bioclim 17). Class 3 overlaps human occupation and management areas. It is influenced by land use and temperature seasonality. All plots in initial and medium fallow phases were located there. This information is relevant for results interpretation, as the sampled tree communities in the initial and intermediate stages may be biased by human influence. Class 4 is found where the altitude is higher, slopes have higher values, and precipitation of the driest quarter has lower values. Class 5, in its turn, is under the more substantial influence of altitude and longitude.

THESIS SECTION III – MODELING RESULTS

Chapter 6: Modeling agricultural transition stages

In the second chapter, I unveiled the worldwide transitioning trend of shifting cultivation systems (SCS). The changes observed in many places have led to reduced economic isolation, agricultural intensification (less plot rotation, shortened fallow length, and extended cultivation periods), greater access to facilities, and land use/land cover changes (LUCC), among other consequences. The *Quilombolas* SCS from the Ribeira Valley is no exception to that, although it is still unclear exactly how the drivers of change impact household welfare, forest cover, and landscape structure. In other words, could the conservation versus development dilemma be solved in the *Quilombola* territories? Modeling is one of the tools that can help to answer this question.

Aims

In this chapter, I aimed to model the impact of SC, agricultural intensification, and socioeconomic changes on household wealth, income, land use dynamics, landscape structure, and trees' community β diversity in Pedro Cubas by integrating MPMAS and GDM modeling tools.

As explained in Chapter 4 (section "Political/economic scenarios"), five scenarios were created through the combination of the FCP version, level of market access, and period. To evaluate agricultural intensification impacts, I selected the Past, Oldpol, and Newpol scenarios for comparison because they represent different historical periods and stages of market integration and access to social benefits and facilities.

MPMAS Results analysis

For each analyzed output, I included the three political scenarios and seven yield curves. Sobol' repetitions were aggregated through average values, but minimum and maximum values reached among the repetitions are also presented. For avoiding exhaustion for the reader, I only show results for the yield curve 13. Also, I show only the values from the second period because the LP structure does not provide standing crops in the first, as they were not "previously" produced. Complete results can be found in Appendix E.

The Past and Oldpol scenarios represent different periods, having different currencies. Therefore, I must state that the economic values of the Past scenario are based on the same prices and liquidity values of the Newpol scenario to be compared. On the other hand, in the Oldpol scenario, economic outputs were corrected with interest rates to compensate for the time differences.

Household welfare

Average income boxplots: All agents' income values were averaged for each yield curve simulation period and Sobol' repetition. In the plot, political scenarios demonstrate Sobol' repetition variation (Figure 29).

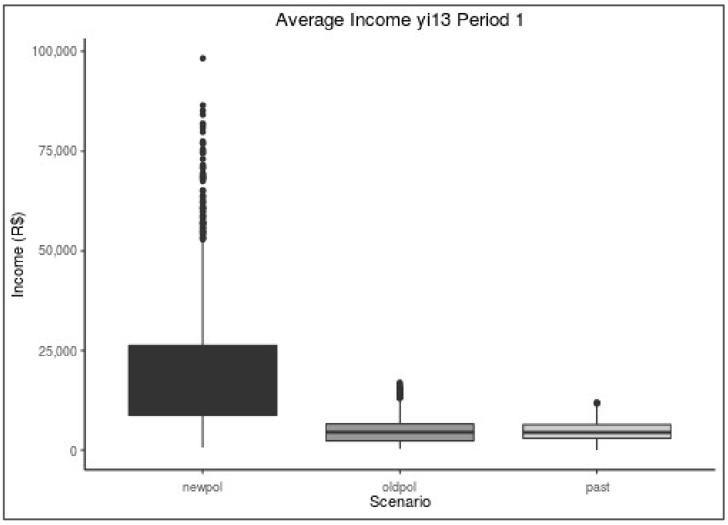
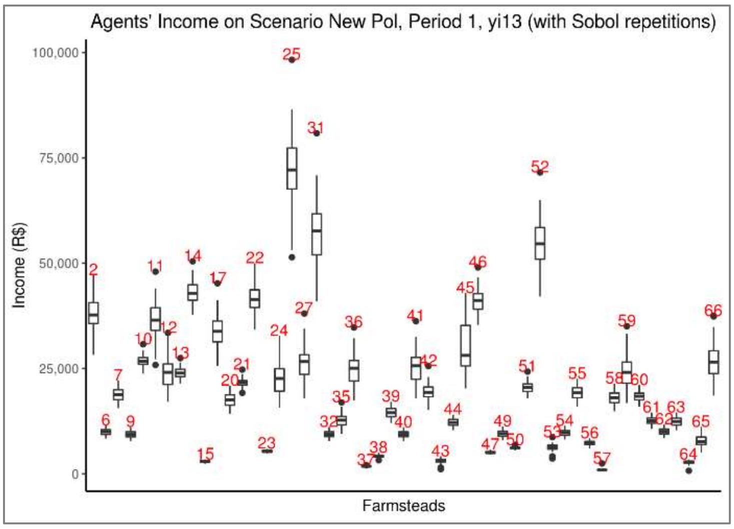
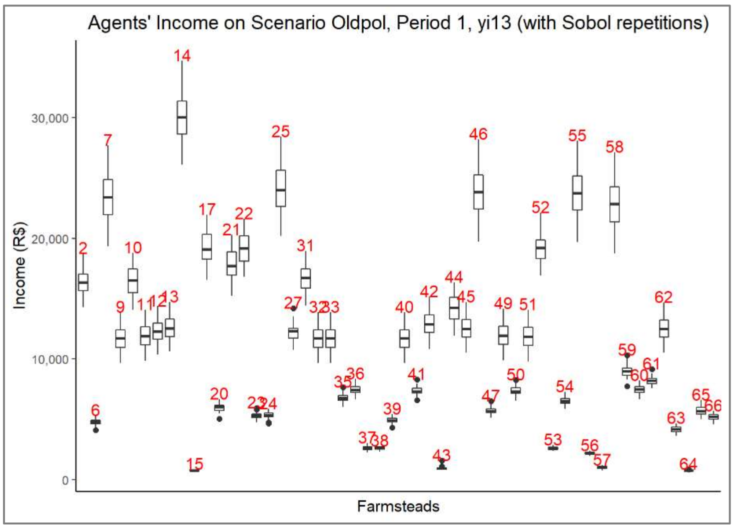


Figure 29: Box plots for Sobol' repetitions on the average community income.

Higher incomes are found in Newpol and more variation among the dataset (Sobol' repetitions), resulting in a more extensive interquartile range and more outliers. The Oldpol and Past scenarios show similar results, although the former has more outliers than the latter.

Agents' income box plot: In this plot (Figure 30), each agent's income value is presented per political scenario. The agent-specific box plots comprise all variations among Sobol' repetitions. Higher individual values are found in the Newpol scenario. The Past scenario has more variation among Sobol's repetitions (box plots cover a more extensive range), and the Oldpol represents the intermediate income values.





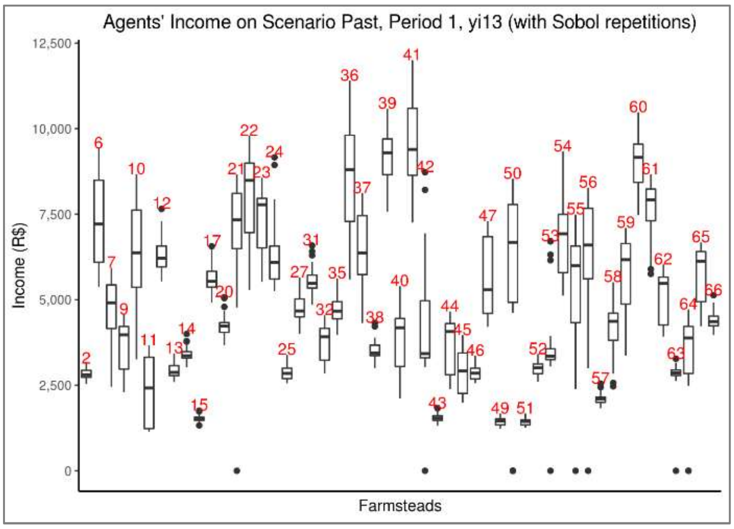
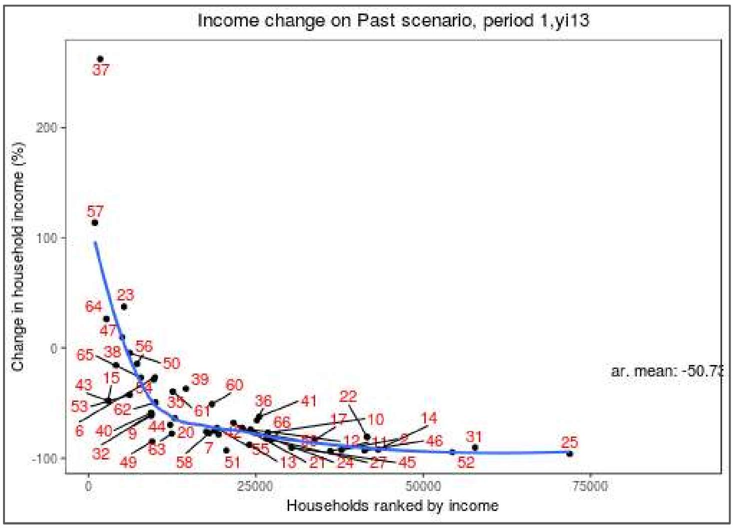


Figure 30: Box plots for Sobol’ repetitions on agents’ income.

Agents’ income variation between political scenarios: This scatter plot shows the agents’ income variation between political scenarios compared to the present context scenario (Newpol). Every agent’s income is averaged through all Sobol’ repetitions and then subtracted from the corresponding value in Newpol (Figure 31). The percentage of change is calculated, and values for each of the agents are plotted. Agents are positioned on the X-axis according to their income in Newpol.



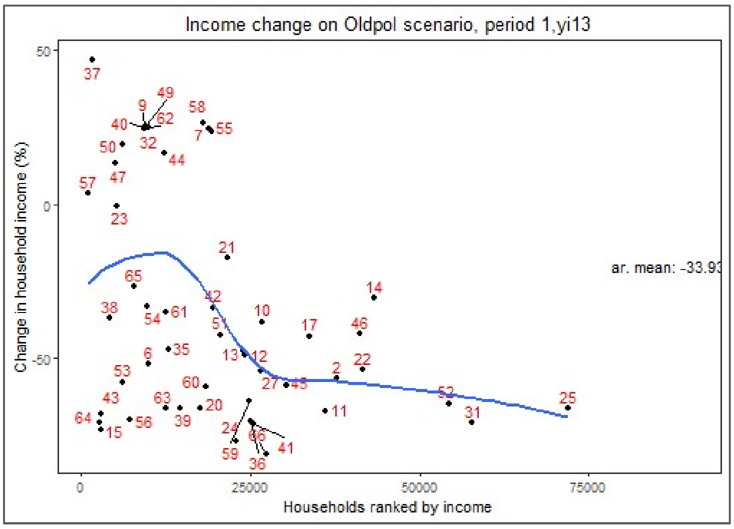


Figure 31: Plots for agents’ income variation between political scenarios.

Most of the Oldpol and Past scenario agents showed an income reduction compared to Newpol. However, the Past has a more significant difference. In both cases, agents' distribution shows that only agents with low income in the Newpol scenario - who are more to the left on the X-axis - increase income, presenting positive values on the Y-axis.

Economic class position table: Agents’ income was compared to the national distribution of economic classes in Brazil (IBGE) in the different political scenarios. Agents were ranked from classes A to E. Table 28 compares the number of agents in diverse economic classes for the average income on Sobol’ repetitions and minimum and maximum values.

Table 28: Number of agents included in each of the IBGE’s economic classes.

Scenario	A	B1	B2	C1	C2	D & E
Past					35 (18-40)	16 (33-11)
Oldpol			0 (0-1)	10 (4-11)	25 (26-25)	17 (22-15)
Newpol	0 (0-1)	6 (3-8)	9 (8-10)	10 (10-11)	21 (17-18)	5 (13-3)

*Results for the minimum and the maximum income obtained in the repetitions are presented in the brackets, respectively.

Some agents in Newpol show better economic conditions, with almost 30% allocated to the middle-class categories (B). In the Oldpol and Past scenarios, all agents were classified as low-income families. Some agents show better conditions in the Oldpol scenario.

Headcount ratio: Table 33 shows the comparison between household income and the World Bank poverty line. For every agent, yearly income values were divided by the number of household members. World Bank's daily poverty line income was converted to an annual income. The best results are found for the Past scenario, where the number of agents under the income poverty line is minor. The Newpol scenario shows the worst results.

Table 29: Headcount ratio.

Scenario	N of agents under the poverty line
Past	1 (16-0)
Oldpol	3 (3-2)
Newpol	4 (8-2)

*Results for the minimum and the maximum income are presented in the brackets, respectively.

Poverty position evaluation based on monthly income: To create Table 30, I first divided household income values by the number of members and then transformed them into monthly values. The results were compared to World Bank values, *Programa Bolsa Familia* (PBF) poverty line, and PBF extreme poverty line (R$ 387.07, R$ 170,00, and R$ 85 per month, respectively, for the year of 2017 and corrected accordingly on the other years).

Table 30: Agents' income compared to World Bank, PBF, and PBF extreme poverty lines.

Scenario	World Bank	PBF	PBF extreme poverty
Past	47 (51-44)	23 (36)	0 (9-0)
Oldpol	13 (15-9)	0 (0)	0 (0-0)
Newpol	12 (20-11)	4 (5)	1 (2-1)

*Results for the minimum and the maximum income values are presented in brackets, respectively.

The best results for the World Bank poverty line were found in the Newpol scenario, with 23% of its agents below the line. In the Past scenario, 90% of the agents are under the World Bank's poverty line, and almost 50% are under the PBF's poverty line. The Oldpol has 25% of its agents under the World Bank's poverty line but none under the others. The Newpol is the only one to present one agent under the extreme poverty line.

Minimum food consumption unmet: Not meeting minimum food consumption is considered an indicator of lousy household welfare. In the LP, a penalty is included in the agent's utility function that he tries to avoid not reaching minimum consumption standards.

The calculations considered the number of times the household did not reach minimum food consumption standards for each food item (e.g., when one household could not consume necessary pork and rice, these were considered different events). The food consumption events were counted twice a year, at the pre and post-harvest periods. Values on the unmet item were averaged using Sobol' repetitions, and the minimum and maximum values were extracted.

The Newpol and the Oldpol scenarios did not show any event of unmet food consumption. However, in the Past scenario, the maximum and average food consumption values gave 47 events it was unmet, while the minimum value of food consumption reached 51 events.

Other consumption unmet: The number of times households did not reach the minimum standards of nonfood items' consumption is presented in Table 31.

Table 31: Total number of events when nonfood items minimum consumption was not met, per household.

Scenario	N of times (average)	N of times (minimum)	N of times (maximum)
Past	101	58	101
Oldpol	4	1	4
Newpol	34	3	34

The worst conditions for acquiring nonfood items were found in the Past scenario and the best in the Oldpol.

Indicators of agricultural intensification

Use of annual crops production: Bar plots show the share of produced crops used for selling to the regular market or the cooperative, for consumption, or for keeping the seeds. Total crops grown by all agents were summed up for each of the simulation periods and averaged for the Sobol' repetitions (Figure 32).

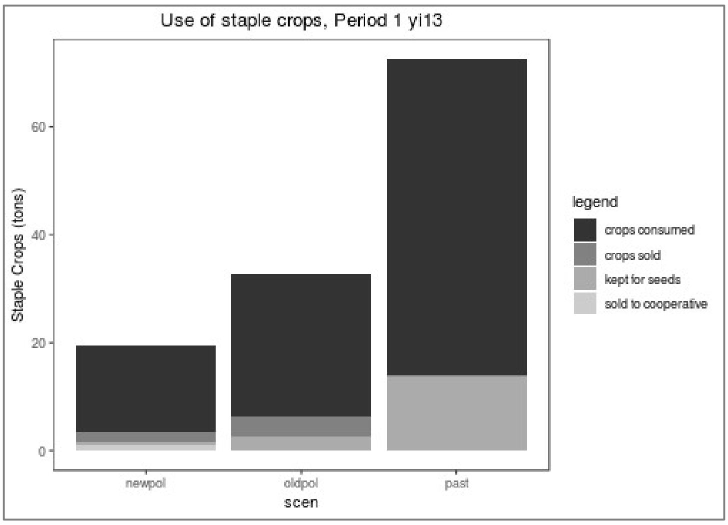


Figure 32: Bars representing the total use of staple crops production.

Much more annuals were produced in the Past scenario, as expected. In all cases, most of the production was used for their consumption. In the Past and the Oldpol scenarios, staples production is shared between consumption, seed stocking, and selling. In Newpol, staples production is shared between own consumption, selling to the regular market, and selling to the cooperative because this is the only scenario with this option.

Comparison of the amount of food produced and bought: Bar plots were also used to show the origin of food consumed in the household, including staples and animal protein. The total amount of food was summed up for each simulation period and averaged for the Sobol' repetitions (Table 32 and Figure 33).

Table 32: Values for food consumption's sources.

	Newpol			Oldpol			Past		
	aver	min	max	aver	min	max	aver	min	max
Food bought	68.26	52.72	142.32	59.56	49.82	69.20	17.07	13.91	29.21
Food produced	20.04	15.15	44.68	28.41	23.53	33.63	72.49	62.05	139.49

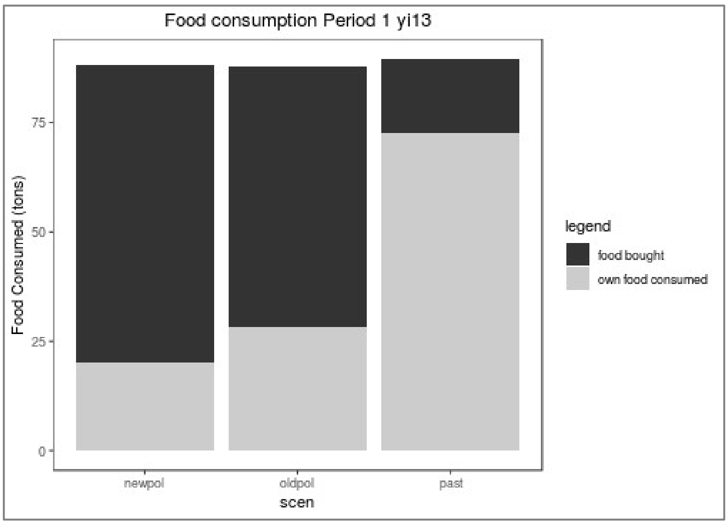


Figure 33: Bars representing the total amount of food consumed and their sources.

The total consumption of staples is similar for all scenarios but a little higher for the Past. This scenario also presented the greater share/amount of own food consumed, followed by Oldpol and Newpol. The proportion of food bought is greater in Newpol.

The number of agents practicing different economic activities: Table 33 presents the average, minimum and maximum values (among Sobol' repetitions) of the number of agents practicing various economic activities.

Table 33: Total number of agents engaged in different economic activities..

Scenario	Economic activity	Aver	Min	Max
Newpol	Annuals production	34	34	34
Oldpol		41	41	41
Past		51	48	51
Newpol	Forest extraction	23	23	23
Oldpol		23	23	23
Newpol	Livestock raising	49	47	51
Oldpol		2	0	15
Newpol	Perennials production	38	38	38
Oldpol		7	7	7

The average values of agents in the Sobol' repetitions are presented, followed by the minimum and maximum values

The Past scenario shows the totality of agents growing staples, while the Oldpol has 78% of its agents practicing this activity and Newpol has 65%. In addition, the Newpol and Oldpol scenarios present the same level of forest extraction, while many more agents implemented livestock raising and perennials production in the Newpol.

Use of household labor: Household labor was calculated by summing all agents' labor (person/days) and then averaging among Sobol' repetitions (Figure 34). Labor types are differentiated between agricultural work (annuals and perennials), forest extraction, and out of farm work. Table 34 shows the minimum and maximum values for each labor type.

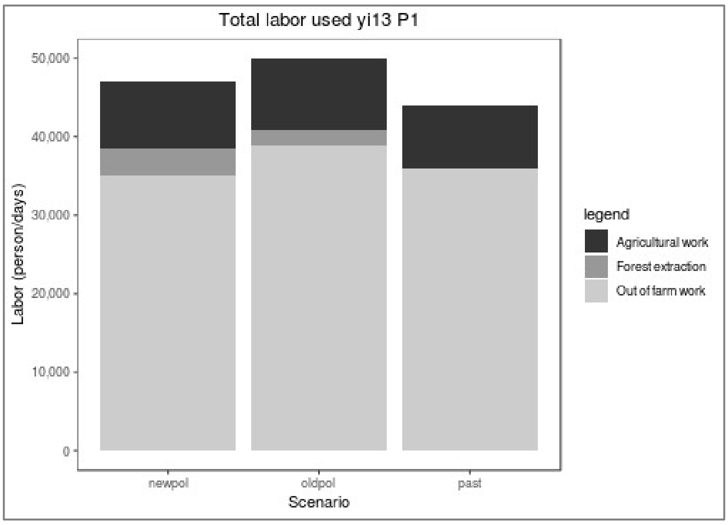


Figure 34: Bars representing the total labor used in the community and the different activities.

Table 34: Values for the different uses of total household labor (person/days).

	Newpol			Oldpol			Past		
	aver	min	max	aver	min	max	aver	min	max
Agricultural work	8598.47	7775.71	15712.00	9069.82	9067.01	9072	7990.45	7269.58	15662.16
Off farm work	34992.96	24454.98	70745.68	38874.20	29699.64	48285.62	36001.63	25368.92	81660.19
Forest extraction	3483.53	1692.92	8179.43	2034.89	1406.75	3437.65	0	0	0

Values of each yield curve were averaged among Sobol' repetitions, and minimum and maximum values were also calculated.

The Oldpol scenario is the one to use more household labor in total, followed by the Newpol scenario. All scenarios show that the greater share is dedicated to out of farm work. The Newpol scenario gives more labor to forest extraction than Oldpol.

Landscape structure: Land use management structure in all political scenarios can be seen in Figure 35. It presents the average area among all Sobol' repetitions calculated for each land use type. For this analysis, the area blocked by FCPs (most of the mature forest) was not considered, which is why there are no late fallow forests in some scenarios. The plots refer to the area available for management and the use made of it. The complete landscape structure is described in the Landscape metrics item below.

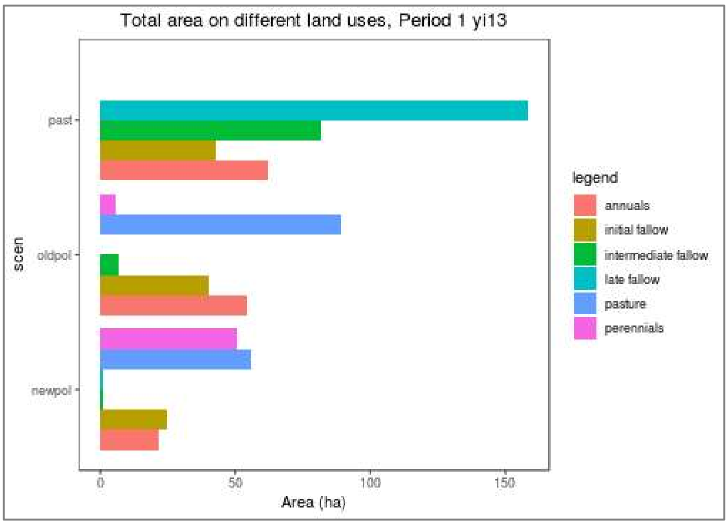


Figure 35: Bars representing the total area dedicated to land use types.

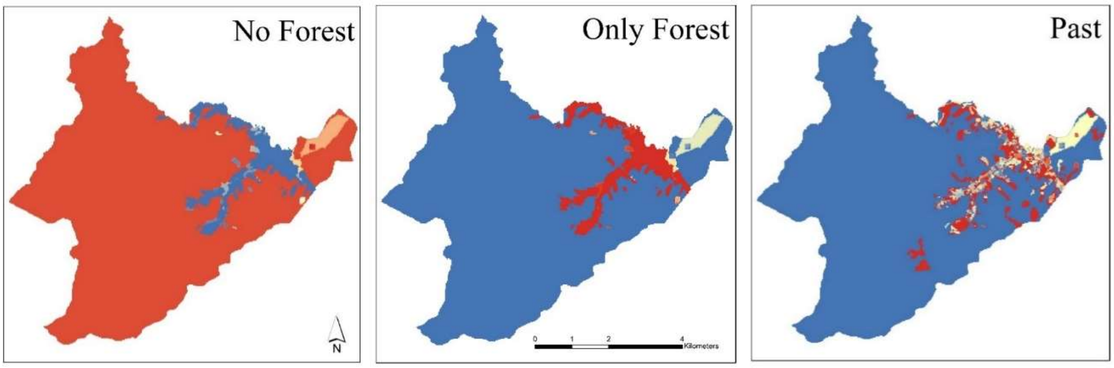
Initial fallow areas are similar between Oldpol and Past scenarios and larger than Newpol. The pasture area is larger in the Oldpol scenario. Land use types are more diverse in the Newpol scenario. Agents in the Past scenario have more fallowed areas, meaning more space available for management, according to the FCPs.

GDM results analysis

The dissimilarity in the *Quilombola* territory landscape regarding plant communities was analyzed considering the baseline (i.e., coincident with the collection period) and the simulated future scenarios landscapes. This analysis was done through a comparison between the calibrated model and the simulated landscape. GDM was calibrated with 11 predictors layers (9 environmental + 2 geographic, see Figure 27) on a raster stack. The layers originated from MPMAS were added, and differences in each plot were calculated.

It is relevant to remind that each MPMAS political scenario was set with a different land use map, as seen above, but GDM was calibrated only with the Newpol land use and distance to forest maps. To find the landscape dissimilarities between the "original" (calibrated) landscape and the one resulting from the simulations, it is significant to compare the corresponding ones. In other words, this means that ß diversity values found in the Past and Oldpol scenarios refer to changes from the Newpol to these scenarios. Although this is the opposite of reality, this analysis is still valuable for indicating how the landscape has transformed in response to agricultural transitions.

GDM outputs consist of maps representing the ß diversity/dissimilarity values of each cell (Figure 36). These values range from 0.531261 to 0.785625, depicting the amount of change expected in biological composition with the environmental changes caused by land use. The No Forest and Only Forest scenarios illustrate how the landscape ß diversity would be in extreme situations[37]. The tree community would show the maximum ß diversity values in most of the territory with no forest, except for the area with a management history. On the other hand, suppose mature forests completely cover the area. In that case, I observe a high index of change in the plants' community in the share of the territory presenting the land use history. These two scenarios are a reference for the scenario's results interpretation.



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[37] The No Forest scenario represents the extreme situation where the whole territory is under some type of management, and the Only Forest scenario represents the situation where the whole territory is under mature forest.

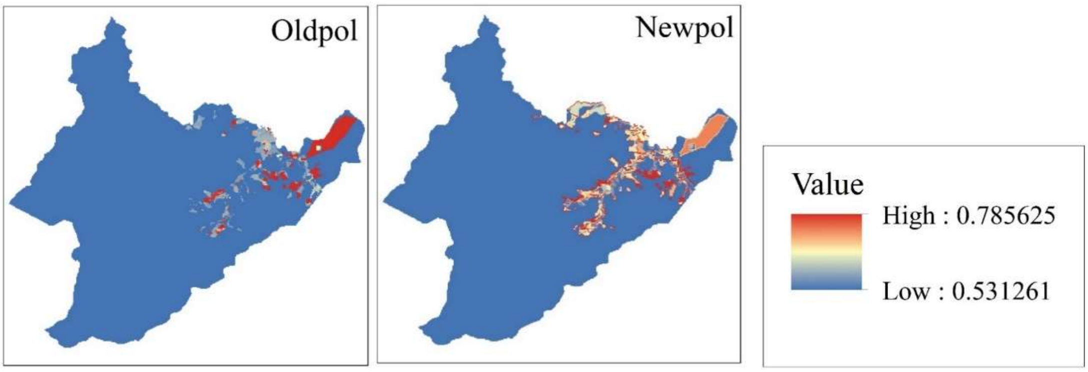

Figure 36: Results from GDM simulations, showing ß diversity (dissimilarity) values per landscape unit.

The Newpol GDM output presents the ß diversity for the Pedro Cubas territory resulting from the MPMAS output. The territory's ß diversity results from the implementation of three years of land use decisions based on income optimization and restricted by SMA 027. A deeper analysis reveals that the areas with higher values include previous forest areas managed by the agents, representing a reduction in the plant diversity in these patches.

The fact that the Past scenario shows more areas that suffered significant changes is visible and expected. MPMAS simulations are based on the landscape from the 1960s. Therefore, the MPMAS input map for the GDM Past simulations does not overlap with the calibrated scenario. In the model, areas with higher change values are expected to be suppressed forests replaced by SC. In the Oldpol scenario, there are areas under much or low change; no intermediate values of change were found. The former represents a similar case to the Past scenario; the latter might include fallowed plots that get near the age of the same areas in the landscape used for GDM calibration (the Newpol input map).

Additionally, the Newpol GDM output was compared to the classes obtained from the combination and clustering of predictors' biological spaces (Figure 28). All of them occur over cluster class 2, where the community distribution is mainly determined by the combination of temperature seasonality, distance to the mature forest, and rivers. The other share of plots revealing important changing values is located over cluster class 3, under direct human occupation, and influenced by land use and temperature seasonality.

To find more precise comparisons between political scenarios, I calculated the total amount of change in the territory. I summed up the dissimilarity values (presented by GDM as the range from 0.531261 to 0.785625) from all the landscape cells (of 25 meters each) to reach the amount of change predicted over the original trees community (Table 45).

Table 35: Result from the sum of all cell index values, based on the average area of each cell type, multiplied by the dissimilarity values.

Scenario	Score of change	Std dev
Oldpol	2038	11.52
Newpol	2050	0.18
Past	2090	0.77
Only Forest	2092	--
No Forest	2925	--

Oldpol is the scenario to present the lower total change value, followed by the Newpol and Past scenarios, respectively, and No Forest is the scenario to achieve the higher value. These results reaffirm what the map showed and what was expected for the Newpol landscape. However, the Past scenario value is very close to the Only forest scenario. This means the difference between the two landscapes (calibrated landscape in the model, referring to Newpol input and output landscape from Past scenario) is so high that it sounds the landscape was entirely replaced by mature forested areas. Thus, the changes in landscape structure caused by agricultural transitions are reflected by the obtained results.

Ranking scenarios

GDM is a suitable method to map dissimilarity throughout the landscape and predict spatial change over time. However, it does not have a formal approach to compare different scenarios. Therefore, I developed a stepwise system to perform such a comparison by calculating an index for the whole landscape. The index was designed by overlapping different spatial data. Values were calculated per landscape grid; the higher the grid value, the better the ecological condition. After that, all grids' values were summed up, and a unique value was obtained for each scenario. The logic behind this method is to establish values according to fallow age: the older the fallow age, the better the ecosystem's quality.

Therefore, fallow age transformation is the main factor of weight: when the cell value was transformed into older fallow ages, the score was positive. On the other hand, when the fallow cell was first replaced by a management land use, the score was negative. With this index, I can avoid the bias created by the GDM calibration using the Newpol land use map to the MPMAS outputs from other scenarios.

Political scenario landscape index = (log(B) – log(A)) * B * C * D, where:

A: Land use input into MPMAS. Values correspond to fallow ages from 0 to 60.

B: Land use output from MPMAS. Values correspond to fallow ages from 0 to 60.

C: ß diversity score landscape. This landscape construction was based on the combination of the map showing the variables' biological space cluster and the values of importance attributed to species on collection plots. Each species had a specific score: 1 if it is a typical initial fallow species, five if it is a standard medium fallow, and 10 if it is typical of late fallow. For each data collection plot, each presence point of species was summed with its respective values. With this procedure, it was possible to value both species diversity and their relative ecological state. The four clusters were valued with the average of the plots' total score in the next step. From 1 to 4, clusters were given the scores of 127, 97, 144, and 18 scores, respectively. The procedure of assigning importance values to plant species, according to their successional performance, has been used in the literature (Peña-Claros, 2003; Villa et al., 2019; Zulu et al., 2019).

D: GDM output landscape, containing the index of change from the landscape used in GDM calibration (values from 0.531261 to 0.785625).

The difference between output and input land use layers is calculated from the logarithm values of fallow ages. Consequently, the variation between obtained difference values won't be very high from one plot to another. This decision was based on the assumption that changes in diversity (richness, basal area, and change in composition) during the fallow period may be higher in the initial stages of the successional process than in older fallows. The use of log approximates the values.

Among all the layers, C is the only one that is repeated for all political/economic scenarios, while layer A is the same for the Newpol and Nopol scenarios and exclusive for the Past and Oldpol scenarios; layers B and D are scenario-specific. Figure 37 illustrates the index composition.

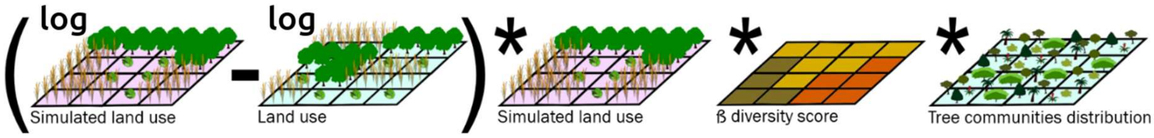

Figure 37: Graphical scheme for the landscape index calculation, produced to assist the ranking of scenarios using GDM outputs.

Besides implementing the index calculation on the MPMAS/GDM scenarios outputs, I also performed the same analysis on the extreme scenarios (the Only Forest and No Forest). The results of both extreme situations will be the best and worst-case scenarios in the political-economic analysis. Table 36 presents the score results. The values of No Forest and Only Forest scenarios show extreme positive and negative situations. All the other scenarios are closer to Only Forest and show high relative scores, although the Newpol scenario has the highest value.

Table 36: Results of the ranking scenarios method.

Scenario	Score	Relative score
No Forest	-664657.90	0
Past	-2162.58	91.36
Oldpol	4528.48	92.28
Newpol	13603.07	93.53
Only Forest	60487.05	100

Landscape metrics

Landscape metrics are quantitative techniques for describing landscape spatial patterns (Jepsen et al., 2006). They are usually implemented to evaluate disturbed landscapes, the connectivity between fragments and their potential for hosting biodiversity in general. Here I am analyzing a forest landscape where most of the matrix consists of mature forests. Still, these indexes can be helpful as a matter of understanding the landscape's complex spatial and temporal dynamics. Such an analysis was implemented in R software[38], with the *landscapemetrics* and *landscapetools* packages[39], over MPMAS output maps. For MPMAS, the metrics were calculated over samples of yield curves and Sobol' repetitions and finally averaged to reach one result per political scenario.

Number of Patches: I grouped different patch types (from 0 to 60 years fallows) into classes, summing the total number of patches on each scenario (Table 37). Newpol presents more patch units under medium and late fallow and mature forest; the Past scenario has more patch units under management, and Oldpol has more units under initial fallow.

Table 37: Total number of patches of each class.

Class	Past	Oldpol	Newpol
Area under management	119	44	39
Initial fallow (1-10 years)	95	165	108
Medium fallow (11-39 years)	76	101	103
Late fallow (40-59 years)	4	10	11
Mature forest (60 to older)	15	12	16

Classes total area: The areas of each patch type were aggregated by summing up values. Table 38 shows the size of each land class and its proportion to the whole territory.

Table 38: Classes total area (ha) for different political scenarios.

Class	Past	%	Oldpol	%	Newpol	%
Area under management	60.85	1.60	152.72	4.01	105.81	2.78
Initial fallow (1-10 years)	87.74	2.30	66.26	1.74	68.06	1.79
Medium fallow (11-39 years)	139.30	3.66	87.83	2.31	97.75	2.57
Late fallow (40-59 years)	8.66	0.23	11.88	0.31	15.44	0.41
Mature forest (60 to older)	3510.28	92.21	3485.96	91.62	3517.44	92.45

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[38] RStudio: Version 1.1.463 – © 2009-2018 RStudio, Inc.

[39] *Landscapemetrics* package, version 1.2.2; *Landscapetools* package, version 0.5.0.

The Oldpol scenario shows the larger area under management and the smaller area under initial and medium fallow and mature forest. The larger area of mature forest is found in the Newpol scenario and the larger late fallow area. Finally, the Past scenario territory is composed of more extensive areas of initial and medium fallows.

Shape index: The shape index is based on the normalized ratio between the patch's perimeter to its area. The higher the values, the more geometric complexity the patch presents compared to the shape of a square. Together with patches' size, their shape can influence its ecosystem's integrity and the presence of sensitive species, and the permeability to animal species inter-patch movements and plant seedling establishment and growth. Patch type values were aggregated by average in the different classes (Table 39).

Table 39: Shape index for the different classes.

Class	Newpol	Oldpol	Past
Area under management	1.37	1.37	1.37
Initial fallow (1-10 years)	1.19	1.10	1.18
Medium fallow (11-39 years)	1.27	1.21	1.34
Late fallow (40-59 years)	1.35	1.37	1.52
Mature forest (60 to older)	1.06	1.06	1.06

Mature forests and areas under management achieve equal shape index values in all scenarios. The higher complexity of medium and late fallow areas is found in the Past scenario, but the higher complexity of the initial fallow is encountered in the Newpol.

Aggregation Index: The aggregation index represents the tendency of patch types to occur in large, aggregated, or spread distributions. Resultant low ranges mean low or no adjacencies, indicating a more permeable landscape for species. Table 40 contains the aggregation values of the different land use classes, obtained by the average of the patch types.

Table 40: Aggregation index for the different classes.

Class	Newpol	Oldpol	Past
Area under management	79.87	81.42	56.34
Initial fallow (1-10 years)	62.92	57.67	63.21

Medium fallow (11-39 years)	60.24	60.88	75.84
Late fallow (40-59 years)	85.30	81.52	84.15
Mature forest (60 to older)	98.45	98.90	98.21

The areas under management are more aggregated in the Oldpol scenario, and areas under recent management (initial fallow) are more aggregated in the Past scenario. On the other hand, medium fallow areas are more aggregated in the Past, late fallow in the Newpol, and Mature forest in the Oldpol. Thus, more permeable landscapes are found in the Past for the area under management, Oldpol for initial fallow, and Newpol for medium fallow.

Simpson's diversity index: Simpson's diversity index reflects the probability that any two randomly selected cells are of different types. The higher the value, the more diverse is the landscape composition. According to our results (Table 41), the Oldpol scenario has a more varied landscape.

Table 41: Simpson's diversity index.

Scenario	Index
Past	0.148
Oldpol	0.159
Newpol	0.143

The diversity index doesn't consider the ecological or socioeconomic importance of patch types and can reflect a diversity of undesired types. In the case of the tree species in our political scenarios, most of the classes are considered important habitats, except for the areas under management, which are types 0 and 1 of the 60 patch types and represent a small portion of the territory. Therefore, this is the case where a higher index level reflects a better aptitude of the landscape to host higher diversity levels because it truly indicates a higher diversity of habitats. With that, species that rely on specific patch types have their presence guaranteed, and the ecosystem's resilience capacity against disturbance and stressors is higher. Therefore, the Oldpol scenario shows higher diversity, while the Newpol offers a lower variety of environments.

Discussion

Agricultural intensification: socioeconomic consequences

Our results suggest that the transformation processes *Quilombolas* have faced are following the global tendencies reported by van Vliet et al. (2012) and Dressler et al. (2016): incomes are higher but at the expense of more inequality; cultural and traditional practices are being lost; and more labor input is necessary nowadays. Average income is higher in the Newpol scenario, as expected, due to increased market access and varied economic activities, and rural assistance. However, Newpol shows signs of economic inequalities, it has more agents under PBF poverty lines, it is the only to show an agent under the extreme poverty line, and more agents in poor conditions of headcount ratio.

Agents in the Past scenario are entirely engaged in SC, as their survival relies upon it. Staples production is used for consumption or seed stocking, as would be expected for isolated smallholder groups. On the other hand, the Newpol scenario has 65% of their agents engaged in SC, while Oldpol has 78%. Thus, the model reflected the conditions generated by agricultural intensification when predicting fewer agents engaged in SC in the present, as shown in the validation procedures. In parallel, for the low market access, agents in the Past scenario have many more events of unmet consumption; agents in the Newpol and Oldpol scenarios buy the majority of staples consumed, being able to consume more.

Many of the Oldpol scenario results indicate it as a transitional state between the Past and Newpol scenarios and that the process of agricultural intensification has continued for the past decade. Oldpol's income, poverty lines, and engagement in SC are some of the indicators, but fewer agents implemented livestock raising and perennials production than in Newpol. The higher level of perennials production nowadays results from historical and economic transitions that are little by little promoting opportunities and pushing the *Quilombolas* to market integration. The sensitivity analysis showed that palm production plays a vital role in income. Therefore, the absence of some economic activities or, in other words, the level of economic transition represented in the scenarios looks more impacting on the community's income than the restriction of staples production. In combination with the management restrictions, the presence of drivers of change makes the understanding of the system even more complex. Besides new economic opportunities in the present, which compensate for the constraints on staples production, there is a tradeoff in the household's wealth conditions.

Moreover, our results agree with Pasinato et al., (2017) observations in *Quilombolas* SCS: reduction in the number of families involved in SC, diversification of agricultural activities, and landscape structure variation. I observed fewer available fallow areas, more diverse land use types, and larger areas are under management in the Newpol and Oldpol scenarios. However, these areas were distributed in a smaller number of patches. Also, fewer areas are dedicated to SC when compared to the Past scenario.

Agricultural intensification: ecological consequences

Pedro Cubas follows a global tendency in SCS, as the diminishment on plots rotation can be observed in the land use maps input in the scenarios. The model reflects this with smaller areas under initial and medium fallow stages in the Newpol scenarios outputs and larger old fallow plots. I don't have elements to analyze plot land use intensity, but it clearly increases with diminished rotation. The estimation of total changes in the tree community's distribution resulting from GDM, together with GDM's outputs comparison, indicates a significant variation in landscape structure over time.

The implementation of pasture and perennial plots is responsible for more extensive areas under management found in fewer patch units and are more aggregated. Additionally, the aggregation index shows less permeable patches under management and initial fallow in the present. The shape index revealed lower structural complexity for the intermediate and mature forest patches for the same period. However, the initial fallow areas show more complexity. The biodiversity index indicates a higher diversity of habitats in the recent past. All these changes potentially impact biodiversity to some extent, both at the patch and the landscape levels. Moreover, the combination of the Newpol scenario MPMAS outputs and the clustered predictors' biological spaces (from GDM) indicates that possible future land uses can impact local forest if combined with climate variability. If climate changes in the region are translated into variations in precipitation regimes and intensification of droughts, the resilience of the Pedro Cubas landscape might be affected.

Elucidations about SCS sustainability

The ecological sustainability of SCS can be evaluated through the Past scenario outputs under the landscape metrics. I am analyzing an area of 3,806.23 ha hosting 52 families. In this context, 92% of the territory is under mature forest, while 1.6% is under management and 6.19% is under fallow of different ages. The territory has a number of plots under management and initial fallow, reaching two plots per family each. The older the fallow, the fewer the number of plots. According to the shape index, areas under management and late fallow are the more permeable classes. According to the aggregation index, and areas under management and initial fallow are more permeable.

From the local flora perspective, this is a territory where the landscape is dominated by the most diverse habitat (mature forest) and 6% of various habitats, where native species that don't occur in the dense forest can be found. Only less than 2% represent areas where local species cannot happen for a couple of years. Therefore, the diversity index of the Past scenario (0.148) reflects local biodiversity. More than that, if no management were found in this territory, the index would be lower, and probably the local flora would be less diverse. The fact that younger fallow areas are more permeable to species dispersion and distribution contributes to the flora diversity.

Chapter 7

I described the conflicting context generated by forest conservation policies (FCPs) in Chapter 3. The description of how Agent-Based Modeling tools (ABMs) are being used to model FCPs is shown in Chapter 5. Here, I investigate, through modeling, the consequences of different FCP models implementation over Pedro Cubas territory.

Aims

I modeled the impact of conservation policies implementation in Pedro Cubas on family wealth, income, land use dynamics, landscape structure, and trees' community β diversity by combining MPMAS and GDM modeling tools.

In Chapter 4 (section "Political/economic scenarios"), I showed the creation of five scenarios through the combination of the FCP version, level of market access, and period. To analyze FCPs impacts, I compared the baseline scenario (Newpol) to counterfactual situations, when the old FCP version was implemented in the present (Presoldpol scenario) and when no FCP was implemented (Nopol scenario). At the end of this chapter, I present a tradeoff analysis, where all modeled political scenarios (five) have their outputs compared.

MPMAS Result analysis

I analyzed Newpol, Nopol, and Presoldpol: for each model output, I produced graphics and tables for the seven yield curves. Also, on each analyzed output, Sobol' repetitions were aggregated through average values, but minimum and maximum values reached in the total Sobol' repetitions were also presented. Only the results for the yield curve 13 are shown; the values are from the second period because the LP structure does not provide standing crops for the agents in the first period, as they were not produced "before." Complete results can be found in Appendix E of the Thesis.

Household welfare

Average income boxplots: The boxplot shows variations on the Sobol'repetitions for the average household income (Figure 38).

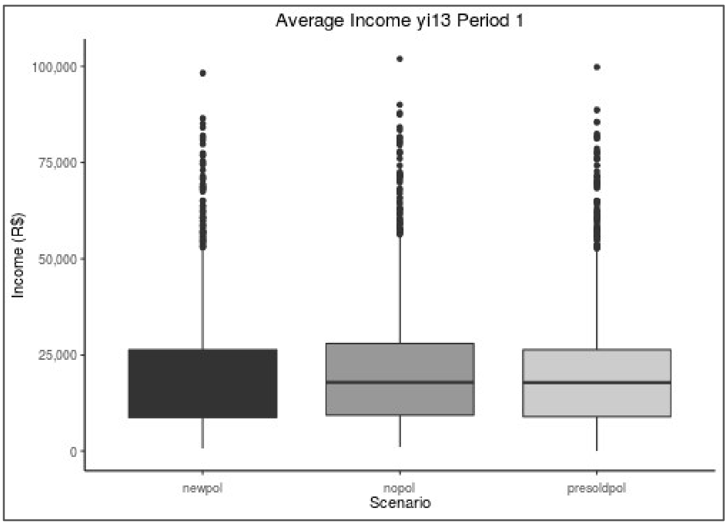

Figure 38: Box plots for Sobol' repetitions on the average community income.

Although Nopol presents higher values in the interquartile range among the Sobol' repetitions, there is not much variation between the scenarios. All political scenarios presented numerous outlier scenarios with higher income values.

Agents' income box plot: All agent's income values are presented per political scenario (Figure 39). The agent-specific box plots comprise all variations among Sobol' repetitions.

These plots show very similar income values for most agents, with a spread distribution on Y-axis. In all cases, agents with lower income values show minor variation among Sobol' repetitions.

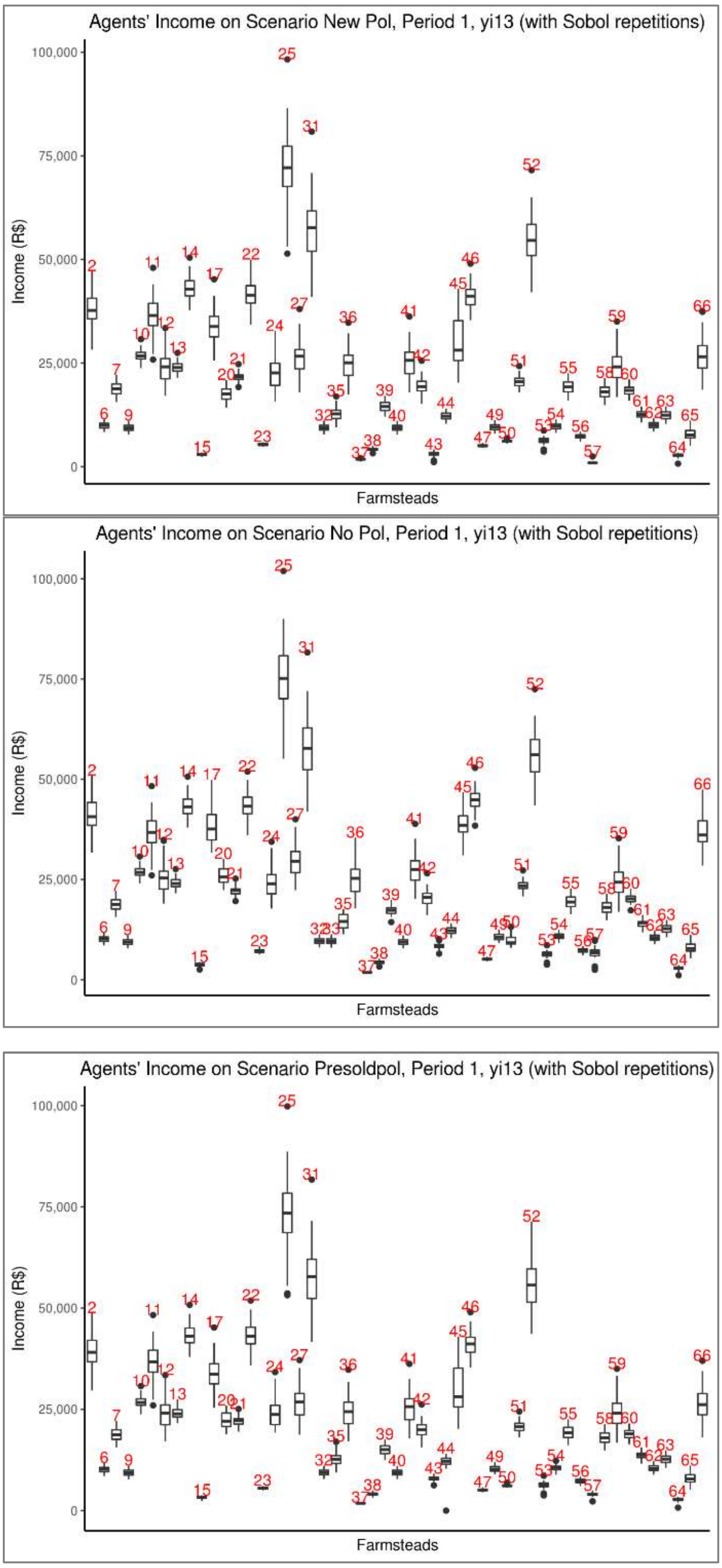

Figure 39: Box plots for Sobol' repetitions on the agents' income.

Income difference: These scatter plots show the agents' income variation between political scenarios compared to Newpol. Every agent's income is averaged through all Sobol' repetitions and then subtracted from the corresponding value in Newpol (Figure 40). The percentage of change is calculated (Y-axis). Agents are positioned on the X-axis according to their income in the Newpol scenario. A different graph is produced for each political scenario, and the overall average of change is plotted.

On average, the Nopol scenario has higher income values, while the Presoldpol presents a lower value of change. Many agents show no change or little change in both cases, being close to the bottom of the Y-axis, although variations are generally positive.

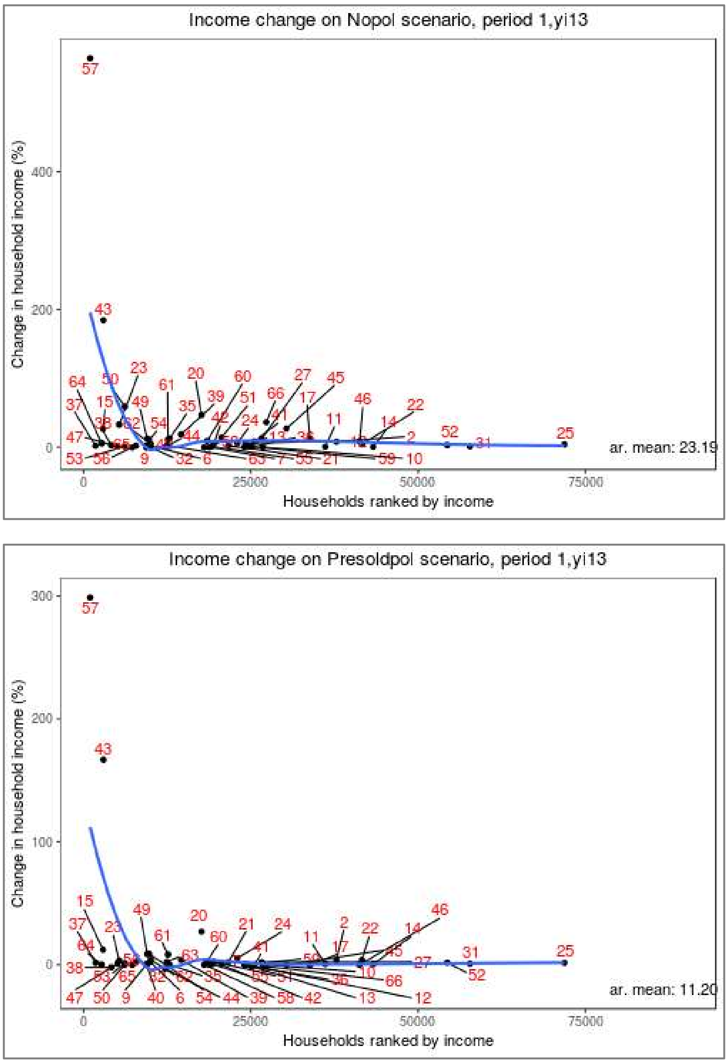

Figure 40: Plots for agents' income variation between political scenarios. Sobol' repetitions were averaged.

Economic class position table: Agents' income is compared to the national definition of economic classes in Brazil (IBGE). It is ranked from classes A to E. Table 42 presents the number of agents on different economic classes.

Table 42: Number of agents represented by each of the IBGE economic classes. B classes represent medium-class, C and D mean poor ones.

Scenario	A	B1	B2	C1	C2	D & E
Newpol	0 (0-1)	6 (3-8)	9 (8-10)	10 (10-11)	21 (17-18)	5 (13-3)
Nopol	1 (0-1)	6 (4-8)	10 (9-11)	13 (12-12)	20 (18-18)	2 (9-2)
Presoldpol	0 (0-1)	7 (3-8)	9 (8-10)	12 (11-11)	19 (18-18)	4 (11-3)

Values are based on the average of all Sobol' repetitions of income. The minimum and the maximum values in Sobol' repetitions are presented in the brackets, respectively.

The Nopol scenario is the only presenting agents in class A, with more agents in class C and fewer agents under poverty conditions (D & E). However, by grouping classes A and B, the three scenarios don't differ much.

Headcount ratio: Table 43 shows the comparison between households' income and the World Bank value for the poverty line. For every agent, yearly income values were divided by the number of household members. World Bank's daily poverty line income was multiplied by 365 for an annual income. The Nopol scenario is the one to present fewer agents under the poverty line, followed by Presoldpol and Newpol.

Table 43: Headcount ratio, accounting for the number of agents under the World Bank's poverty line.

Scenario	N of agents under the poverty line, P1
Newpol	4 (8-2)
Nopol	2 (4-2)
Presoldpol	3 (7-2)

The minimum and the maximum income values found in Sobol' repetitions are presented in the brackets, respectively.

Poverty position evaluation based on monthly income: To create Table 44, I first divided household income values by the number of members and transformed them into monthly values. The results were compared to World Bank values, *Programa Bolsa Familia* (PBF) poverty line, and PBF extreme poverty line (R$ 387.07, R$ 170,00, and R$ 85 per month, respectively, for the year of 2017 and corrected accordingly on the other years).

Table 44: Agents' income compared to World Bank, PBF, and PBF extreme poverty lines.

Scenario	World Bank	PBF	PBF extreme poverty
Newpol	12 (20-11)	4 (5)	1 (2-1)
Nopol	11 (14-11)	2 (2)	1 (1-1)
Presoldpol	11 (16-11)	4 (5)	1 (2-1)

Values are based on the average of all Sobol' repetitions of income. The minimum and the maximum income values found in Sobol' repetitions are presented in brackets, respectively.

There is not much variation for the scenarios, although the Nopol scenario is slightly better, presenting fewer agents under the different poverty lines.

Minimum food consumption unmet table: The calculations considered the number of times that the household did not reach minimum food consumption standards for each food item. The food consumption events were counted twice a year, considering all staples and animal protein items at the pre and post-harvest periods. In the Yield curve 13, no events of unmet food consumption were found for these scenarios.

Other consumption unmet table: The number of times households did not reach the minimum standards of nonfood items' consumption is presented in Table 45. With minor differences, the Presoldpol is the scenario to show fewer events of unmet consumption, followed by Nopol and Newpol.

Table 45: Total number of events when nonfood items minimum consumption was not met, per household.

Scenario	N of times (average)	N of times (minimum)	N of times (maximum)
Newpol	34	3	34
Nopol	33	5	33
Presoldpol	32	3	32

Calculations were based on the average values of all Sobol' repetition, maximum and minimum values.

Indicators of agricultural intensification

Use of annual crops production: Bar plots were used to show the share of produced crops used for selling to the regular market or the cooperative, for consumption, or for keeping the seeds. Total crops grown by all agents were summed up for each of the simulation periods and averaged for the Sobol' repetitions (Figure 41).

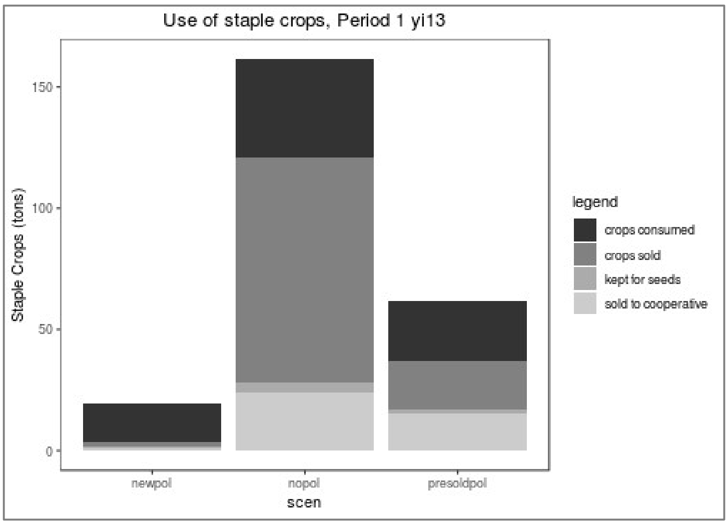

Figure 41: Bars representing the total use of staple crops production.

Agents in the Nopol scenario produced much more annual crops, followed by Presoldpol and Newpol, respectively. In Nopol, most crops grown were used for selling to the regular market, although a share was sold to the cooperative. Both Nopol and Presoldpol scenarios can use their products for all the available activities. The Newpol scenario was not keeping the staples for seeds.

Comparison between the amount of food produced and food bought: Bar plots were used to show the food consumed source. The total amount of food was summed up and averaged for the Sobol' repetitions (Table 46, Figure 42).

Table 46: Values for food consumption sources.

	Newpol			Nopol			Presoldpol		
	aver	min	max	aver	min	max	aver	min	max
Food bought	68.26	52.72	142.32	40.45	35.08	46.91	52.50	45.95	59.63
Food produced	20.04	15.15	44.68	44.34	38.00	51.98	28.79	24.57	34.13

Total consumption, summed per simulation, is averaged between Sobol' repetitions. Maximum and minimum values are also presented.

The Nopol scenario presents a more significant share of its staple crop consumption. On the other hand, the Newpol shows the greater amount of food bought and the greater total consumption.

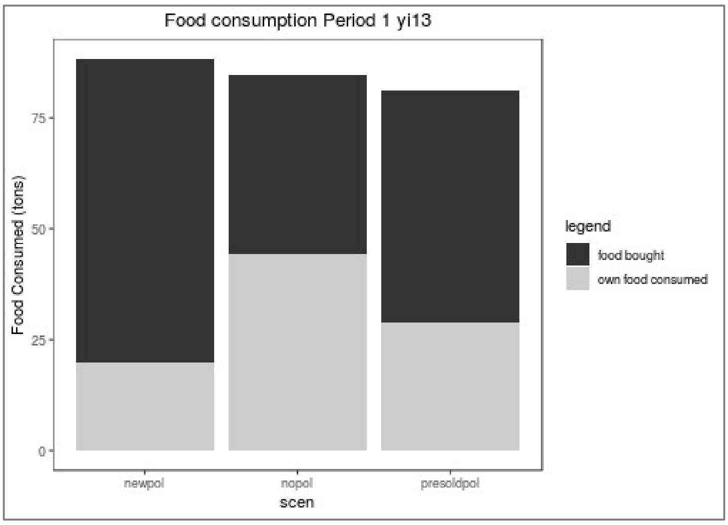

Figure 42: Total amount of food consumed and their sources.

The number of agents engaged in different economic activities: Table 47 presents the average, minimum and maximum values (among Sobol' repetitions) of the number of agents practicing various economic activities.

Table 47: Total number of agents engaged in different economic activities.

Scenario	Economic activity	Number of agents	min	max
Newpol	Annuals production	34	34	34
Nopol		48	48	48
Presoldpol		43	43	43
Newpol	Perennials production	38	38	38
Nopol		38	38	38
Presoldpol		38	38	38
Newpol	Livestock raising	49	47	51
Nopol		49	47	52
Presoldpol		49	46	51
Newpol	Forest extraction	23	23	23
Nopol		23	23	23
Presoldpol		23	22	23

The average values of agents in the Sobol' repetitions are presented, followed by the minimum and maximum.

The Nopol scenario shows more agents on staples production, followed by Presoldpol. Livestock raising, perennials production and forest extraction are implemented by the same number of agents in all scenarios.

Use of household labor: Household labor was calculated by summing all agents' labor (person/days) and then averaging among Sobol' repetitions (Figure 43). Labor types are differentiated between agricultural work, implemented for annuals and perennials production, forest extraction, and out of farm work. Table 48 shows the minimum and maximum values for each labor type and political scenario extracted from Sobol' repetitions.

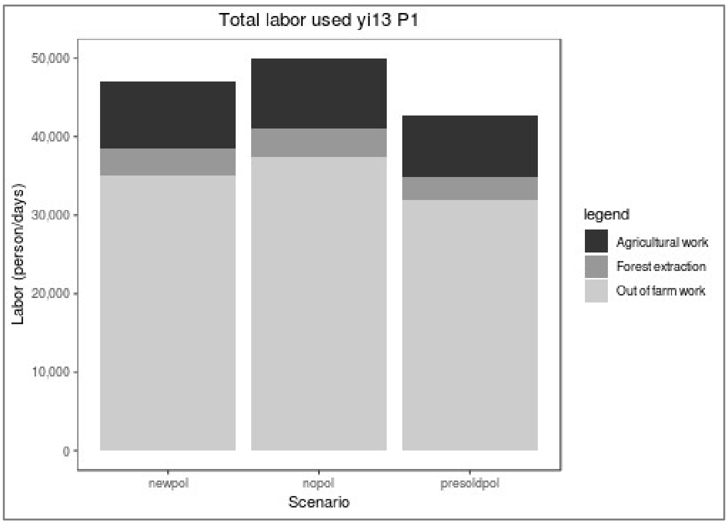

Figure 43: Bars representing the total labor used in the community, distributed in different activities.

The scenario to use less labor is Presoldpol, followed by Newpol and Nopol. The proportion of each labor type is similar in all scenarios.

Table 48: Values for the different uses of total household labor.

	Newpol			Nopol			Presoldpol		
	aver	min	max	aver	min	max	aver	min	max
Agricultural work	8598.47	7775.71	15712.00	9001.88	8980.00	9020.22	7806.43	7759.28	7851.87
Out of farm	34992.96	24454.98	70745.68	37444.00	28925.26	45572.75	31976.25	24870.98	38656.02
Forest extraction	3483.53	1692.92	8179.43	3533.02	1934.01	5677.22	2806.69	1410.66	4731.43

The values were averaged among Sobol' repetitions, and the minimum and maximum values were also calculated.

The total area dedicated to annuals and perennials production: The total area of all agents dedicated to annuals and perennials was summed up and averaged among Sobol' repetitions (Figure 44). Table 49 presents the minimum and maximum values.

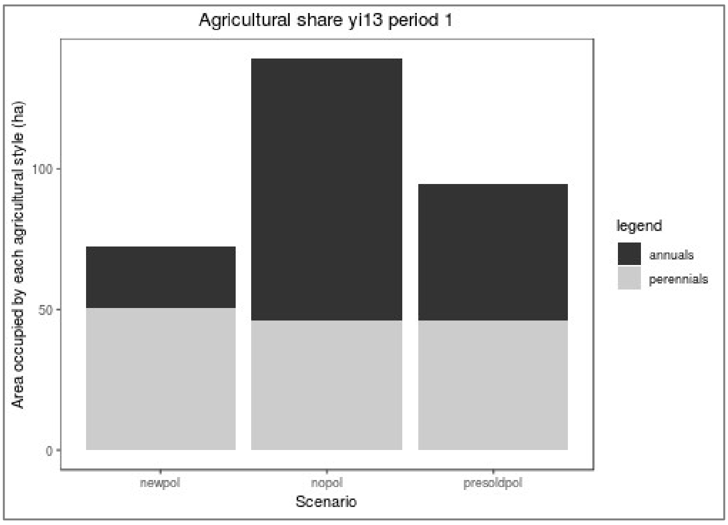

Figure 44: Bars representing the total area dedicated to annuals and perennials production.

The perennial area is the same for Presoldpol and Nopol but more extensive in the Newpol. The area dedicated to annuals is larger in the Nopol, followed by Presoldpol and Newpol.

Table 49: Values calculated for agriculture, including the total area (ha) used for annuals and perennials production.

Scen	Ann aver	Ann min	Ann max	Per aver	Per min	Per max
Newpol	349.47	291	728	811.8	738	1476
Nopol	1490.7	1231	1737	738	738	738
Presoldpol	772.93	778.93	715	844	738	738

Average among Sobol' repetitions are presented first, followed by the minimum and maximum.

Landscape structure: Land use management structure in all political scenarios can be seen in Figure 45. It presents the average area among all Sobol' repetitions calculated from the sum of each land use type. For this analysis, the area blocked by FCPs (most of the mature forest) was not considered, which is why there are no late fallow forests in some scenarios. The plots refer to the area available for management and the use made of it.

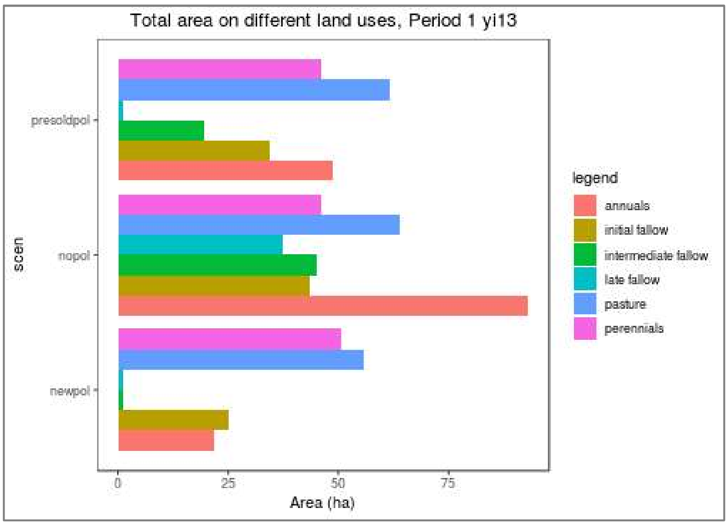

Figure 45: Bars representing the total area dedicated to each land use type.

Agents in the Nopol scenario have larger fallowed areas available for management, as FCPs are not blocking their use and larger areas are dedicated to annuals production. The Newpol is the one to present less available plots for agriculture (all fallow ages). Pasture areas are smaller in the Newpol scenario and similar in the other ones.

GDM results analysis

GDM outputs consist of maps representing the ß diversity/dissimilarity values of each cell (Figure 46). These values range from 0.531261 to 0.785625. The No Forest and Only Forest scenarios illustrate how the landscape ß diversity would be in extreme conditions[40] (already exposed in Chapter 6).

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[40] The No Forest scenario represents the extreme situation where the whole territory is under some type of management, and the Only Forest scenario represents the situation where the whole territory is under mature forest.

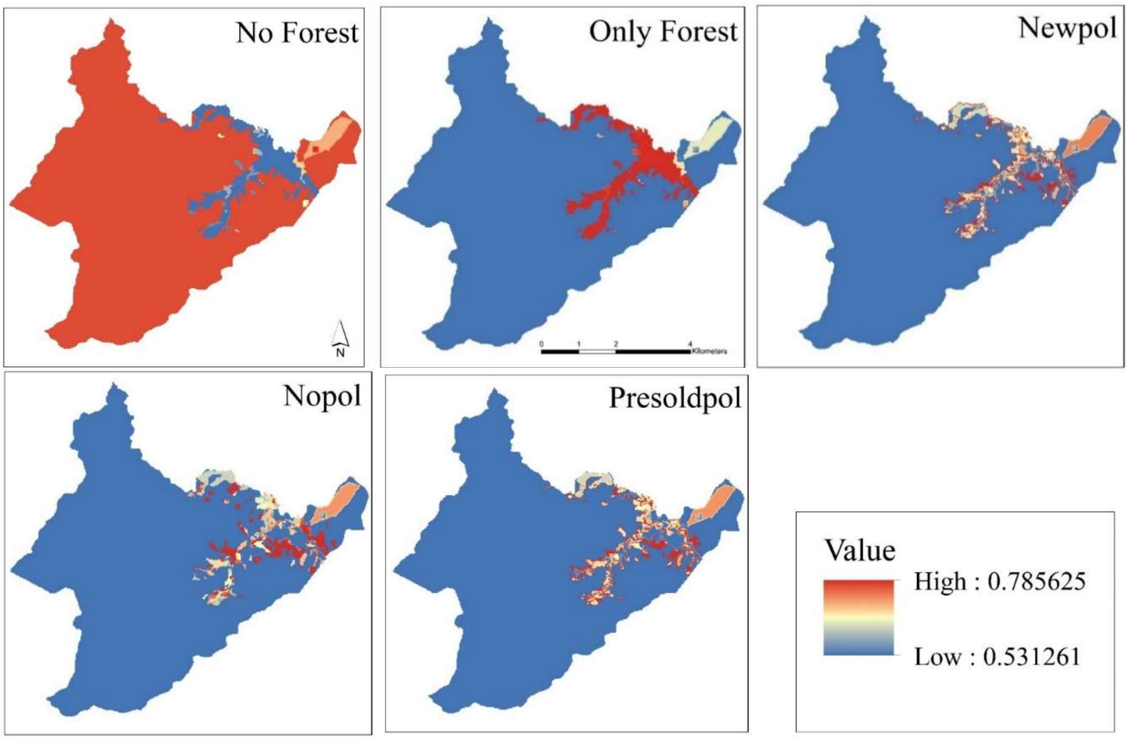

Figure 46: Results from GDM simulations, showing ß diversity (dissimilarity) values per landscape unit.

From the visual interpretation, the Nopol scenario presented larger areas under bigger change and, together with Newpol and Presoldpol, several plots under intermediate change. To find more precise comparisons between political scenarios, I run other procedures like calculating the total amount of modification in the territory. This was a simple procedure of summing up the dissimilarity values from all landscape cells (Table 50).

Table 50: Result from the sum of all cell index values, based on the average area of each cell type, multiplied by the dissimilarity values.

Scenario	Score of change	Std dev
Newpol	2050	0.18
Nopol	2053	1.54
Presoldpol	2056	
Only Forest	2092	--
No Forest	2925	--

By estimating the value of change in the whole territory, I can observe that Newpol is the scenario to change less and Presoldpol to change most, among political scenarios. Still, values are close if compared to the extreme situation scenarios. Patches presenting the higher values in the Newpol and Nopol scenarios include those that were forest before and were submitted to management by agents, representing the diminishment of the community diversity in these patches. Compared to the clustering of predictors' biological spaces, the great majority of the ß community variation in the Nopol scenario occurs over the share of the territory where trees community is constrained by water. In the Newpol and Presoldpol, it occurred mainly over the same part and partially over the area that is most influenced by human occupation.

Ranking scenarios

This rating compares the scenarios on their environmental quality performance (explained in Chapter 6). The main weight factor in this estimation is the fallow age transformation through time: when it gets older, it is higher, and vice-versa (Table 51).

Table 51: Results of the ranking scenarios method.

Scenario	Score	Relative Score
No forest	-664657.90	0
Nopol	-14666.00	89.64
Newpol	13603.07	93.53
Presoldpol	21509.35	94.62
Only forest	60487.05	100

The values of No Forest and Only Forest scenarios show extreme positive and negative situations. The Newpol scenario is closer to the Only Forest scenario. The Nopol scenario is the one to present the lower score, probably because more fallow and forest areas were converted to agricultural uses, as indicated by the land use bars in Figure 45.

Landscape metrics

I implemented landscape metrics to understand the landscape's complex spatial and temporal dynamics (explained in Chapter 6).

Number of Patches: Patch types were grouped into classes by calculating the total number of patches for every political scenario (Table 52).

Table 52: Total number of patches of each class.

Class	Newpol	Nopol	Presoldpol
Area under management	39	59	39
Initial fallow (1-10 years)	108	83	132
Medium fallow (11-39 years)	103	68	159
Late fallow (40-59 years)	11	3	14
Mature forest (60 to older)	16	13	80

The Nopol scenario presents more patch units under management but fewer of all other classes. The Presoldpol scenario has more areas under all fallow ages and mature forest.

Classes total area: Table 53 shows the extension of each class, obtained by the sum of the patch types areas. The classes proportion to the whole territory are also presented.

Table 53: Classes total area (ha) for different political scenarios.

Class	Newpol	%	Nopol	%	Presoldpol	%
Area under management	105.81	2.78	205.49	5.40	144.90	3.76
Initial fallow (1-10 years)	68.06	1.79	77.86	2.05	58.46	1.52
Medium fallow (11-39 years)	97.75	2.57	60.48	1.59	77.05	2.00
Late fallow (40-59 years)	15.44	0.41	4.15	0.11	13.88	0.36
Mature forest (60 to older)	3546.75	92.45	3456.83	90.85	3556.30	92.36

The Nopol scenario has the larger area under management and initial fallow and the minor under mature forest. The Newpol has the larger size under medium, late fallow, mature forest, and the smaller under management. From the Newpol to the Presoldpol scenario, the area under management increases, to the cost of all the other classes that diminish their area. In the case of Nopol, most of the new management is used from the mature forest and medium fallow.

Shape index: Patch type values of shape index were aggregated by average to compose the different classes (Table 54).

Table 54: Shape index for the different classes.

Class	Newpol	Nopol	Presoldpol
Area under management	1.37	1.37	1.33
Initial fallow (1-10 years)	1.19	1.19	1.09
Medium fallow (11-39 years)	1.27	1.27	1.20
Late fallow (40-59 years)	1.35	1.18	1.28
Mature forest (60 to older)	1.06	1.06	1.09

The Presoldpol scenario presents lower values for areas under management, initial and medium fallow, where the other two scenarios have the same values. However, the higher index value of mature forest patches– and therefore more spatial complexity – is found in the Presoldpol scenario. On the other hand, the Newpol scenario shows more spatial complexity in the late fallow.

Aggregation Index: Table 55 presents the aggregation values of different classes obtained by the average of the patch types. The areas under management to be more permeable to species (less aggregated) are found in the Newpol, whereas the Presoldpol presents more permeable initial and medium fallow areas.

Table 55: Aggregation index for the different classes, for the political scenarios.

Class	Newpol	Nopol	Presoldpol
Area under management	79.87	82.34	81.47
Initial fallow (1-10 years)	62.92	79.59	54.56
Medium fallow (11-39 years)	60.24	69.22	57.69
Late fallow (40-59 years)	85.30	94.33	72.41
Mature forest (60 to older)	98.45	98.75	98.51

Simpson's diversity index: Simpson's diversity index reflects the probability that any two randomly selected cells would be of different types (Table 56). Here, the Nopol scenario has a more diverse landscape.

Table 56: Simpson's diversity index.

Scenario	Index
Newpol	0.143
Presoldpol	0.144
Nopol	0.171

The diversity index doesn't consider the ecological or socioeconomic importance of patch types and can reflect a diversity of undesired types. In the case of the tree, most classes are vital habitats, except for the areas under management, which are types 0 and 1 and represent a small portion of the territory. However, in the Nopol scenario, I find more plots under management than the other scenarios on a landscape that is of mature forest in its majority. Therefore, it might reflect fewer habitats available in the Nopol if compared to others.

Discussion

FCPs socioeconomic impacts in Pedro Cubas

Different consequences of FCPs implementation on local people's livelihoods are described in Chapter 2. In Ribeira Valley, most *Quilombola* communities were not displaced but were submitted to other constraints. In our model, according to the economic classes and headcount ratio results, the analyzed FCPs are not making a difference in *Quilombola*'s general economic conditions. However, they are a bit worse when FCPs are implemented. On the other hand, the absence of an FCP and the implementation of the older FCP led to an improvement in agents' income, diminishing the number of agents below the poverty lines, improving non-food consumption standards, leading to higher annuals production, sales, and higher consumption of own crops. Additionally, more area was available for agriculture, agents were more engaged in SC and used less labor in general. In most cases, the Nopol scenario showed a better performance than Presoldpol (and Newpol), except for the labor force.

For being more restrictive to land use and management, the newer version of FCP is the one to present less available areas for agriculture and, therefore, lower staples production, causing a worsening of different well-being conditions. Agents have, for example, to buy more food to compensate for restrictions on staples production and produce more perennials. However, the same number of agents engaged in livestock raising, perennials production, and forest extraction indicates that the existence of FCPs does not impact these economic activities.

The high increase in staples production, observed in the Nopol scenario, allows agents to diversify the activities for their use. Additionally, the Nopol land use types variation shown in the landscape structure bar plots indicates that intermediate fallow areas are preferred for SC if available, since they are more fertile. This is one of the leading indicators of how FCPs are limiting staple production, reinforcing that the availability of productive areas for staple production impacts household wealth and food security.

FCPs effectiveness: *Quilombola* landscape structure and ß diversity

The Newpol scenario is the one to present larger areas of intermediate and late fallows, together with mature forests, which is preferred for conservation, in principle. Both the Presoldpol and Nopol scenarios have smaller areas under perennials but more areas under pasture. The expected consequence of eliminating conservation policies would be converting late fallow to crop production, doubling the size under management, and increasing initial fallow areas. The existence of conservation policies leads to more sites under late fallow and less under initial fallow. Yet, I am arguing about the conversion of 2.62% of the territory, according to our simulations.

Regarding shape, I have observed that the implementation of the older FCP version has caused the reduction of landscape permeability in areas under management and initial and medium fallow areas, but a higher complexity of mature forest. At the same time, the absence of FCPs caused the loss of permeability in late fallow areas but no change in the other classes. Aggregation results showed that the older FCP version had caused more permeable initial, medium and late fallow areas, whereas the absence of restrictions leads to less permeability in all classes.

Interestingly, the Nopol scenario revealed a higher diversity index value. It could be interpreted as higher diversity of habitats and a positive outcome from the exclusion of SMA 027. Still, results indicate that this variation was caused by more significant areas under management in a landscape dominated by forest. In parallel, when referring to changes revealed by GDM results on the total ß diversity, the Nopol and Presoldpol scenario values are close to the Newpol. However, the more significant change was observed in the Presoldpol. Comparing the difference between Newpol and Nopol values (3 units of change) to the difference between Newpol and No Forest scenarios (900 units of change) indicates that the absence of conservation policies won't cause a significant impact on the local forests. Possible negative effects are pretty low if compared to the possibility of completely removing the local forest.

And, finally, the higher levels of forest conversion caused the ranking values to be lower in the Nopol scenario but still high if compared to the complete conversion of the forest (No forest scenario). However, the Presoldpol scenario is the one to achieve a closer result to complete forest conversion. Moreover, the forest landscape matrix is a primary condition for all scenarios; the presence or absence of FCPs won't affect ecological dynamics directly in the territory with low population density and covered mainly by mature forest.

Tradeoff analysis

A trade-off analysis was performed to rank political scenarios by comparing both models' results simultaneously. Therefore, I evaluated the socioeconomic and environmental performances among the political/economic scenarios simultaneously.

Values from 1 to 5 were attributed to the scenarios, where five was given to the best performance. All previously described results analyses were selected, and I produced a rank for well-being performance and another for forest conservation performance. In the well-being rank, I considered as a better performance those scenarios with higher income values, where staple crops were consumed in larger amounts and where consumption was unmet fewer times (Table 57). In the conservation rank, I attributed higher values for those scenarios with larger areas of old fallow or mature forests, more occasional forest extraction events happened, smaller areas were dedicated to any use type, landscape metrics showed better landscape conditions for conservation, and where GDM outputs presented better biological conditions for the studied tree community (Table 58). Additionally, I included the total performance value by summing up all values.

Table 57: Scenarios ranking based on well-being performance.

Well-being performance	Newpol	Presoldpol	Oldpol	Nopol	Past
Average income	3	4	1	5	2
Economic class positions	3	4	1	5	2
Head count ratio	1	2	3	4	5
Poverty position evaluation – World Bank	3	4	2	5	1
Poverty position evaluation – Bolsa Família	3	3	5	4	1
Poverty position evaluation – Bolsa Família extrema pobreza	2	2	5	3	4
Food consumption unmet	2	2	2	2	1
Other consumption unmet	2	4	5	3	1
Use of annuals (consumption)	1	3	2	4	5
N° of agents producing staples	1	3	2	4	5
Total food consumption	4	1	3	2	5
Food sources	1	3	2	4	5
Household labor use	3	5	1	2	4
Share of perennials/annuals area	1	4	3	2	5
Area blocked by FCPs	1	3	2	5	5
TOTAL	31	47	39	54	51

Table 58: Scenarios ranking based on ecological performance.

	Ecological performance	Newpol	Presoldpol	Oldpol	Nopol	Past
MPMAS outputs	Area dedicated to perennials	3	2	4	2	5
	Area dedicated to pasture	4	3	1	2	5
	N° of agents practicing forest extraction	1	1	1	1	4
Landcape metrics	Total area under management	4	3	2	1	5

	Total area of mature forest	5	4	2	1	3
	Total area of late fallow forest	5	4	3	1	2
	Diversity index	1	2	4	5	3
	Shape index for areas under management	3	1	3	3	3
	Shape index initial fallow	4	1	2	4	3
	Shape index intermediate fallow	4	1	2	4	5
	Aggregation index for areas under management	4	2	3	1	5
	Aggregation for initial fallow areas	3	5	4	1	2
	Aggregation for intermediate fallow areas	4	5	3	2	1
	TOTAL	45	34	34	28	46
	TOTAL PERFORMANCE	76	81	73	82	97

The Past scenario was the one to present the best combination of well-being and ecological conditions. At the same time, the worst was found in the Oldpol scenario and second-worst in the Newpol. By plotting the results, one can better visualize scenarios' performances (Figure 47). The Nopol scenario has the best performance on farmers' well-being but the worse on conservation standards. On the other hand, the scenario with better conservation performance (Past) has the second-best well-being performance.

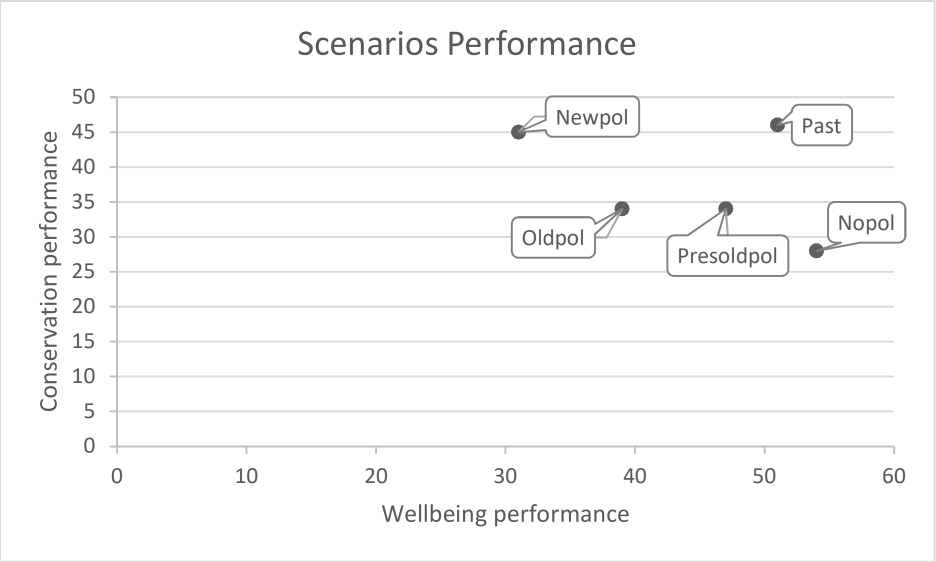

Figure 47: Scatter plot showing scenarios performance on well-being and ecological conservation standards.

Results indicate that if farmers' behavior is guided by production and consumption optimization, the well-being conditions are better in the present, without any FCP implemented. On the other hand, the Past scenario shows that practicing exclusively SC is less impacting conservation, and the well-being performance is relatively good. The *Quilombola* SCS experienced socioeconomic transformations and diversification of agricultural activities that changed the balance between socioeconomic gains and conservation priorities. In other words, for the present scenarios, well-being conditions significantly improve when removing FCPs' restrictions, but environmental conditions change to the worst scenario (Nopol). Also, implementing the most restrictive FCP moves the scenario to the worst well-being conditions (Newpol). Based on these results, SC should no longer be the main culprit of forest biodiversity loss since it's the less harmful activity practiced.

Is it possible to suggest different strategies for environmental conservation?

The tradeoff analysis results showed that FCP implementation plays a relevant role in conservation in the present context, when agricultural intensification occurs, and activities such as perennials and pasture are established. This fact suggests that the more isolated *Quilombos,* still relying solely on SC (as the examples of Bombas and Praia Grande in Chapter 3), are causing even lower environmental impacts on their territories' landscape. Based on that, I recommend the differentiation of rules implemented over these territories. More flexible policies or their absence could assure subsistence in the communities that don't access economic alternatives without compromising forest conservation.

Instead of being treated as drivers of deforestation, *Quilombolas* should be perceived as allies for forest conservation and construct new functional links between livelihoods and biodiversity. Furthermore, participatory conservation approaches are suggested to include local people in the decision-making processes, which helps prevent conflicts with state and park managers and reduce monitoring costs. On the same token, the local knowledge on biodiversity and ecological processes has to be highlighted due to its importance for forest conservation.

Perennials plantation is one of the main drivers of ecological impacts, but it is also responsible for the higher income share. Therefore, one of the options for landscape conservation in the long term would be to replace perennials with other profitable but less impacting activities. The other option is to transform it into a less harmful activity to the environment by establishing consortiums with other crops or orchards, turning patches more permeable to other species, preserving the soil (i.e., agroforestry system), replacing agrochemical inputs, and therefore avoiding soil and water pollution. However, perennials establishment has to follow a unique model, determined by the credit program, including agrochemicals (fertilizers and pesticides) and commercial seedlings.

Finally, offering economic alternatives to Juçara palm extraction is a must for the Atlantic Forest conservation since this palm tree was initially very abundant in the understory layers - reaching 50% of the individuals in mature forests -, and is a crucial resource for the local fauna.

THESIS SECTION IV – CONCLUDING REMARKS

Chapter 8: Conclusion

Quilombola communities in the Ribeira Valley have faced the pressure of different drivers of change in the last decades, responsible for a transitional process in their livelihood dimensions. Among such drivers, São Paulo State's FCPs have constrained their traditional agricultural system, causing conflicts between farmers and the government. The present research was inspired by this challenging scenario and the importance of constructing a territorial land use plan to achieve both Atlantic Forest conservation and economic welfare. This study aimed to evaluate farmers' existing agricultural systems and the perception of FCPs implementation in different *Quilombola* communities. It also aimed to simulate the impact of the recent agricultural transition and FCPs implementation on family wealth, income, land use dynamics, landscape structure, and trees' community β diversity in Pedro Cubas. The chosen modeling tools were the Mathematical Programming-based Multi-Agent Systems (MPMAS) and the Generalized Dissimilarity Modeling (GDM). Here, I bring the conclusions from this study's results. The research questions addressed in this thesis were:

- Is SCS still relevant for *Quilombolas'* subsistence? What is the farmers' perception regarding FCPs implementation?
- What are the consequences of SCSs implementation on the forest landscape (structure and diversity)?
- What are the consequences of the SCS intensification on farmers' wealth, forest landscape structure, and local tree communities' distribution?
- What are the consequences of FCPs application on farmers' wealth, forest landscape structure, and local tree communities' distribution?
- Is it possible to improve family wealth and minimize the ecological impacts of land use simultaneously? What are the best strategies for that?

To address the first question, I hypothesized that only a small share of households would still practice traditional SC, mainly for keeping cultural traditions alive. Results revealed that less than 32% of the families from 14 *Quilombola* communities were practicing SC to some extent. Despite it being practiced by a minority, it was still relevant for subsistence. Additionally, I assumed that the majority of farmers had negative perceptions of FCPs implementation. I found that 83% of the interviewed *Quilombolas* faced some type of problem with the FCPs.

To answer the following question, I used MPMAS and GDM as modeling tools. Regarding the consequences of SCS to the forest landscape, our second hypothesis predicted that the *Quilombola* SCS would promote a diversity of habitats. The landscape metrics results of the Past scenario showed that 92% of the territory was covered by mature forest and 6% by different forest habitats. Therefore, the SCS potentially leads to a higher diversity of flora species and a higher diversity of niches and populations.

To evaluate the consequences of *Quilombola* SCS transitions, our third hypothesis predicted an improvement of family well-being and forest degradation at the same time. The scenarios comparison showed an improvement in average income, accompanied by signs of economic inequality. Simultaneously, the landscape metrics indicated pasture and perennial areas as the main drivers of deforestation. They are more impacting than SCS and were responsible for a less permeable structure for local species. Intensification was also reflected in the diminished rotation of plots, lower diversity of habitats, and lower permeability of fallowed areas. Moreover, GDM results showed a significant change in landscape structure/tree community for at least 10% of the territory in the last decades.

Regarding the consequences of FCPs application, I assumed they negatively impacted farmers' wealth and were responsible for diminishing landscape heterogeneity. The comparison of Nopol, Presoldpol, and Newpol scenarios indicates that well-being conditions improve if FCPs are entirely excluded. In that case, farmers can use more productive plots, produce more staples, consume more of their production, and are less dependent on the external market. In other words, food security is improved. This could happen to the cost of more ecological impacts due to new economic practices such as perennials production, forest extraction, and pasture implementation, but not to SC itself. FCPs implementation prevented the suppression of forested areas on only 2.6% of the territory, and GDM results indicated that the total ß diversity in the territory would not be significantly affected. Alternatives for Pedro Cubas and other *Quilombola* communities under the same context should include FCP flexibilization to SC implementation and the stimulation of new and less impacting economic activities. Constraining land use should focus on the mentioned more impacting activities.

I also presumed the traditional SCS could not provide food security to *Quilombolas* in the present, but farmers have to rely on government subsidies, forest extraction, producer organizations, and perennial crops. Our results showed that when FCPs are absent in the present conditions, livestock raising, perennials, and forest extraction will continue to be practiced and complementing household subsistence.

Our last hypothesis referred to the potential of modeling methods to unveil processes and dynamics from the represented socioecological system. For MPMAS, most dynamics were revealed by the sensitivity and uncertainty analyses, as the variation on staples consumptions among yield curve scenarios, the sensitivity of income to different parameters, and the relative importance of each income source. In parallel, the GDM model's calibration highlighted the importance of environmental predictors of climate for the studied tree community, indicating forest vulnerability to potential climate variability in the future, especially if precipitation regime variation and intensification of droughts are expected.

SCSs may cover 280 Mha nowadays in the tropics, but they are expected to shrink in the following decades until they disappear. Perennial agriculture, urbanization and forest conservation are among the many drivers that limit the access to land and ecosystem services provision of shifting cultivators, threatening their livelihood security if no development efforts are directed towards these farmers (Heinimann et al., 2017). Our findings indicate that SC will resist in the future as a safety net for *Quilombolas*, partly thanks to the presence of new social actors who have supported them. However, the central SC practice encouragement comes from *Quilombolas* and their willingness to keep traditions alive for socio-cultural reasons and livelihood security, combined with their political empowerment, greater participation in debate arenas, and decision processes.

Contributions

One of the main contributions of this work was assessing current SCS practices in the Ribeira Valley region and the conflicting context generated by FCPs restrictions (Chapter 3). This research showed to policymakers and state organizations the importance of SC for *Quilombolas'* livelihoods. After this, the new resolution (SMA 189 from 2018) included SC as forest management, shifting from the perception of an impacting activity. Additionally, the government has opened the possibility of establishing land use plan agreements in partnership with *Quilombolas*.

The innovation of this research relies, at first, on the integration of MPMAS, GDM, and landscape metrics for modeling an agricultural system. MPMAS has been combined and coupled to various other tools, but GDM and landscape metrics are integrated for the first time. The experience reinforces the flexibility of these modeling tools and the multiple possibilities of performing simulation experiments for different purposes at multiple levels.

There is also a novelty in analyzing economic and environmental outcomes from the simulation of agricultural transition and FCPs impacts, using real-world data, with SC as a central subsistence strategy. I was able to uncover emergent dynamics of the social-ecological system, such as the sensitivity of income to crop prices and perennial yields and how agricultural intensification interferes with the FCPs' impacts.

The discussion of SCS sustainability is still an open chapter. The literature on this topic is vast but usually not based on the result of modeling complex systems. The simulation of the context where SCS was traditionally practiced indicates the relationship between *Quilombolas* and the forest was sustainable. However, this is context-specific and depends on combining a series of factors (low population density, low impact technology, and long-term fallow plots) that I cannot find in present times.

The experiment implemented in Pedro Cubas could be replicated to other contexts of smallholder agriculture, not necessarily to evaluate FCPs but other policy impacts or climate changes, or even for other purposes, such as territorial planning.

Finally, I expect that Quilombolas embrace the results of the modeling experiments as instruments of negotiation with the government and policymakers. I hope the results will contribute, to some extent, to conflict resolution, improvement of smallholders' livelihoods, and poverty conditions.

Future research

During the Thesis development, a list of topics to be further developed emerged. First, I indicate more research on the household characteristics and processes related to the decision on growing staples. Such a decision is crucial to understanding the studied social-ecological system, and it seems to be not purely economic behavior. Unfortunately, our dataset was not able to show all influencing drivers.

I modeled one *Quilombola* community for the limitations in our dataset, although it is located in a region of dozens of others. Sampling other communities' households would be interesting for including different contexts, increasing the sample size (diminishing the uncertainty in the model), and for the possibility of new processes emergence.

The complex relationship between crop yield, soil fertility and fallow age is one of the most challenging parameters to be estimated. Fertility is subject to fallow development, impacting aboveground biomass, soil structure, soil nutrients, among other factors. In the case of mountainous areas, aspect, altitude and slope add even more complexity. A modeling tool would be appropriate, in this case, to assist in the input estimations with all the complexities involved and the necessary specificities of the agricultural plots. I indicate LUCIA (Land Use Change Impact Assessment tool) or similar tools that can include most of the essential factors influencing this relationship.

The Atlantic Forest hosts a high level of biodiversity, and I was able to include only 19 tree species in our model. I recommend modeling other plant species distribution because it would increase our knowledge about the local forest dynamics. In this sense, modeling animal species would be interesting as well and complementary to the flora knowledge. I also recommend the use of different methods for species distribution modeling.

In the present Thesis, I aimed at improving the analysis of conservation policies and *Quilombolas* territorial planning. However, I haven't included the possibility of climate variation. Therefore, I suggest that future modeling attempts could consider climate changes and the possible impacts on crop productivity and the local flora.

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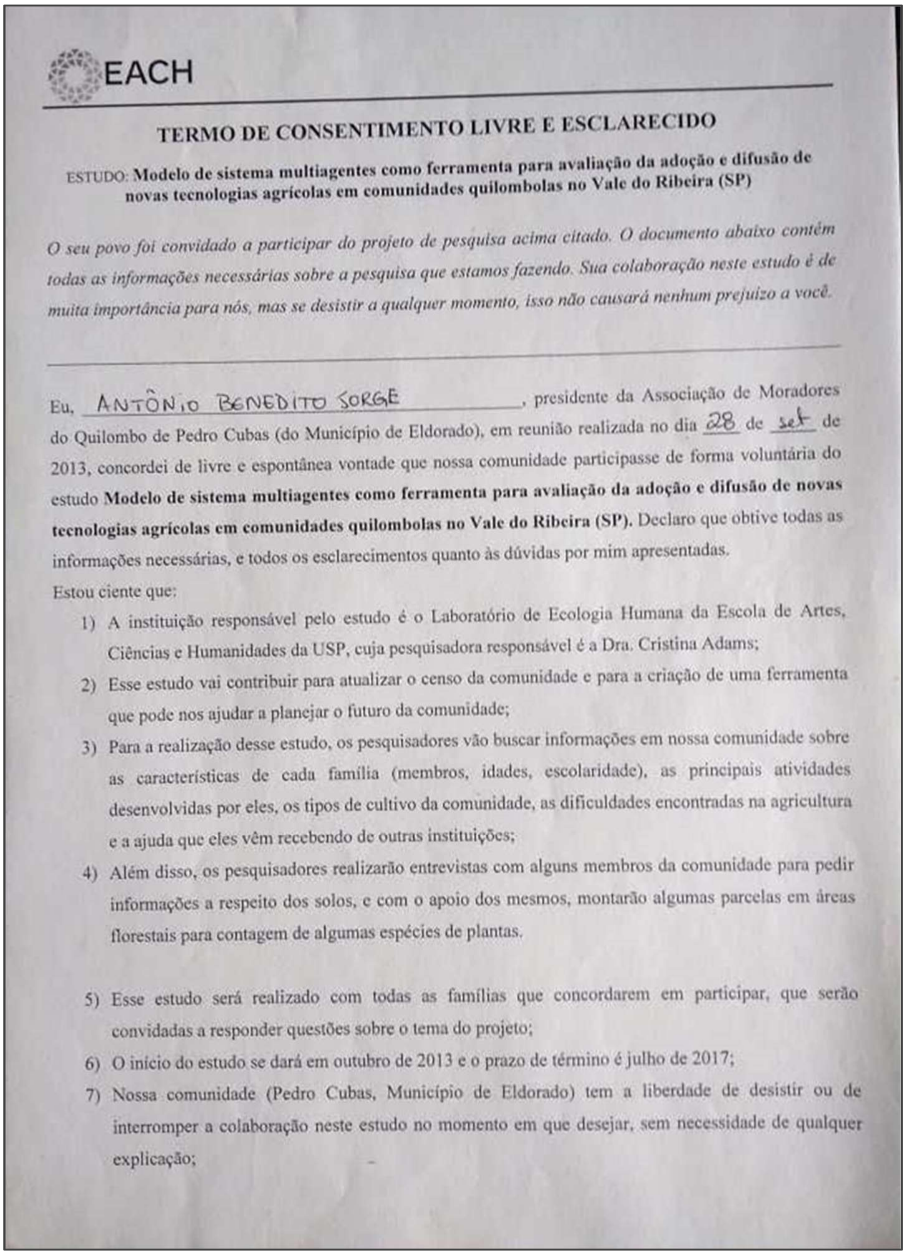
Appendix A: Consent Form

The following consent form was obtained in 2013 September, allowing this research to happen. It was signed by Pedro Cubas, association president, two testimonies, and the project responsible researcher.



EACH

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

ESTUDO: **Modelo de sistema multiagentes como ferramenta para avaliação da adoção e difusão de novas tecnologias agrícolas em comunidades quilombolas no Vale do Ribeira (SP)**

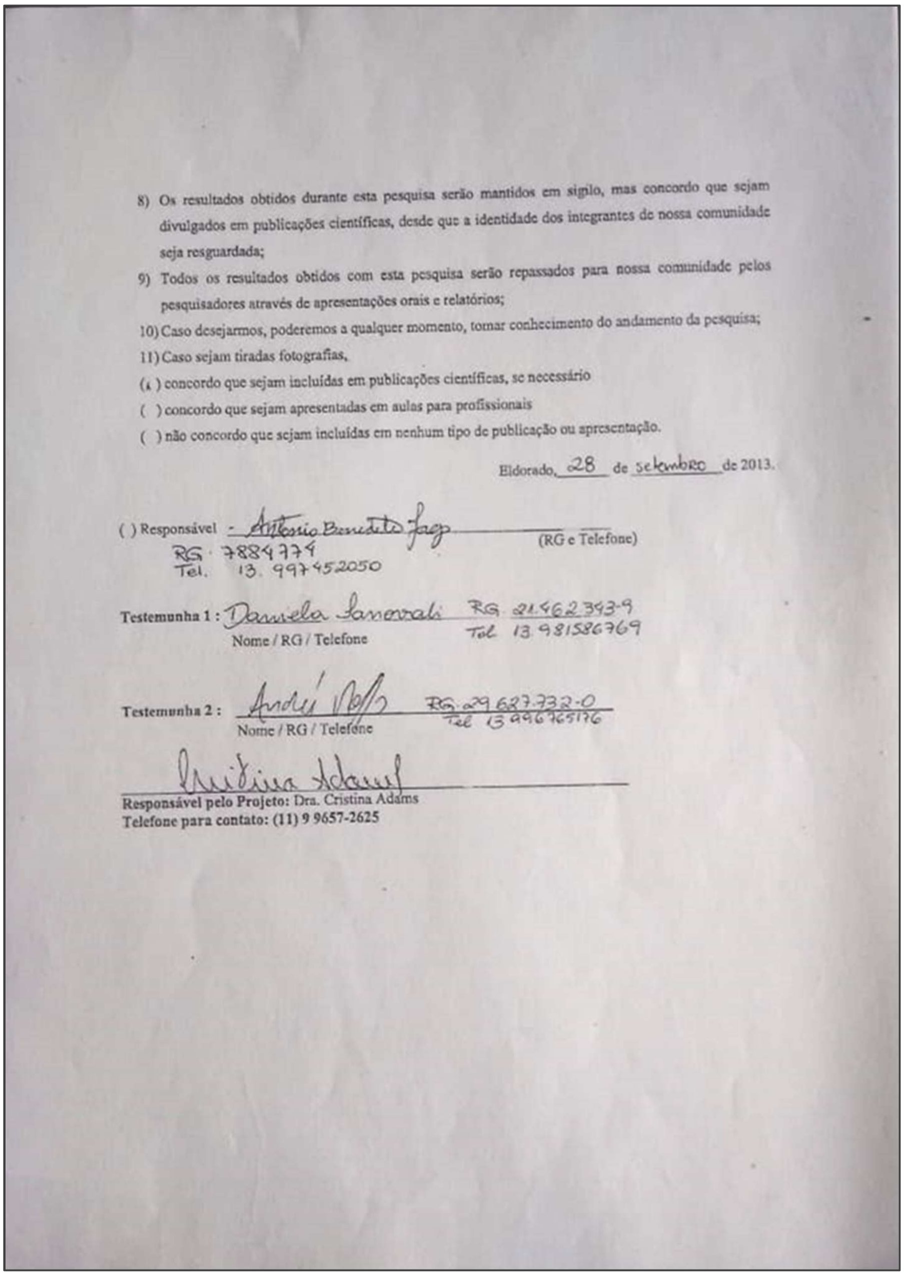
O seu povo foi convidado a participar do projeto de pesquisa acima citado. O documento abaixo contém todas as informações necessárias sobre a pesquisa que estamos fazendo. Sua colaboração neste estudo é de muita importância para nós, mas se desistir a qualquer momento, isso não causará nenhum prejuízo a você.

Eu, ANTÔNIO BENEDITO SORGE, presidente da Associação de Moradores do Quilombo de Pedro Cubas (do Município de Eldorado), em reunião realizada no dia 28 de set de 2013, concordei de livre e espontânea vontade que nossa comunidade participasse de forma voluntária do estudo **Modelo de sistema multiagentes como ferramenta para avaliação da adoção e difusão de novas tecnologias agrícolas em comunidades quilombolas no Vale do Ribeira (SP).** Declaro que obtive todas as informações necessárias, e todos os esclarecimentos quanto às dúvidas por mim apresentadas.

Estou ciente que:

1) A instituição responsável pelo estudo é o Laboratório de Ecologia Humana da Escola de Artes, Ciências e Humanidades da USP, cuja pesquisadora responsável é a Dra. Cristina Adams;
2) Esse estudo vai contribuir para atualizar o censo da comunidade e para a criação de uma ferramenta que pode nos ajudar a planejar o futuro da comunidade;
3) Para a realização desse estudo, os pesquisadores vão buscar informações em nossa comunidade sobre as características de cada família (membros, idades, escolaridade), as principais atividades desenvolvidas por eles, os tipos de cultivo da comunidade, as dificuldades encontradas na agricultura e a ajuda que eles vêm recebendo de outras instituições;
4) Além disso, os pesquisadores realizarão entrevistas com alguns membros da comunidade para pedir informações a respeito dos solos, e com o apoio dos mesmos, montarão algumas parcelas em áreas florestais para contagem de algumas espécies de plantas.

5) Esse estudo será realizado com todas as famílias que concordarem em participar, que serão convidadas a responder questões sobre o tema do projeto;
6) O início do estudo se dará em outubro de 2013 e o prazo de término é julho de 2017;
7) Nossa comunidade (Pedro Cubas, Município de Eldorado) tem a liberdade de desistir ou de interromper a colaboração neste estudo no momento em que desejar, sem necessidade de qualquer explicação;



8) Os resultados obtidos durante esta pesquisa serão mantidos em sigilo, mas concordo que sejam divulgados em publicações científicas, desde que a identidade dos integrantes de nossa comunidade seja resguardada;
9) Todos os resultados obtidos com esta pesquisa serão repassados para nossa comunidade pelos pesquisadores através de apresentações orais e relatórios;
10) Caso desejarmos, poderemos a qualquer momento, tomar conhecimento do andamento da pesquisa;
11) Caso sejam tiradas fotografias,

(x) concordo que sejam incluídas em publicações científicas, se necessário
( ) concordo que sejam apresentadas em aulas para profissionais
( ) não concordo que sejam incluídas em nenhum tipo de publicação ou apresentação.

Eldorado, 28 de setembro de 2013.

( ) Responsável - Antonio Benedito (RG e Telefone)
RG. 7884774
Tel. 13. 997452050

Testemunha 1 : Daniela RG. 21.462.343-9
Tel 13.981586769
Nome / RG / Telefone

Testemunha 2 : André RG. 29.627.732-0
Tel 13 996765176
Nome / RG / Telefone

Cristina Adams
Responsável pelo Projeto: Dra. Cristina Adams
Telefone para contato: (11) 9 9657-2625

Appendix B: GDM exploratory analyses

Principal Component analysis

The resulting eigenvalues – an indicator of the amount of variance accounted for all axes – are shown below. PCA on the grids shows fewer predictors because fewer soil types were found on the collection plots than on the whole territory. Those values show us that the first component takes most of the data variation in both cases.

For the whole territory:

```
  PC1    PC2    PC3    PC4    PC5    PC6    PC7    PC8
14.914 4.666 2.429 2.153 1.448 1.124 1.062 0.989
(Showing 8 of 30 unconstrained eigenvalues)
```

For the grids:

```
  PC1    PC2    PC3    PC4    PC5    PC6    PC7    PC8
16.709 3.669 2.552 2.284 1.643 1.018 0.700 0.587
(Showing 8 of 26 unconstrained eigenvalues)
```

I also took the values of the coefficients of variables against the first two principal components for the whole landscape and the grids (Figures B.1 and B.2, respectively). For the entire territory PCA, the lower PC1 values occur on altitude, Bioclim 14, 17, and 19 (related to precipitation). The higher values are found on Bioclim 1, 5, 6, 8, 9, 10, 11, and 15 (all related to temperature except for 15: precipitation seasonality). On PC2, the lower values refer to Bioclim 12, 16, and 18, all referring to precipitation, and the higher values found on Bioclim 2, mean diurnal range of precipitation. PC1 accounts for most of the variation on altitude, precipitation, and temperature, while PCA2 is mainly related to a variation on precipitation.

```
                      PC1         PC2
Land_use     -0.093032520 -0.13658276
soil_CAL      0.008295224  0.15599128
soil_CGNFNQ   0.073019536  0.04853375
soil_CL      -0.013540332 -0.01105615
soil_CNL     -0.049380297 -0.14918742
soil_NCL     -0.018186045 -0.01449492
altitude     -0.240842069 -0.03544164
aspect        0.032755934  0.01848958
slope        -0.061615101 -0.07482499
rugosity     -0.192508174 -0.05626061
```

```
dist_houses -0.153084166 -0.20105596
dist_roads  -0.113633948 -0.16710823
dist_matfor  0.079797312  0.12320428
dist_river  -0.073981066 -0.01165427
bioc_1       0.249107263  0.04600306
bioc_2      -0.088784371  0.41266236
bioc_3      -0.015340550  0.32916500
bioc_4      -0.174390237  0.04756133
bioc_5       0.247640444  0.06241852
bioc_6       0.250953917  0.02348831
bioc_7      -0.112614365  0.36599051
bioc_8       0.248557233  0.04416773
bioc_9       0.250469017  0.04312691
bioc_10      0.247812630  0.04631979
bioc_11      0.250469017  0.04312691
bioc_12     -0.153828931 -0.32056616
bioc_13      0.192663713 -0.29752876
bioc_14     -0.234337510 -0.08833033
bioc_15      0.248632940 -0.03462546
bioc_16      0.177508737 -0.32435707
bioc_17     -0.237561304 -0.02062842
bioc_18      0.163534230 -0.32010058
bioc_19     -0.237561304 -0.02062842
```

Figure B.1: PCA variables coefficients on the first and second principal components, for the whole territory.

On the grids, the lower coefficient values occur on Bioclim 17 and 19 (precipitation) and the higher of Bioclim 6 and 15 (Min Temperature of Coldest Month and Precipitation Seasonality). On PC2, the higher coefficient value is found on Bioclim 12 (annual precipitation), and the lower value is found on soil CNL. In this case, PC1 and PC2 are accounting for precipitation, mostly.

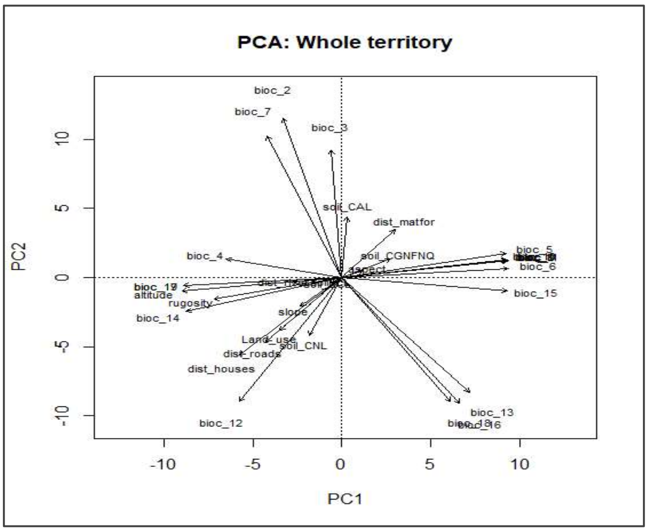
```
                  PC1          PC2
Land_use     0.0003360625 -0.099032962
soil_CAL    -0.0847680870  0.243878649
soil_CGNFNQ  0.0700639955  0.195327115
soil_CNL    -0.0231994388 -0.297578862
altitude    -0.2264001353 -0.101010837
aspect       0.0343752282 -0.136301376
slope       -0.1050822170 -0.176618406
rugosity    -0.1929418285 -0.125094981
dist_houses -0.0328042749  0.215431943
dist_roads   0.0205728233 -0.068567576
dist_matfor -0.0086699156  0.264142300
dist_river  -0.0638077502  0.036990424
bioc_1       0.2248098925 -0.148370102
bioc_2      -0.2026731988 -0.242180087
bioc_3      -0.1725762474 -0.235400839
bioc_4      -0.2189126065  0.005069246
bioc_5       0.2152680934 -0.183844545
bioc_6       0.2364347602 -0.083976835
bioc_7      -0.2049108222 -0.226878806
bioc_8       0.2248492420 -0.145816806
bioc_9       0.2277969269 -0.139807949
bioc_10      0.2223431519 -0.152840118
bioc_11      0.2277969269 -0.139807949
```

```
bioc_12      0.0830536318  0.400455926
bioc_13      0.2262679661  0.153726497
bioc_14     -0.2176421744  0.156387815
bioc_15      0.2413415467 -0.043319072
bioc_16      0.2213386002  0.171489672
bioc_17     -0.2300017152  0.119601622
bioc_18      0.2125661740  0.160129222
bioc_19     -0.2300017152  0.119601622
```

Figure B.2: PCA variables coefficients on the first and second principal components, for the grids.

Figure B.3 presents biplots produced by PCA. The higher spectrum of variation on the components was found in the whole territory PCA. This is completely expected as it comprises the larger area but also the grids PCA was restricted to a smaller spectrum of altitude/aspect/slope, for referring only to agricultural plots. Also, the variables are positioned on a more concentrated shape on the territory analysis, showing more explicit correlations among predictors. On the graph for the whole territory, it is also clear that most of the Bioclim variables are highly influenced by the first principal component, and some to the second, i.e. the variables 2, 3 and 7. Altitude and rugosity are highly influenced by PC1 and correlated, together with Bioclim variables for precipitation.

I conclude that, among all variables included for the exploratory analyses, precipitation, and temperature-related Bioclim variables, together with altitude and slope, are the variables to vary the most within the *Quilombolas* territory. On the grids, a smaller number of variables are influenced by PC1, but they are representing temperature and precipitation as well.



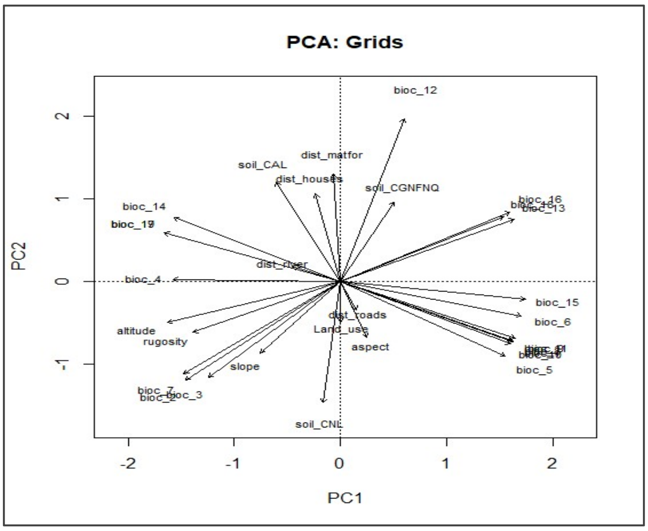


Figure B.3: Biplots to represent the PCA analysis over the whole territory (including three *Quilombola* communities) and the grids where they were collected.

Detrended Correspondence Analysis (DCA)

I implemented a Detrended Correspondence Analysis (DCA) to ensemble individuals of the 19 species in each plot and across transects. The result was a scatterplot, positioning the ensembles along axes according to their similarities or differences in their floristic composition (Figure B.4). The resulting axes are often used to infer ecological gradients that significantly influence these ensembles' characteristics. The visual analysis helped us identify through the position of ensembles, which were these ecological factors.

All transects in the field were split into five parts (a to e), where a was consistently higher and closer to the mature forest area. When applying the sessions of each transect to a DCA, I could see that, for each group of species, there was no pattern of distribution along the transect, which means that the distance to the mature forest is not playing a role in the species distribution.

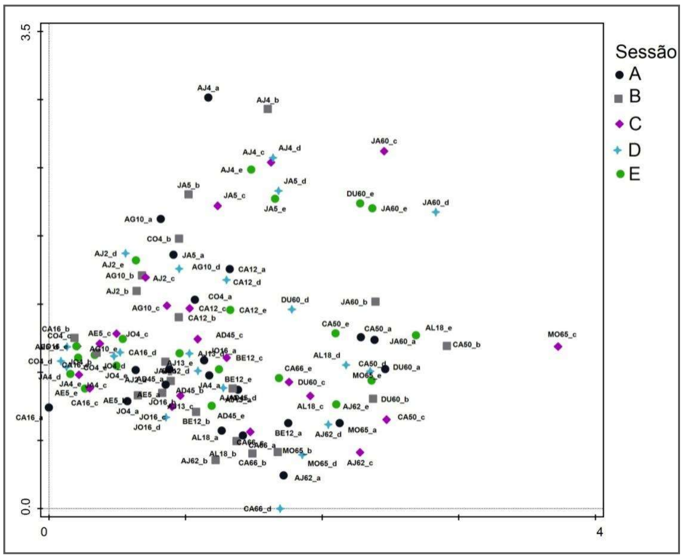


Figure B.4: Result of a DCA analysis for the sessions a to e of each of the transects in the fallow plots.

However, by plotting the whole species ensembles of each fallow plot and the ensembles of individuals of each species (differentiated by the number of individuals and the fallow plots they appear in), I could find a pattern of distribution. Figure B.5 shows fallow plots (represented by characters and numbers indicating fallow age) and species (represented by 'sp' plus a number). The axes represent the ecological factors that are causing this distribution. Fallow plots are distributed according to their age: almost all old fallow plots are together on the left side; intermediate areas are in the middle, sometimes mixed with young fallow areas, which are positioned more to the right. Species allocation in the scatterplot is similar to the distribution of the fallow plots: typical species of younger fallow are placed to the upper right, in the same direction as young fallow areas. Species that are abundant in the intermediate ages of fallow occupy the lower right and upper left. Finally, the large species in older areas are positioned to the lower-left area.

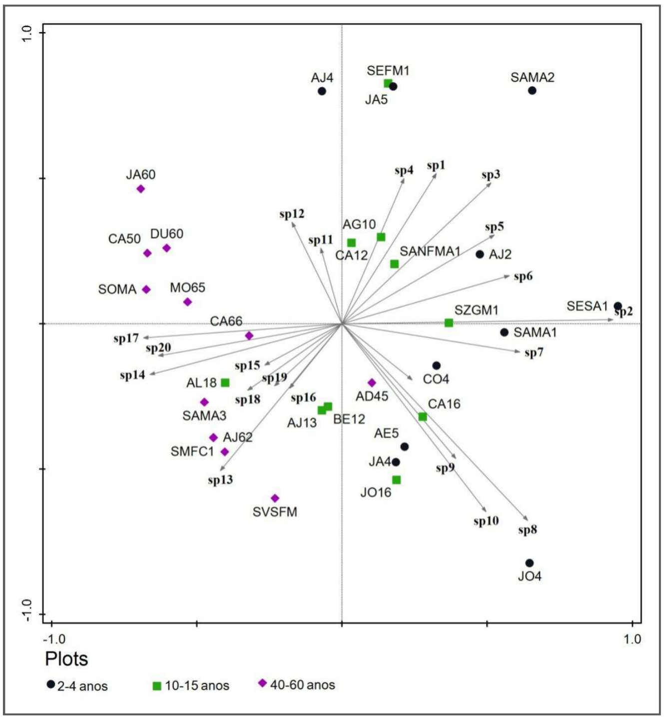
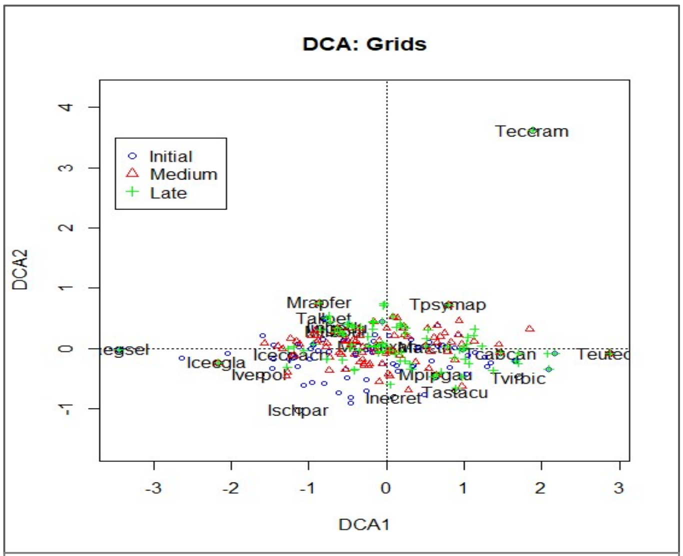


Figure B.5: Results of a DCA analysis for the fallow plots (represented by characters and numbers). The symbols indicate the group age of each fallow plot. The species are represented by ‘sp’ and a number (sp1-sp7: indicators of young fallow areas; sp8-sp13: intermediate fallow areas; sp14-sp19 abundant species on old fallow plots). sp1*: Cecropia glaziovii,* sp2: *Cecropia pachystachya,* sp3: *Nectandra reticulata,* sp4: *Schizolobium parahyba,* sp5: *Vernonia polyanthes,* sp6: *Aegiphylla sellowiana,* sp7: *Inga edulis,* sp8: *Tibouchina pulchra,* sp9: *Alchornea triplinervia,* sp10: *Rapanea ferruginea,* sp11: *Campomanesia xanthocarpa,* sp12: *Piper gaudichaudianum,* sp13: *Psychotria mapourioides,* sp14: *Euterpe edulis,* sp15: *Astrocaryum aculeatissimum,* sp16: *Allophyllus petiolulatus,* sp17: *Cabralea canjerana,* sp18: *Guapira opposita,* sp19: *Ecclinusa ramiflora,* sp20: *Virola bicuhyba.*

In general, species abundance and distribution of plots are shown as expected, apart from the fact this particular group of species could not indicate tree dispersion or the distance to mature forest areas. However, it is far from giving us information on how species will be distributed throughout the landscape, depending on the scenarios/policies I run. To achieve and discuss the final results, several procedures have to be performed.

Figure B.6 shows the ordination plot produced by DCA analysis, showing the species distribution and points of the collection (311 units) for the two environmental first axis and on transects (251 units). Each of the represented points corresponds to one of the species. As a matter of better visualization, the DCA for the grids plot was repeated with the exclusion of *Ecclinusa ramiflora,* as it configures an outlier among the others.


DCA: Grids
Initial
Medium
Late
Teceram
Mrapfer
Tpsymap
Talbet
egsel
Iceegla
Icecpach
Iverpol
Mpipgau
Tcabcan
Tvirbic
Teuteo
Inecret
Tastacu
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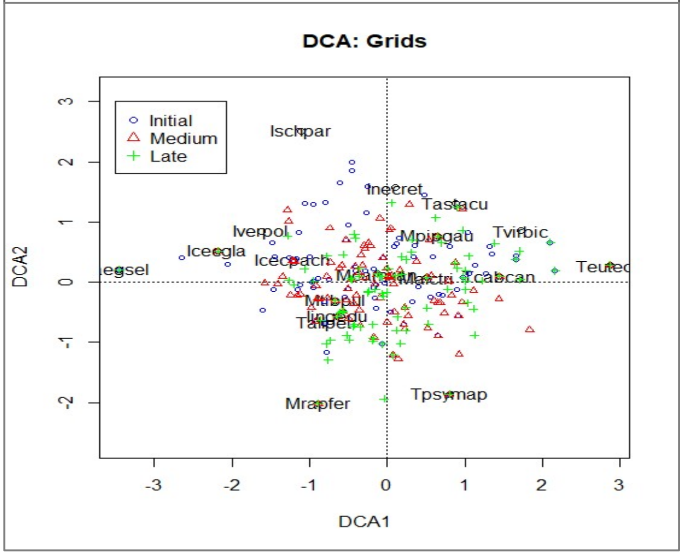
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2
3

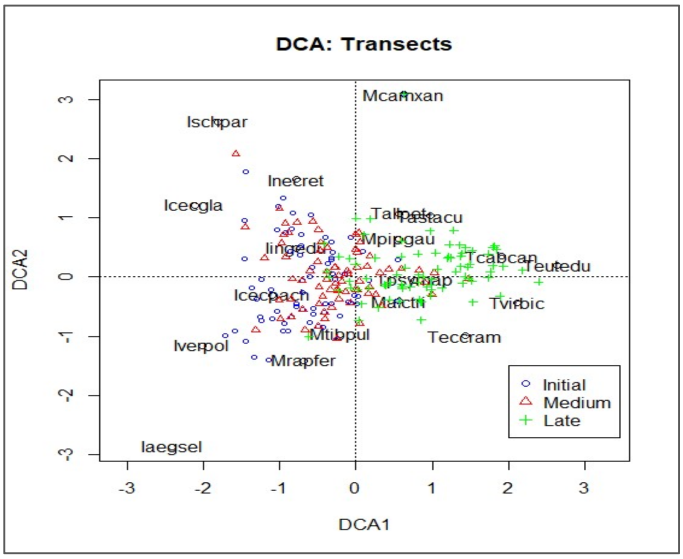


Figure B.6: Scatter plots produced by the DCA analysis for the grids and the transects. The one provided for grids was repeated without the outlier (Teccram). The first words letter indicates the fallowing group: I = initial, M = medium, and T = late fallow age. Plots are distinguished in the fallow age group they belong to on their points representation. Species codes represented are: *Cecropia glaziovii* – Icecgla*; Cecropia pachystachya* – Icecpach; *Schizolobium parahyba* – Ischpar; *Nectandra reticulata* – Inecret; *Vernonia polyanthes* – Iverpol; *Aegiphylla sellowiana* – Iaegsel; *Inga edulis* – Iingedu; *Tibouchina pulchra* – Mtibpul; *Alchornea triplinervia* – Malctri; *Rapanea ferruginea* – Mrapfer; *Piper gaudichaudianum* – Mpipgau; *Campomanesia xanthocarpa* – Mcamxan; *Astrocaryum aculeatissimum* – Tastacu; *Guapira opposita* – Tguaopp; *Psychotria mapourioides* – Tpsymap; *Cabralea canjerana* – Tcabcan; *Allophyllus petiolulatus* – Tallpet; *Euterpe edulis* – Teutedu; *Ecclinusa ramiflora* – Teccram; *Virola bicuhyba* - Tvirbic

The DCA2 axis is a bit wider on its range on the grids. Species are distributed along the axis DCA1 according to the fallow age in both cases, although not in the same order. Probably DCA1 refers to land use or any correlated environmental predictor. On the other hand, the distribution of plots does not make it that clear in the case of the grids, where the ages of fallow plots are more mixed on their distribution. In transects, where environmental variation and the number of species are higher, plots distribution also fits an axis representing the fallow process. DCA1 has species and plots more distributed, and DCA2 shows more distribution on transects.

DCA2 differs on each scatter plot, showing different species on their extremities, and the transects scatter plot reveals species and samples are more distributed along this axis. On the grids, the extremities species are *Ecclinusa ramiflora* and the opposite *Schizolobium parahyba*. The former was only found on the first botanical data collection in 2008, meaning it is registered in our dataset for the west portion of samples only, including environmental specificities, which could explain its distance to the others and the position to indicate a turnover on the community. On the transects, the DCA2 axis doesn't indicate any pattern, although the presence of *Camponanesia xantocarpha, Schizolobium parayhba,* and *Nectandra reticulada* on one extreme and the opposite *Vernonia polyanthes*, *Rapanea ferruginea,* and *Aegiphylla sellowiana* might indicate differences in water needs or water stress tolerance. Anyway, DCA2 for transects could be a different predictor than DCA2 on the grids, although it is not clear for our interpretation.

I expected to infer the main ecological gradients influencing the studied distribution patterns with the DCA, revealing similarities or differences in their floristic composition. Instead, DCA on transects shows more differences among species and sampling sites than the grids. One of the reasons might be the more significant average number of species found on them (4.5 against 3.7 on the grids), as one transect potentially includes more than one grid. The forest succession process is evident on the first axis, but the other axis does not show conclusive results. Next, I have complementary results for the scatter plots: Eigenvalues and axis lengths for DCA analyses (Table B.2).

Table B.2: Detrended correspondence analysis results for grids and transects.

DCA	Axis 1	Axis 2	Axis 3	Axis 4
Grids Eigenvalues	0.6134	0.4573	0.4116	0.3601
Grids axis lengths	6.3241	4.5388	4.3598	3.6168
Transects Eigenvalues	0.5230	0.3170	0.2864	0.2536
Transects axis lengths	4.1141	4.4911	4.0884	2.7441

The maximum axis length indicates the point where a complete species turnover takes place. For example, the maximum value for the grids was 6.3 SD. In comparison, the maximum for transects was 4.5 SD, meaning the community taken within the transects is more capable of responding to environmental drivers than the community within the grids. This is expected because one transect contains more ecological variation than one grid, which has only one value per predictor.

Spearman's correlation

Spearman's correlation analysis was also implemented to show strong variables correlations. Table B.3 shows, for analyses on the grids and on the whole territory, among which environmental predictors, these strong correlations were found.

Table B.3: Strong correlations and anticorrelations found on Spearman's test for environmental predictors, both for the whole landscape and the grids samples.

Grids	Whole territory
Soil CNL * Soil CGNFNQ	Land use* Distance to mature forest
altitude*rugosity* Bioc_1:Bioc_11, Bioc_13: Bioc_19	altitude*rugosity* Bioc_1* Bioc_6* Bioc_8: Bioc_11* Bioc_14* Bioc_15* Bioc_17* Bioc_19
slope*rugosity	Bioc_2* Bioc_3* Bioc_7* Bioc_13* Bioc_16* Bioc_18
Bioc_3* Bioc_12* Bioc_13* Bioc_16* Bioc_18	Bioc_4* Bioc_14* Bioc_15* Bioc_17* Bioc_19
	Bioc_12* Bioc_14

I can observe strong correlations between two soil types on the grids, altitude to rugosity and Bioclim variables, slope to rugosity, and other Bioclim variables. Strong correlations were found on the whole territory: land use to distance to mature forest patches and many correlations between Bioclim variables. More correlations are expected for the entire territory for the reason they are many more samples. Correlations among Bioclim variables are also expected as they are different measures for temperature and precipitation only. Correlations between rugosity and altitude or slope are also expected, as the former is calculated by combining altitude and slope.

Appendix C: Validation results

Nash-Sutcliffe model efficiency coefficient (NSE)

NSE coefficients are presented for MPMAS outputs of annuals and initial fallow areas for all yield curves and Sobol' repetitions. Perennials outputs show the same results for all scenarios (0.999) and therefore are not presented.

Table C.1: NSE coefficients for annuals area, for all Sobol' repetitions and yield curves in the Newpol outputs, and first two simulation periods.

	Annuals - P0/Yield curves						
Sobol	3	4	7	8	11	12	13
1	0.012	0.021	0.231	0.244	0.192	0.000	0.200
2	-0.045	-0.051	0.187	0.196	0.151	-0.034	0.168
3	-0.044	-0.101	0.208	0.200	0.235	-0.045	0.189
4	-0.066	-0.063	0.143	0.145	0.125	-0.056	0.125
5	-0.117	-0.119	0.166	0.150	0.127	-0.064	0.123
6	-0.043	-0.033	0.189	0.187	0.142	-0.014	0.172
7	-0.059	-0.078	0.229	0.245	0.212	-0.040	0.227
8	-0.054	-0.064	0.254	0.224	0.074	-0.054	0.100
9	-0.065	-0.089	0.219	0.099	0.048	-0.043	0.171
10	-0.046	-0.050	0.221	0.201	0.170	-0.016	0.201
11	-0.050	-0.038	0.074	0.073	0.079	-0.019	0.121
12	-0.050	-0.042	0.234	0.216	0.175	-0.031	0.202
13	-0.102	-0.092	0.279	0.282	0.286	-0.087	0.284
14	-0.051	-0.075	0.196	0.189	0.170	-0.047	0.149
15	-0.078	-0.007	0.264	0.249	0.216	-0.037	0.270
16	-0.063	-0.037	0.242	0.264	0.190	-0.039	0.269
17	-0.080	-0.084	0.188	0.189	0.154	-0.061	0.180
18	-0.013	-0.027	0.181	0.181	0.139	-0.026	0.150
19	-0.079	-0.072	0.126	0.128	0.095	-0.066	0.110
20	-0.016	-0.032	0.190	0.190	0.180	-0.040	0.176
21	0.041	0.012	0.238	0.153	0.128	0.000	0.174

22	-0.029	-0.044	0.123	0.121	0.114	-0.038	0.126
23	-0.034	-0.087	0.303	0.301	0.252	-0.034	0.292
24	-0.092	-0.097	0.182	0.210	0.160	-0.015	0.200
25	-0.033	-0.036	0.183	0.183	0.154	-0.027	0.161
26	-0.038	-0.036	0.175	0.191	0.189	-0.013	0.200
27	-0.050	-0.055	0.161	0.177	0.150	-0.043	0.175
28	-0.024	-0.044	0.218	0.227	0.190	-0.015	0.222
29	-0.046	-0.030	0.149	0.138	0.132	-0.038	0.121
30	-0.041	-0.041	0.224	0.270	0.257	-0.040	0.259
Average	-0.049	-0.053	0.199	0.194	0.163	-0.036	0.184
Std dev	0.032	0.032	0.049	0.054	0.055	0.020	0.053
	Annuals – P1/Yield curves						
1	0.198	0.151	0.213	0.209	0.215	0.076	0.168
2	0.200	0.189	0.170	0.187	0.189	0.109	0.134
3	0.110	0.004	0.192	0.198	0.212	0.057	0.145
4	0.182	0.164	0.148	0.144	0.195	0.014	0.153
5	0.202	0.188	0.125	0.099	0.211	0.092	0.100
6	0.198	0.193	0.198	0.189	0.178	0.112	0.151
7	0.001	-0.020	0.201	0.195	0.184	-0.036	0.185
8	-0.014	0.008	0.220	0.222	0.223	0.032	0.132
9	0.192	0.183	0.176	0.057	0.131	0.118	0.125
10	0.163	0.174	0.119	0.148	0.111	0.114	0.105
11	0.174	0.157	0.083	0.077	0.202	0.094	0.100
12	0.049	0.025	0.213	0.175	0.203	-0.004	0.173
13	0.179	0.174	0.230	0.228	0.222	-0.024	0.233
14	0.209	0.192	0.197	0.199	0.228	0.120	0.146
15	-0.012	-0.026	0.190	0.200	0.187	-0.038	0.189
16	-0.008	-0.010	0.238	0.250	0.232	-0.013	0.241
17	0.199	0.181	0.191	0.193	0.205	0.109	0.163
18	0.190	0.192	0.190	0.204	0.205	0.102	0.160
19	0.049	0.034	0.035	0.054	0.079	0.071	0.064
20	0.195	0.205	0.174	0.171	0.229	0.027	0.178
21	0.196	0.178	0.166	0.181	0.154	0.082	0.169
22	0.197	0.197	0.142	0.140	0.227	0.095	0.134

23	-0.006	0.001	0.208	0.218	0.217	-0.043	0.201
24	-0.008	-0.029	0.147	0.155	0.193	0.037	0.144
25	0.179	0.180	0.167	0.177	0.215	0.098	0.158
26	0.197	0.173	0.111	0.125	0.094	0.133	0.111
27	0.189	0.165	0.170	0.191	0.215	0.081	0.170
28	0.038	0.015	0.126	0.151	0.195	0.016	0.140
29	0.185	0.190	0.142	0.127	0.218	0.062	0.132
30	0.192	0.165	0.171	0.200	0.175	0.109	0.188
Average	0.134	0.120	0.168	0.169	0.191	0.060	0.153
Std dev	0.085	0.088	0.045	0.049	0.040	0.054	0.038

Table C.2: NSE coefficients for initial fallow, for all Sobol' repetitions and yield curves in the Newpol outputs, and first two simulation periods.

	Fallow initial - P0/Yield curves						
Sobol	3	4	7	8	11	12	13
1	0.776	0.773	0.713	0.713	0.712	0.740	0.708
2	0.763	0.761	0.701	0.707	0.701	0.731	0.698
3	0.787	0.787	0.665	0.677	0.676	0.755	0.705
4	0.774	0.766	0.704	0.701	0.701	0.750	0.704
5	0.748	0.753	0.714	0.706	0.706	0.757	0.706
6	0.729	0.725	0.652	0.681	0.652	0.723	0.676
7	0.763	0.777	0.688	0.696	0.688	0.724	0.687
8	0.773	0.774	0.712	0.710	0.711	0.744	0.711
9	0.724	0.725	0.636	0.628	0.630	0.718	0.668
10	0.686	0.689	0.588	0.589	0.590	0.696	0.586
11	0.753	0.731	0.694	0.688	0.705	0.731	0.702
12	0.743	0.727	0.674	0.676	0.655	0.721	0.706
13	0.744	0.747	0.711	0.709	0.708	0.757	0.710
14	0.728	0.730	0.712	0.713	0.712	0.721	0.712
15	0.778	0.777	0.681	0.681	0.681	0.759	0.681
16	0.790	0.764	0.663	0.711	0.678	0.724	0.703
17	0.782	0.779	0.746	0.748	0.746	0.781	0.746
18	0.737	0.739	0.717	0.712	0.704	0.738	0.709
19	0.745	0.700	0.586	0.588	0.587	0.710	0.594

20	0.672	0.679	0.713	0.711	0.711	0.739	0.709
21	0.739	0.738	0.633	0.633	0.632	0.712	0.645
22	0.747	0.754	0.708	0.707	0.713	0.746	0.716
23	0.791	0.796	0.694	0.694	0.691	0.741	0.685
24	0.791	0.772	0.699	0.699	0.701	0.719	0.699
25	0.732	0.735	0.717	0.723	0.717	0.728	0.711
26	0.710	0.717	0.618	0.619	0.618	0.715	0.615
27	0.763	0.744	0.705	0.720	0.715	0.743	0.717
28	0.761	0.762	0.691	0.691	0.689	0.698	0.678
29	0.734	0.737	0.686	0.669	0.668	0.738	0.707
30	0.726	0.727	0.651	0.674	0.649	0.729	0.698
Average	0.750	0.746	0.682	0.686	0.682	0.733	0.690
Std dev	0.030	0.029	0.039	0.039	0.039	0.019	0.036
	Fallow initial – P1/Yield curves						
1	0.662	0.651	0.553	0.575	0.581	0.644	0.603
2	0.687	0.690	0.590	0.624	0.617	0.649	0.617
3	0.651	0.646	0.428	0.458	0.448	0.651	0.495
4	0.689	0.701	0.594	0.610	0.589	0.677	0.619
5	0.578	0.653	0.516	0.516	0.516	0.665	0.512
6	0.617	0.612	0.441	0.480	0.432	0.619	0.490
7	0.652	0.689	0.500	0.494	0.500	0.618	0.500
8	0.664	0.677	0.554	0.539	0.547	0.651	0.590
9	0.634	0.636	0.417	0.415	0.419	0.623	0.474
10	0.493	0.507	0.308	0.308	0.310	0.566	0.308
11	0.674	0.651	0.582	0.563	0.573	0.657	0.619
12	0.610	0.595	0.538	0.526	0.529	0.620	0.604
13	0.658	0.673	0.611	0.593	0.591	0.700	0.595
14	0.580	0.571	0.547	0.546	0.552	0.621	0.584
15	0.692	0.692	0.506	0.506	0.507	0.674	0.515
16	0.662	0.670	0.485	0.573	0.543	0.623	0.600
17	0.664	0.651	0.575	0.581	0.581	0.696	0.602
18	0.647	0.597	0.613	0.626	0.617	0.647	0.628
19	0.641	0.582	0.314	0.304	0.307	0.597	0.307
20	0.494	0.468	0.610	0.621	0.620	0.654	0.621

21	0.626	0.623	0.371	0.372	0.372	0.608	0.394
22	0.660	0.644	0.591	0.576	0.598	0.678	0.617
23	0.709	0.710	0.539	0.548	0.555	0.654	0.547
24	0.705	0.687	0.536	0.537	0.553	0.620	0.556
25	0.595	0.576	0.541	0.572	0.579	0.632	0.611
26	0.605	0.602	0.366	0.365	0.366	0.595	0.357
27	0.674	0.669	0.601	0.615	0.593	0.666	0.639
28	0.651	0.646	0.434	0.433	0.434	0.571	0.417
29	0.579	0.597	0.515	0.500	0.499	0.649	0.546
30	0.642	0.643	0.555	0.546	0.562	0.649	0.605
Average	0.637	0.634	0.511	0.517	0.516	0.639	0.539
Std dev	0.053	0.056	0.088	0.090	0.090	0.033	0.097

Efficiency based on standardized absolute error analysis (ESAE)

Table C.3: ESAE coefficients for all Yield curves and Sobol' repetition of the Newpol political scenario.

	P0/Yield curves						
Sobol	3	4	7	8	11	12	13
1	0.676	0.672	0.768	0.763	0.712	0.688	0.768
2	0.693	0.675	0.780	0.773	0.701	0.696	0.783
3	0.670	0.661	0.778	0.772	0.676	0.685	0.775
4	0.685	0.672	0.778	0.778	0.701	0.693	0.776
5	0.686	0.675	0.760	0.760	0.706	0.672	0.761
6	0.692	0.685	0.792	0.787	0.652	0.692	0.788
7	0.689	0.672	0.779	0.779	0.688	0.698	0.780
8	0.673	0.664	0.766	0.766	0.711	0.682	0.761
9	0.703	0.687	0.795	0.796	0.630	0.701	0.789
10	0.727	0.707	0.813	0.810	0.590	0.706	0.818
11	0.690	0.682	0.780	0.782	0.705	0.692	0.772
12	0.687	0.678	0.783	0.783	0.655	0.692	0.775
13	0.694	0.682	0.768	0.767	0.708	0.681	0.766
14	0.690	0.682	0.767	0.765	0.712	0.686	0.763
15	0.671	0.662	0.779	0.778	0.681	0.681	0.784
16	0.664	0.665	0.774	0.754	0.678	0.690	0.763

17	0.678	0.667	0.762	0.760	0.746	0.673	0.761
18	0.690	0.679	0.774	0.775	0.704	0.690	0.781
19	0.701	0.700	0.824	0.821	0.587	0.702	0.827
20	0.712	0.694	0.768	0.769	0.711	0.690	0.774
21	0.699	0.684	0.792	0.788	0.632	0.692	0.786
22	0.692	0.677	0.763	0.763	0.713	0.691	0.762
23	0.665	0.649	0.765	0.764	0.691	0.677	0.772
24	0.661	0.662	0.780	0.779	0.701	0.690	0.775
25	0.693	0.679	0.764	0.761	0.717	0.693	0.774
26	0.716	0.699	0.816	0.812	0.618	0.708	0.812
27	0.685	0.678	0.772	0.760	0.715	0.690	0.766
28	0.682	0.669	0.771	0.771	0.689	0.698	0.778
29	0.694	0.684	0.769	0.773	0.668	0.689	0.766
30	0.700	0.689	0.802	0.795	0.649	0.697	0.786
Average	0.689	0.678	0.779	0.777	0.682	0.691	0.778
Std dev	0.015	0.013	0.017	0.017	0.039	0.008	0.016
	P1/Yield curves						
1	0.754	0.741	0.877	0.874	0.874	0.751	0.865
2	0.754	0.730	0.872	0.860	0.868	0.750	0.866
3	0.751	0.726	0.899	0.888	0.895	0.742	0.889
4	0.749	0.726	0.865	0.865	0.875	0.746	0.863
5	0.785	0.749	0.871	0.873	0.882	0.736	0.872
6	0.764	0.741	0.893	0.890	0.904	0.746	0.888
7	0.738	0.711	0.890	0.892	0.894	0.746	0.891
8	0.732	0.710	0.869	0.869	0.870	0.732	0.854
9	0.760	0.745	0.905	0.901	0.912	0.755	0.893
10	0.814	0.782	0.930	0.927	0.929	0.768	0.931
11	0.753	0.735	0.874	0.877	0.876	0.743	0.858
12	0.751	0.735	0.879	0.883	0.884	0.747	0.863
13	0.758	0.736	0.854	0.859	0.863	0.726	0.855
14	0.778	0.759	0.864	0.872	0.873	0.752	0.862
15	0.731	0.710	0.891	0.890	0.889	0.741	0.887
16	0.729	0.710	0.874	0.854	0.865	0.738	0.852
17	0.761	0.739	0.875	0.873	0.876	0.738	0.866

18	0.768	0.757	0.861	0.856	0.863	0.749	0.854
19	0.756	0.742	0.936	0.936	0.937	0.757	0.932
20	0.786	0.730	0.850	0.851	0.854	0.740	0.851
21	0.783	0.755	0.904	0.899	0.903	0.754	0.899
22	0.762	0.745	0.856	0.859	0.862	0.741	0.850
23	0.717	0.697	0.881	0.876	0.873	0.731	0.879
24	0.725	0.713	0.885	0.884	0.885	0.745	0.880
25	0.763	0.754	0.875	0.866	0.871	0.749	0.860
26	0.783	0.758	0.928	0.926	0.929	0.764	0.929
27	0.751	0.732	0.865	0.853	0.866	0.743	0.852
28	0.742	0.723	0.899	0.900	0.895	0.750	0.903
29	0.784	0.760	0.863	0.863	0.872	0.740	0.856
30	0.761	0.742	0.879	0.878	0.877	0.749	0.865
Average	0.758	0.736	0.882	0.880	0.884	0.746	0.876
Std dev	0.021	0.019	0.022	0.022	0.021	0.009	0.024

Scatter plots for observed and simulated values

Scatter plots were produced to perform visual comparisons between observed and simulated values of different land use categories. All land use classes were aggregated and presented individually and disaggregated. Obtained values resulted from the average of all Sobol's repetitions. However, many of the plots show precisely the same results. For avoiding exhaustion, I present here the examples of different results and mention their repetitions, which will be presented in the supplementary material of the Thesis.

Aggregate results

Yield curves 03, 04, and 12 are identical for both periods and differ from the curves 07, 08, 11, and 13, which are identical among them either.

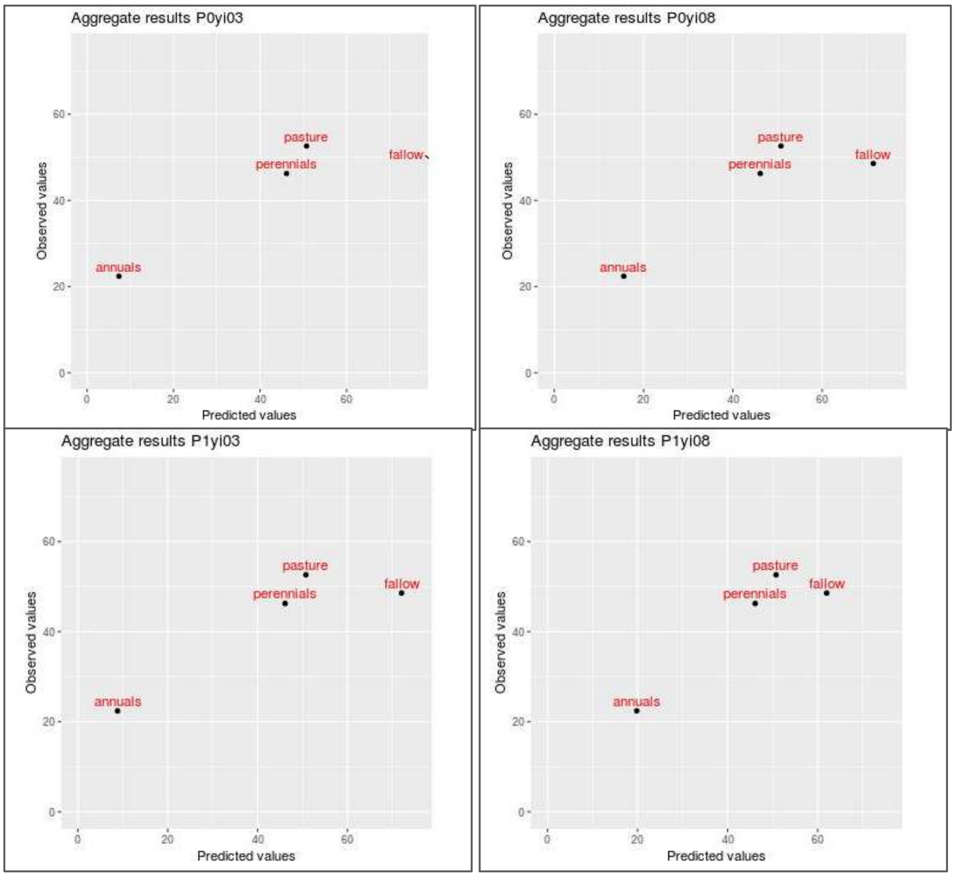
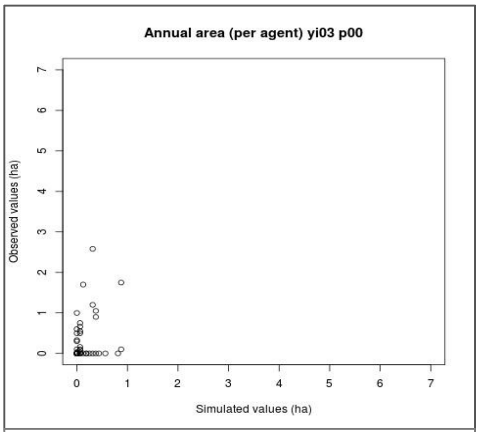
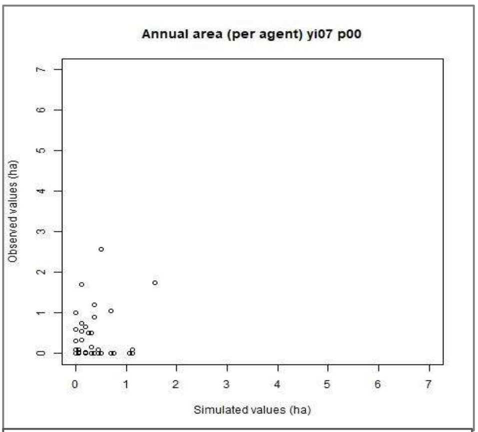


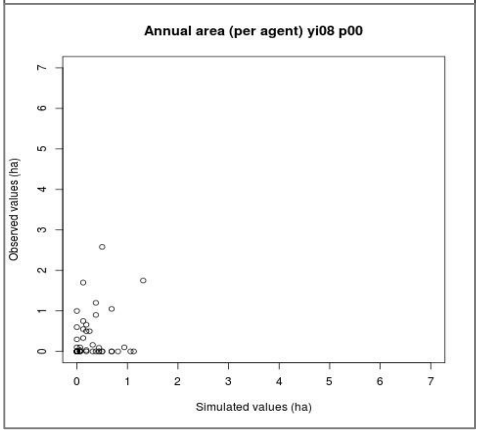
Figure C.1: Comparisons of observed lasses area and model outputs, aggregated.

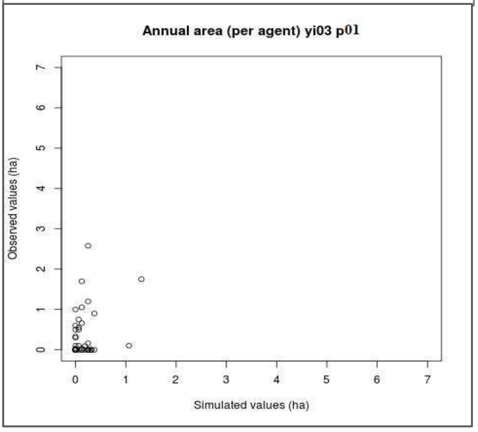
Disaggregated results

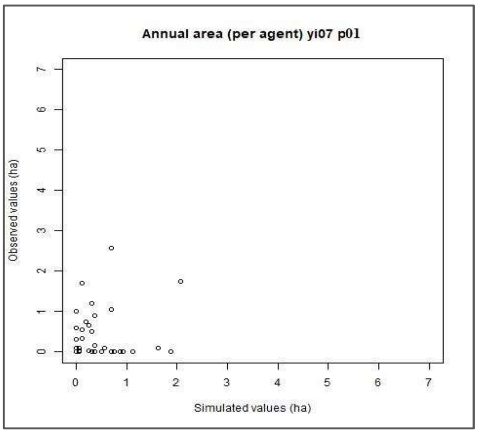
Annuals area: yield cures 03, 04, and 12 are identical, and 07, 11, and 13 are similar. Income and Perennials areas have all yield curves with the same results for both periods. Initial fallow: 03, 04, and 12 are identical, and 07, 08, 11, and 13.

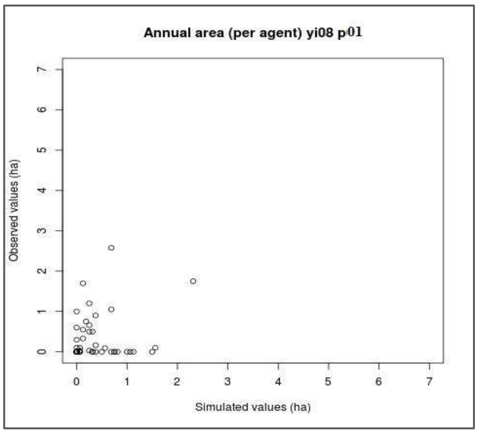

Annual area (per agent) yi03 p00

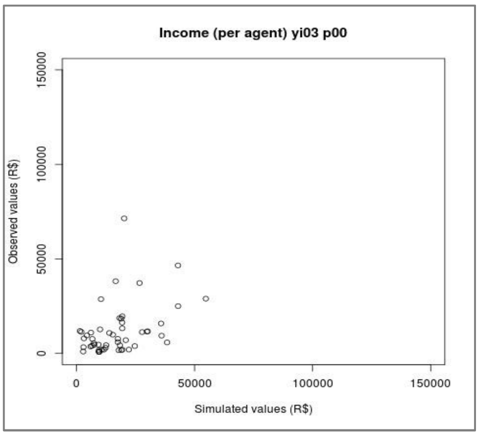

Annual area (per agent) yi07 p00

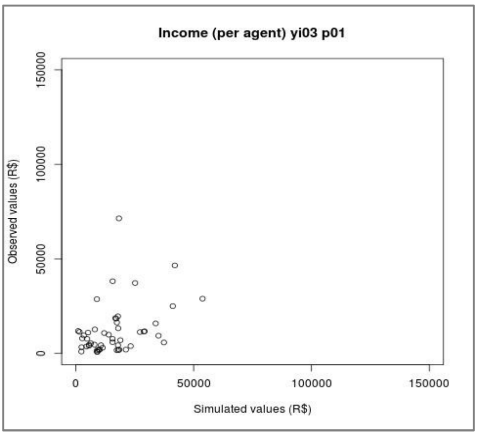

Annual area (per agent) yi08 p00

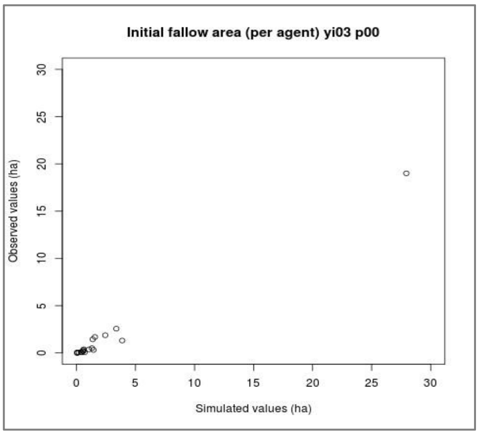

Annual area (per agent) yi03 p01

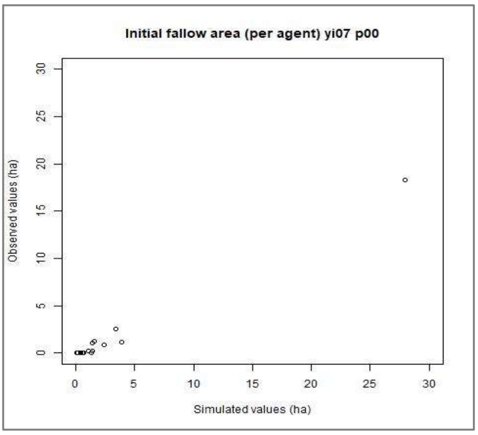

Annual area (per agent) yi07 p01

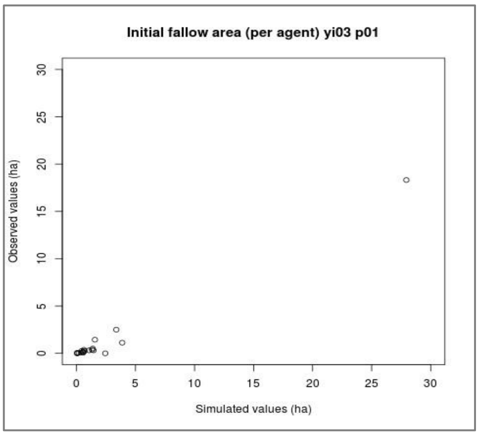

Annual area (per agent) yi08 p01

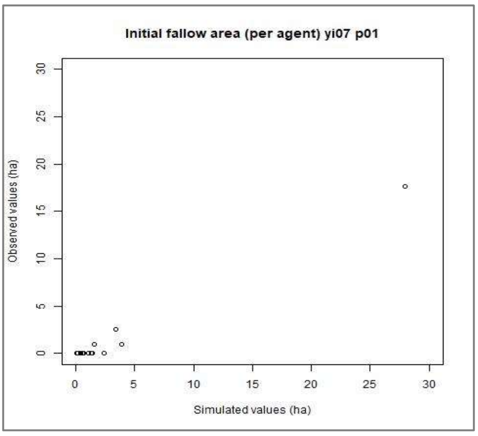

Income (per agent) yi03 p00

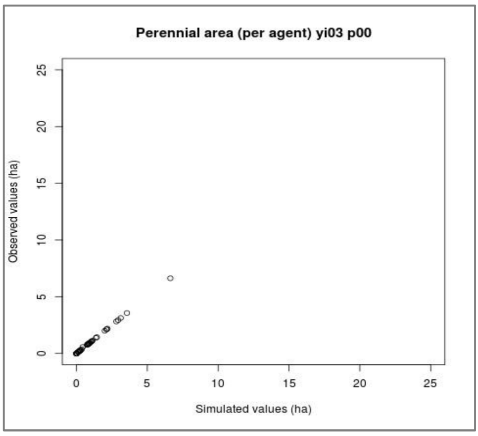

Income (per agent) yi03 p01

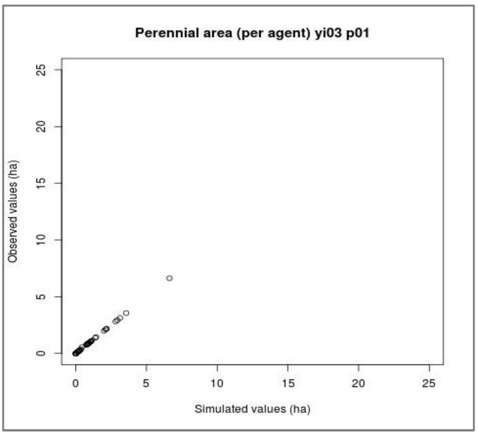

Initial fallow area (per agent) yi03 p00


Initial fallow area (per agent) yi07 p00


Initial fallow area (per agent) yi03 p01

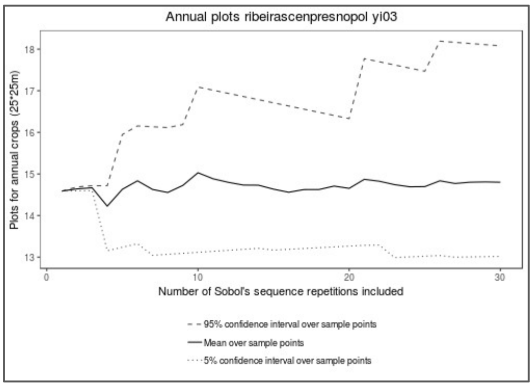

Initial fallow area (per agent) yi07 p01

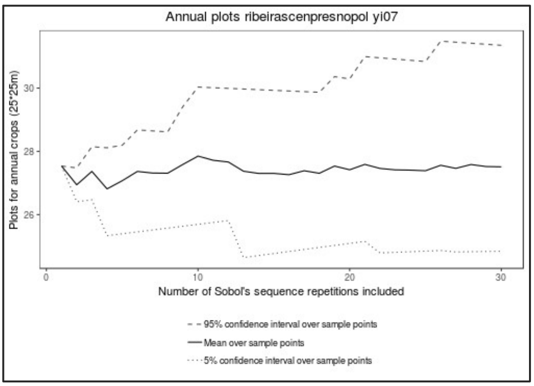

Perennial area (per agent) yi03 p00
Observed values (ha)
0
5
10
15
20
25
Simulated values (ha)
0
5
10
15
20
25

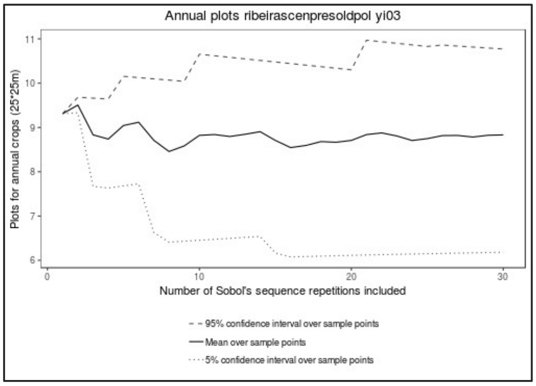

Perennial area (per agent) yi03 p01
Observed values (ha)
0
5
10
15
20
25
Simulated values (ha)
0
5
10
15
20
25

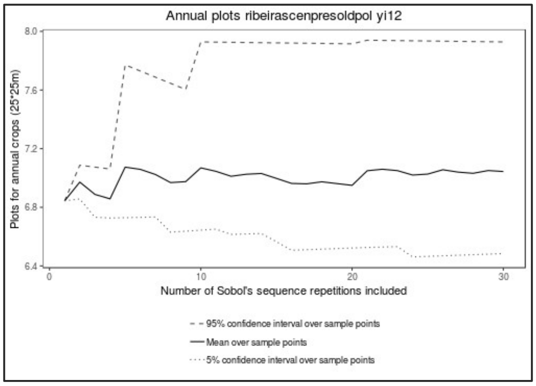
Appendix D: Convergence plots for MPMAS outputs

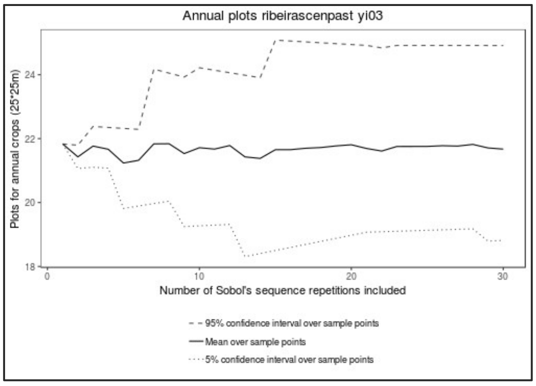
A convergence analysis was run for each of the political scenarios, yield curves, and chosen outputs. Another convergence analysis was implemented to compare the baseline and the other four political scenarios for the same outputs. In many cases, different yield curves show the same values and are not presented here but in the supplementary material.

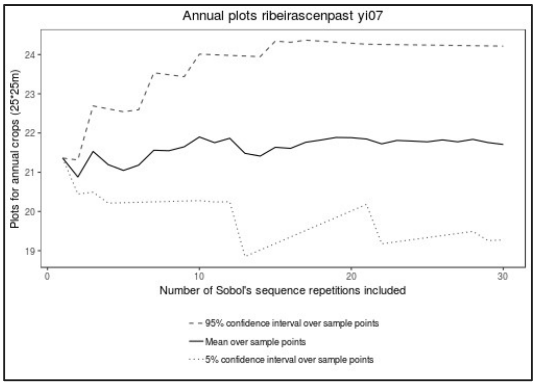


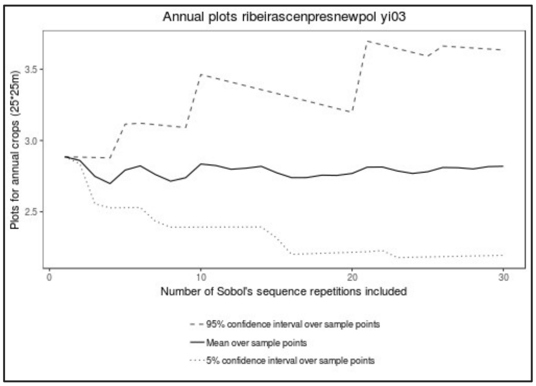


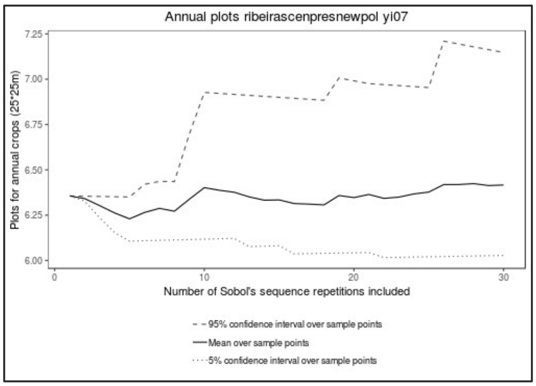


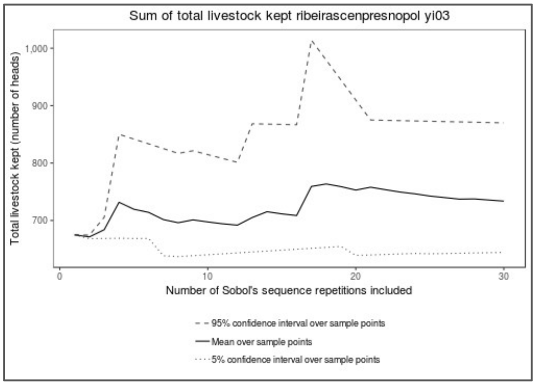


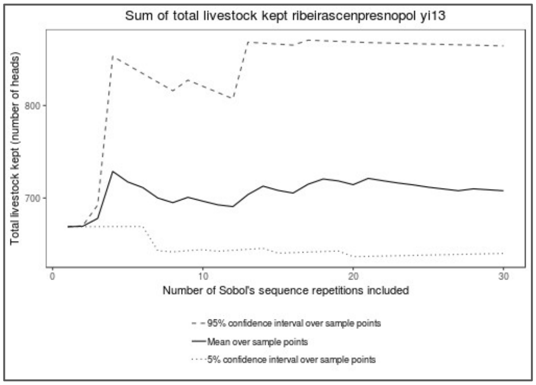


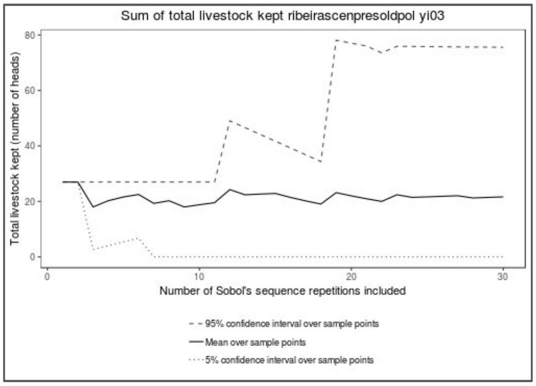


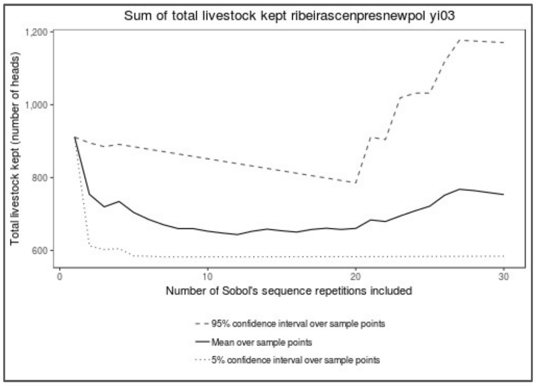

Annual plots ribeirascenpresnewpol yi03

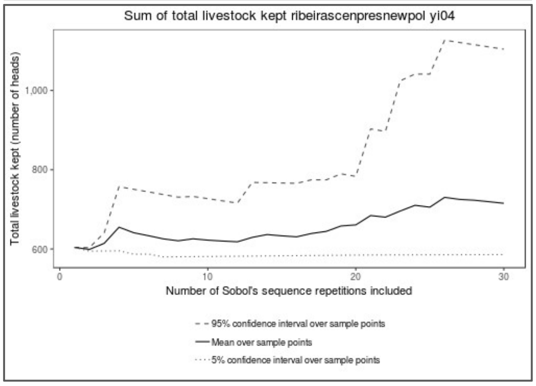

Annual plots ribeirascenpresnewpol yi07

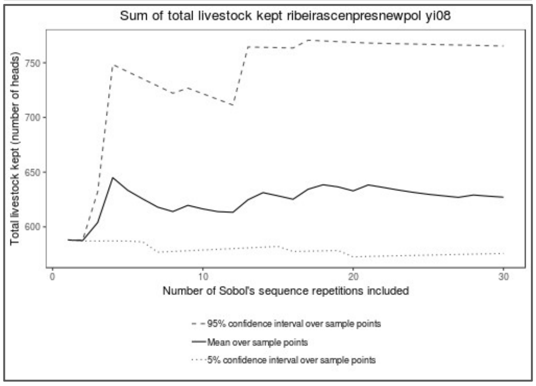

Sum of total livestock kept ribeirascenpresnopol yi03

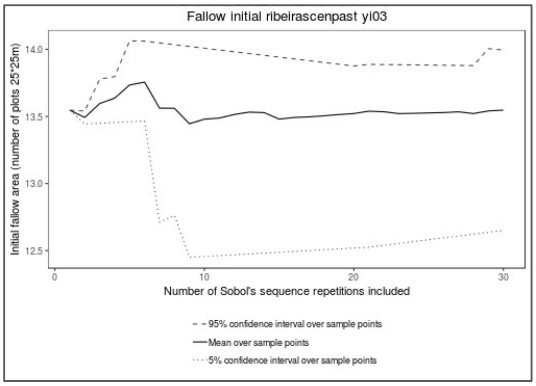

Sum of total livestock kept ribeirascenpresnopol yi13

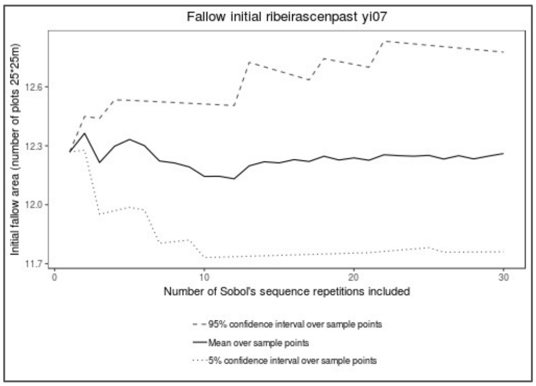

Sum of total livestock kept ribeirascenpresoldpol yi03

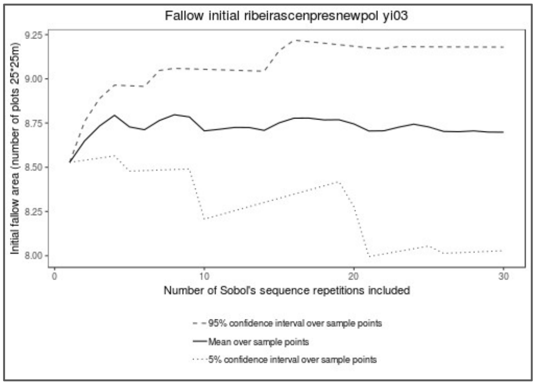

Sum of total livestock kept ribeirascenpresnewpol yi03

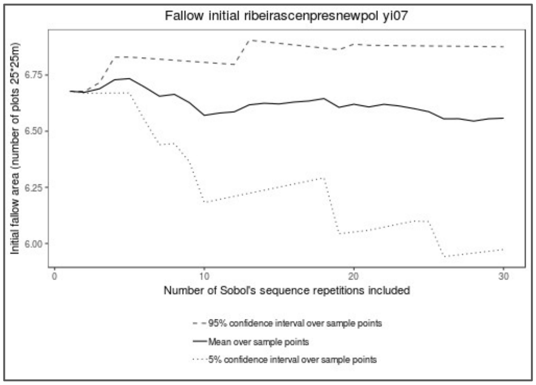

Sum of total livestock kept ribeirascenpresnewpol yi04


Sum of total livestock kept ribeirascenpresnewpol yi08

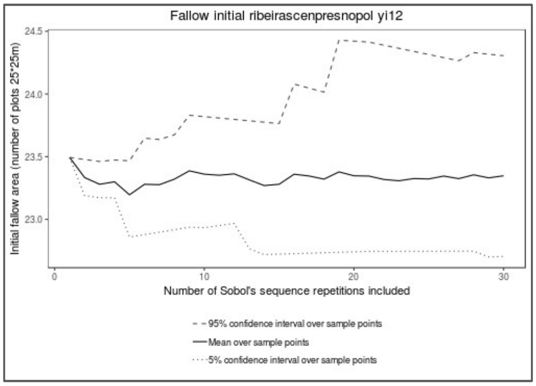

Fallow initial ribeirascenpast yi03
Initial fallow area (number of plots 25*25m)
14.0
13.5
13.0
12.5
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

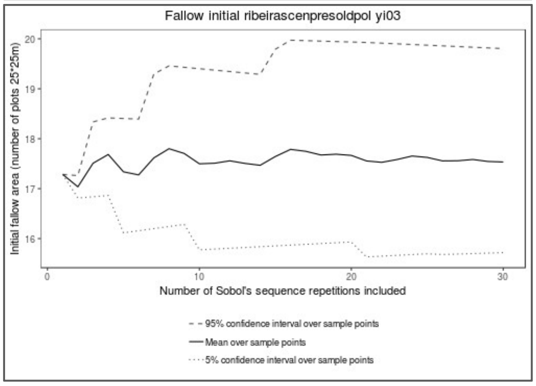

Fallow initial ribeirascenpast yi07
Initial fallow area (number of plots 25*25m)
12.6
12.3
12.0
11.7
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

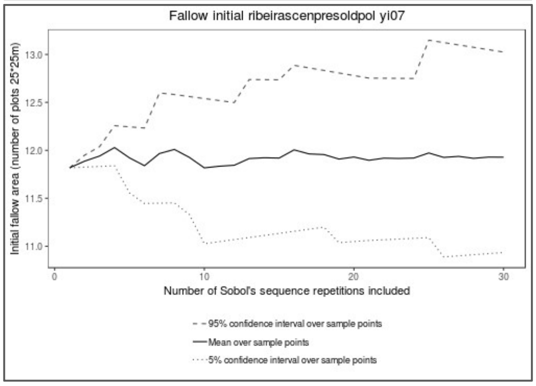

Fallow initial ribeirascenpresnewpol yi03
Initial fallow area (number of plots 25*25m)
9.25
9.00
8.75
8.50
8.25
8.00
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

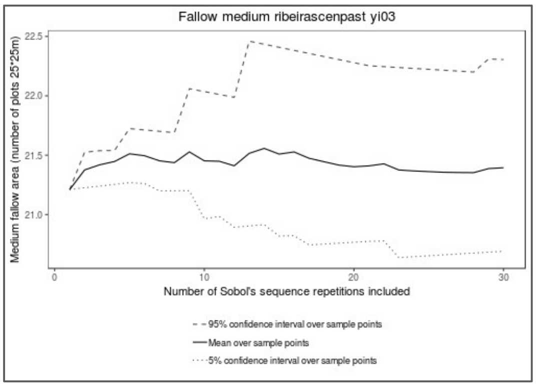

Fallow initial ribeirascenpresnewpol yi07
Initial fallow area (number of plots 25*25m)
6.75
6.50
6.25
6.00
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

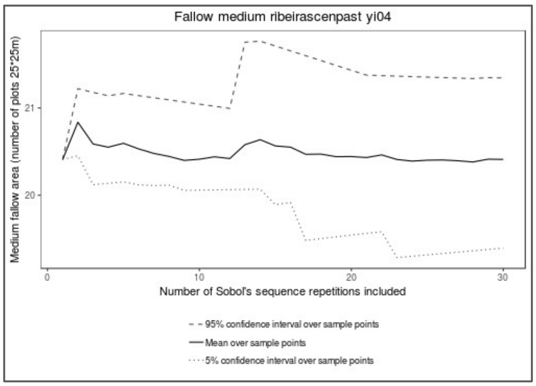

Fallow initial ribeirascenpresnopol yi03
Initial fallow area (number of plots 25*25m)
22.0
21.6
21.2
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

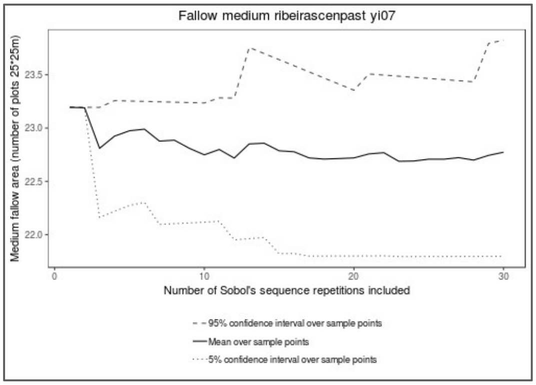

Fallow initial ribeirascenpresnopol yi12
Initial fallow area (number of plots 25*25m)
24.5
24.0
23.5
23.0
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

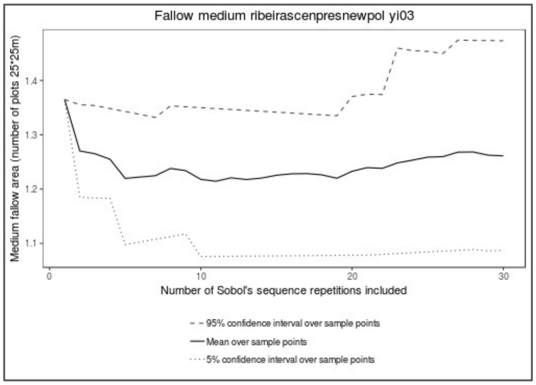

Fallow initial ribeirascenpresoldpol yi03
Initial fallow area (number of plots 25*25m)
20
19
18
17
16
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

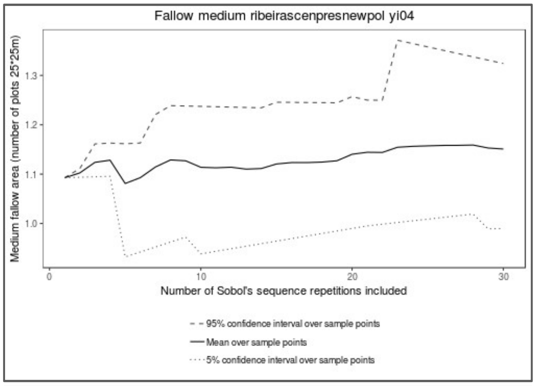

Fallow initial ribeirascenpresoldpol yi07
Initial fallow area (number of plots 25*25m)
13.0
12.5
12.0
11.5
11.0
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

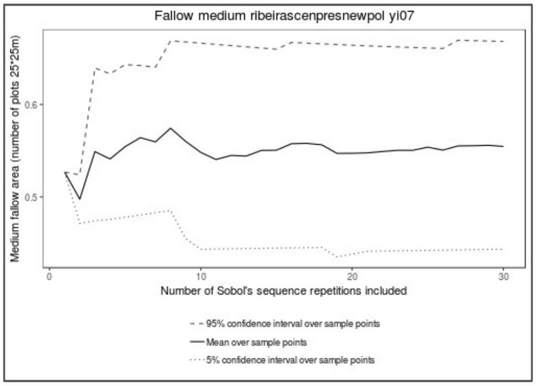

Fallow medium ribeirascenpast yi03

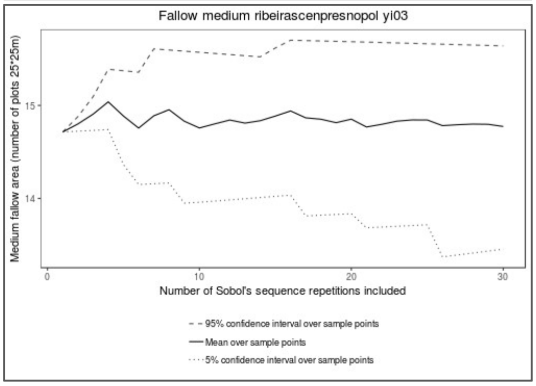

Fallow medium ribeirascenpast yi04

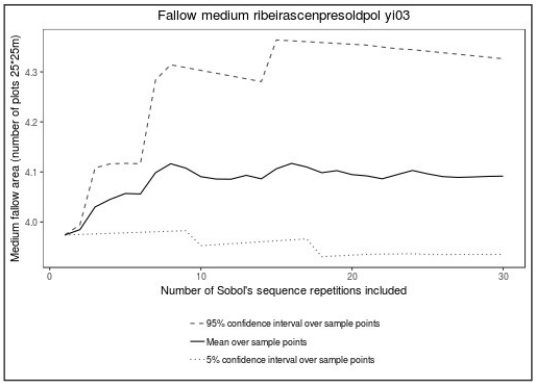

Fallow medium ribeirascenpast yi07

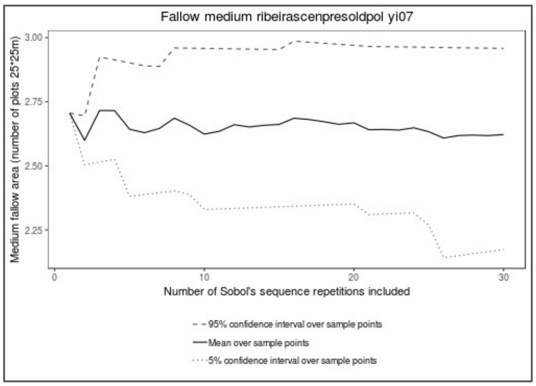

Fallow medium ribeirascenpresnewpol yi03

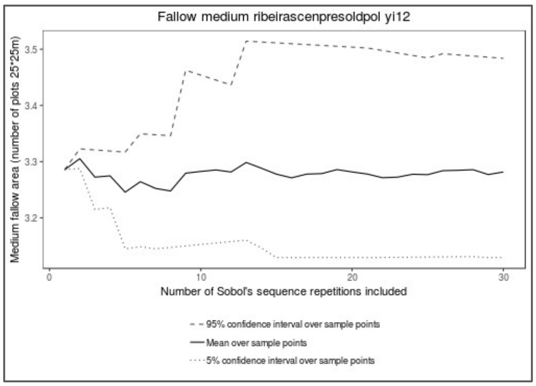

Fallow medium ribeirascenpresnewpol yi04

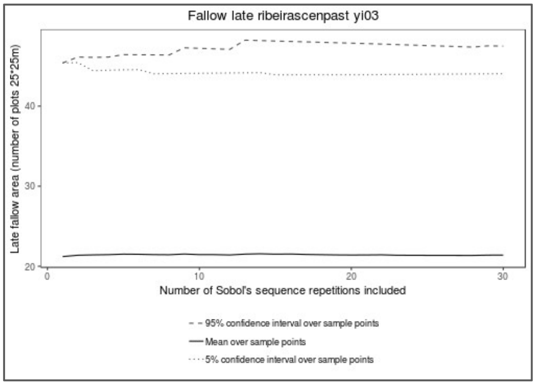

Fallow medium ribeirascenpresnewpol yi07


Fallow medium ribeirascenpresnopol yi03

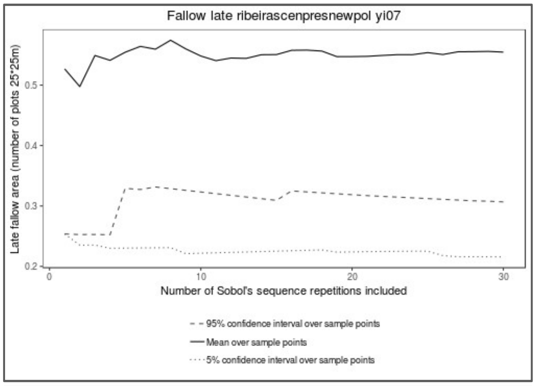

Fallow medium ribeirascenpresoldpol yi03

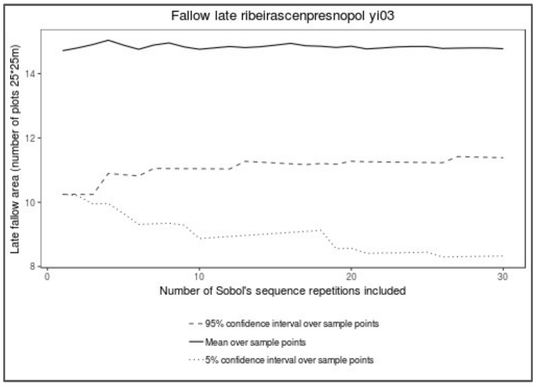

Fallow medium ribeirascenpresoldpol yi07
Medium fallow area (number of plots 25*25m)
3.00
2.75
2.50
2.25
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

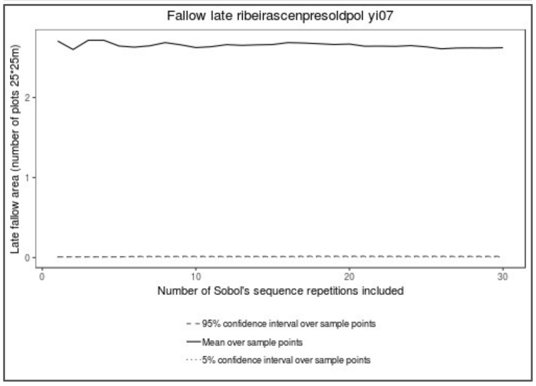

Fallow medium ribeirascenpresoldpol yi12
Medium fallow area (number of plots 25*25m)
3.5
3.4
3.3
3.2
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

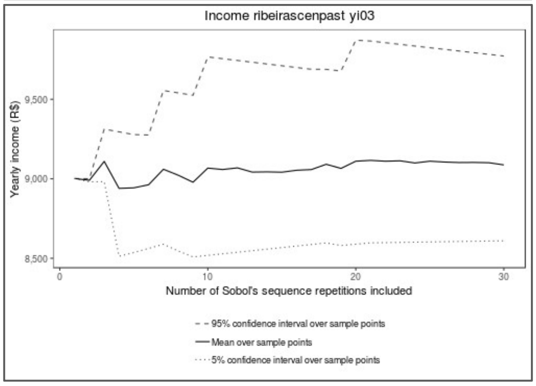

Fallow late ribeirascenpast yi03
Late fallow area (number of plots 25*25m)
40
30
20
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

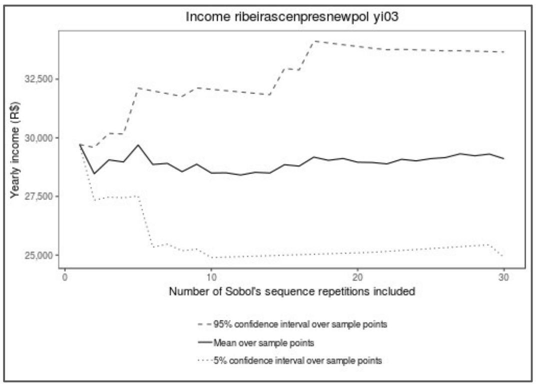

Fallow late ribeirascenpresnewpol yi03
Late fallow area (number of plots 25*25m)
1.2
0.9
0.6
0.3
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

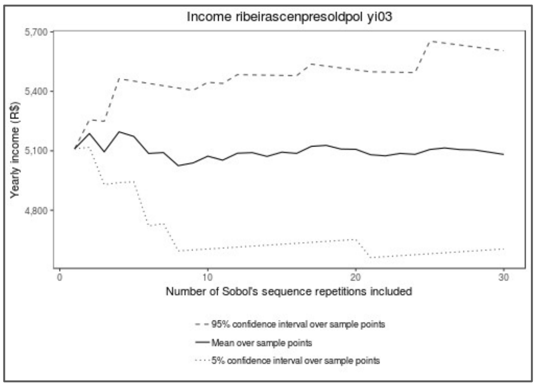

Fallow late ribeirascenpresnewpol yi07
Late fallow area (number of plots 25*25m)
0.5
0.4
0.3
0.2
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

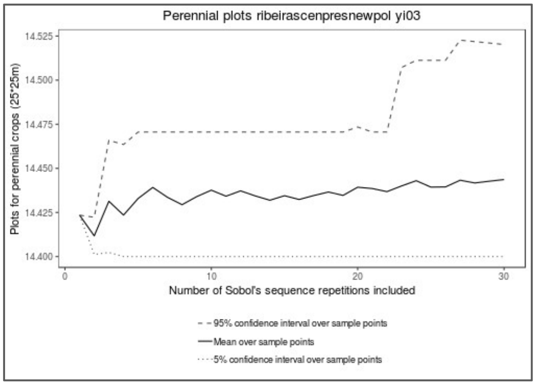

Fallow late ribeirascenpresnopol yi03
Late fallow area (number of plots 25*25m)
14
12
10
8
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

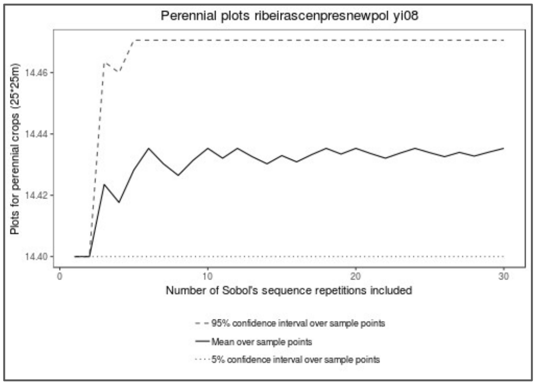

Fallow late ribeirascenpresoldpol yi07
Late fallow area (number of plots 25*25m)
2
1
0
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

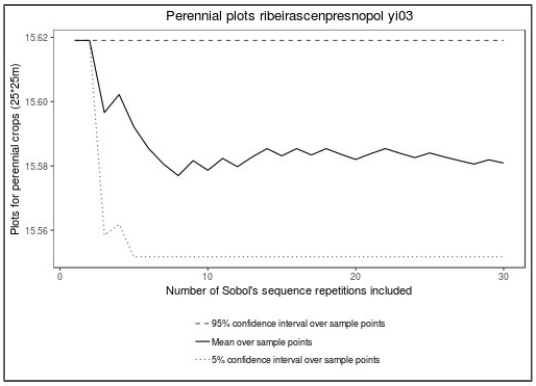

Income ribeirascenpast yi03
Yearly income (R$)
9,500
9,000
8,500
0
10
20
30
Number of Sobol's sequence repetitions included
95% confidence interval over sample points
Mean over sample points
5% confidence interval over sample points

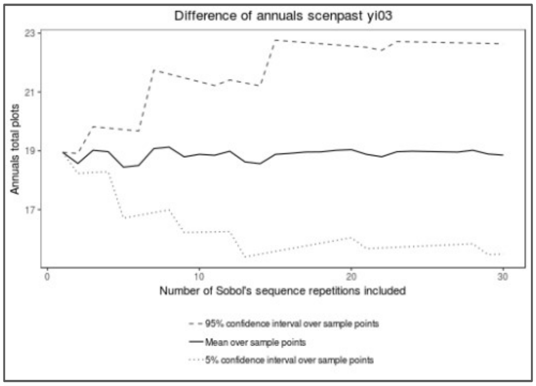

Income ribeirascenpresnewpol yi03

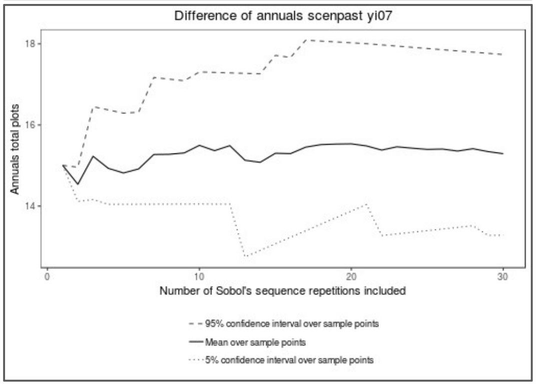

Income ribeirascenpresoldpol yi03

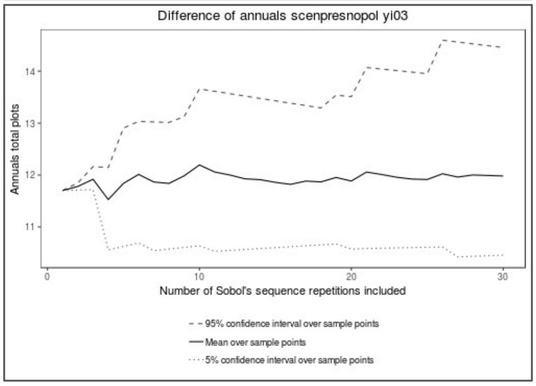

Perennial plots ribeirascenpresnewpol yi03

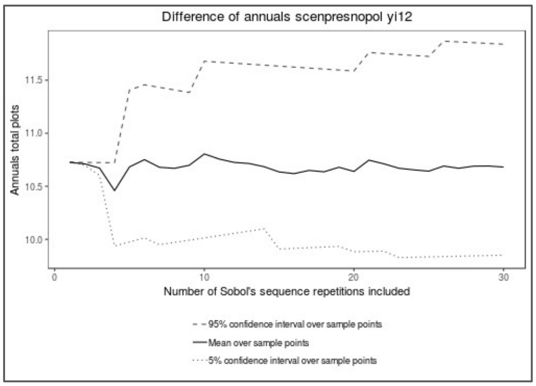

Perennial plots ribeirascenpresnewpol yi08

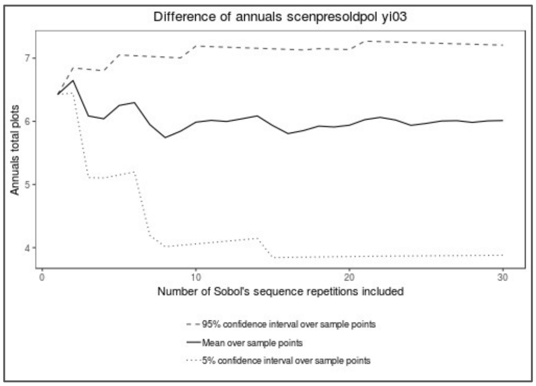

Perennial plots ribeirascenpresnopol yi03

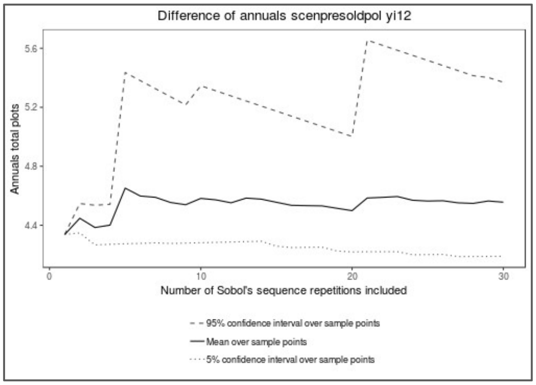

Difference of annuals scenpast yi03

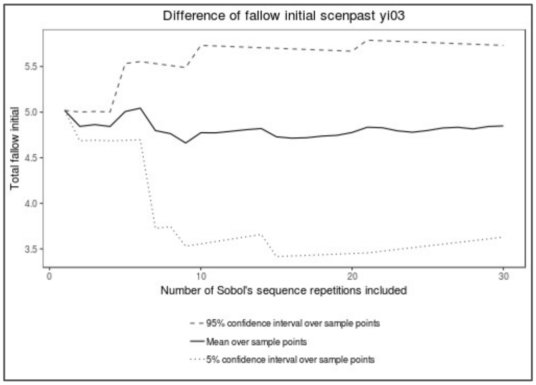

Difference of annuals scenpast yi07

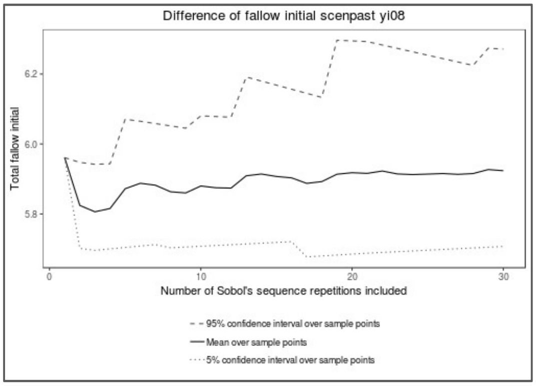

Difference of annuals scenpresnopol yi03

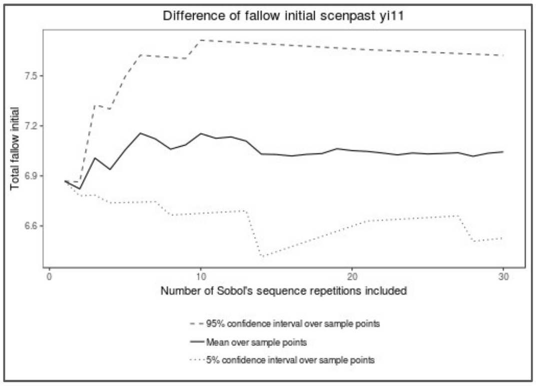

Difference of annuals scenpresnopol yi12

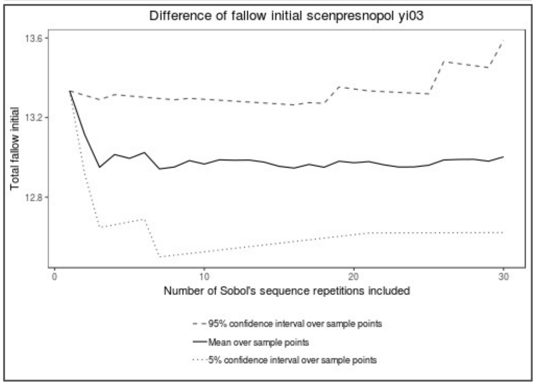

Difference of annuals scenpresoldpol yi03

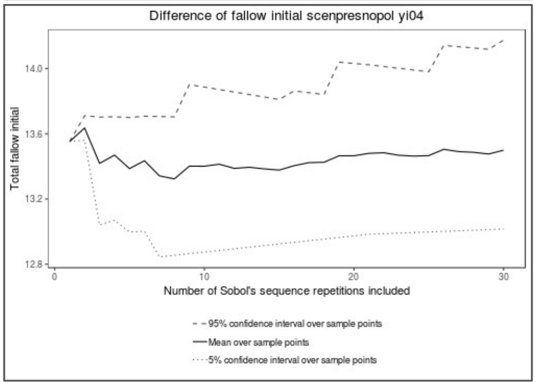

Difference of annuals scenpresoldpol yi12

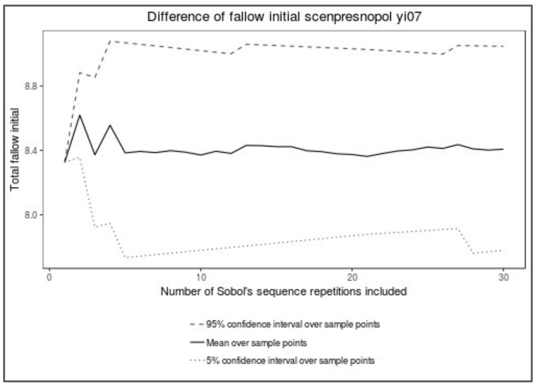

Difference of fallow initial scenpast yi03

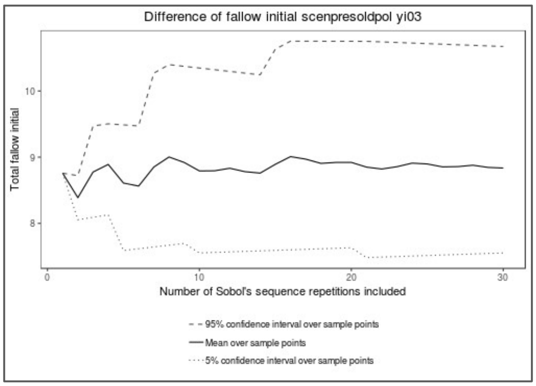

Difference of fallow initial scenpast yi08

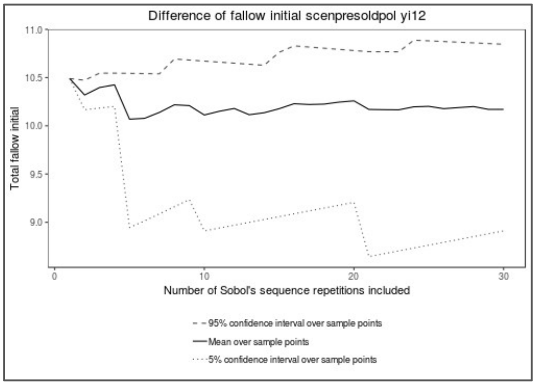

Difference of fallow initial scenpast yi11

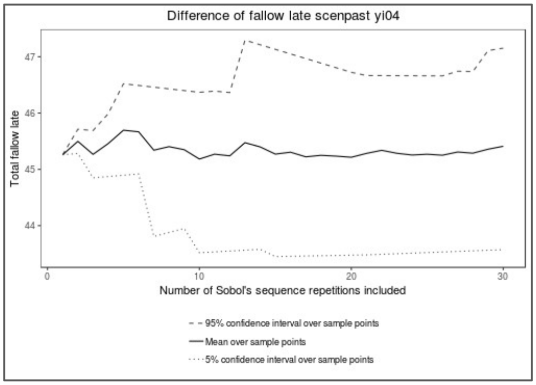

Difference of fallow initial scenpresnopol yi03


Difference of fallow initial scenpresnopol yi04

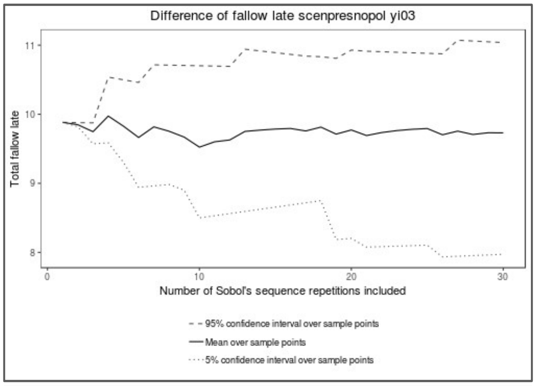

Difference of fallow initial scenpresnopol yi07

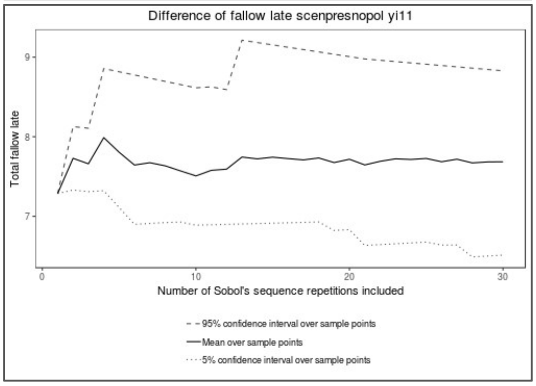

Difference of fallow initial scenpresoldpol yi03

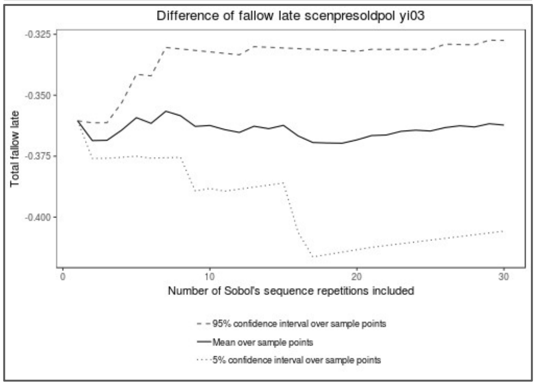

Difference of fallow initial scenpresoldpol yi12

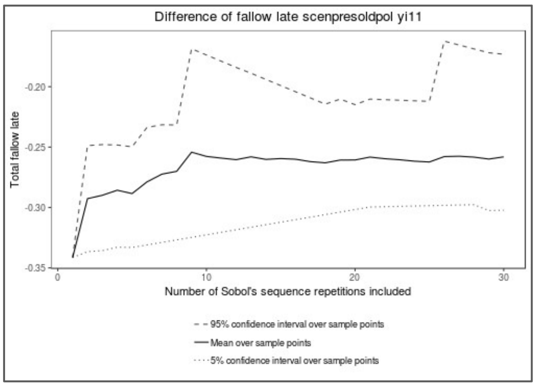

Difference of fallow late scenpast yi04

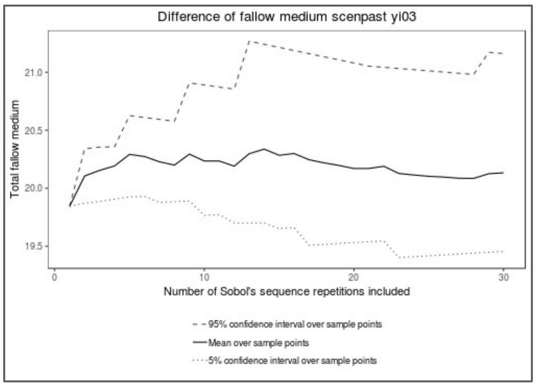

Difference of fallow late scenpast yi12

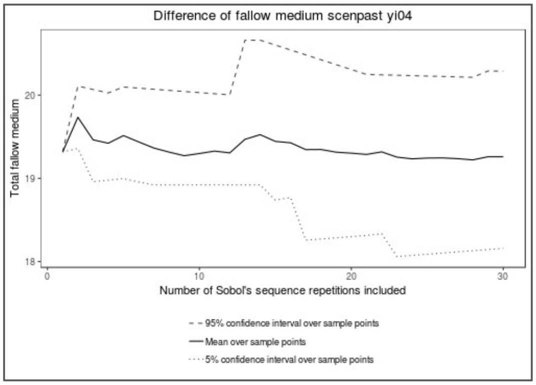

Difference of fallow late scenpresnopol yi03


Difference of fallow late scenpresnopol yi11

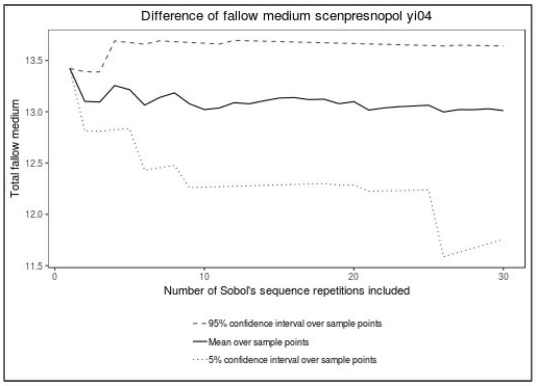

Difference of fallow late scenpresoldpol yi03


Difference of fallow late scenpresoldpol yi11

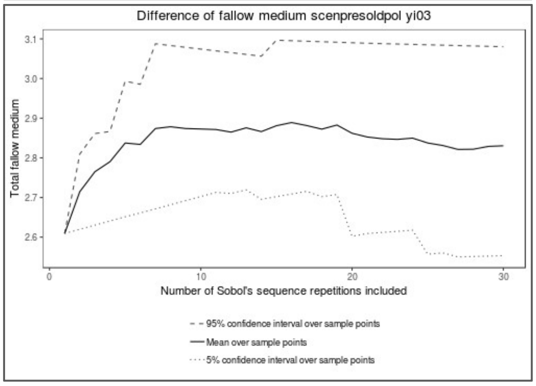

Difference of fallow medium scenpast yi03

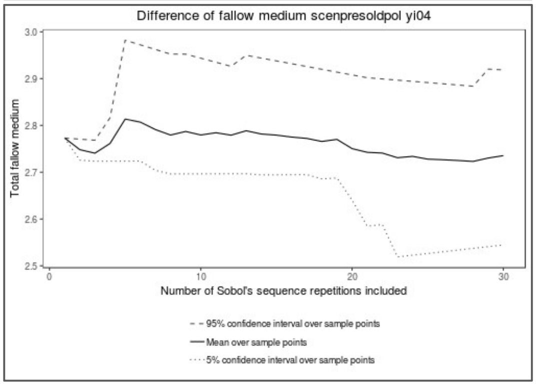

Difference of fallow medium scenpast yi04

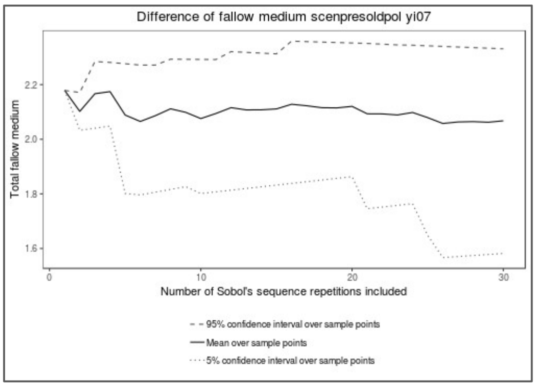

Difference of fallow medium scenpast yi11

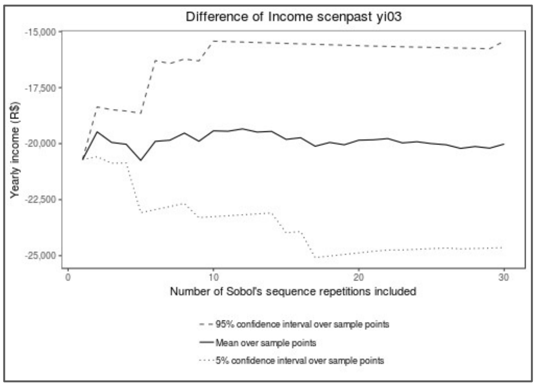

Difference of fallow medium scenpresnopol yi04

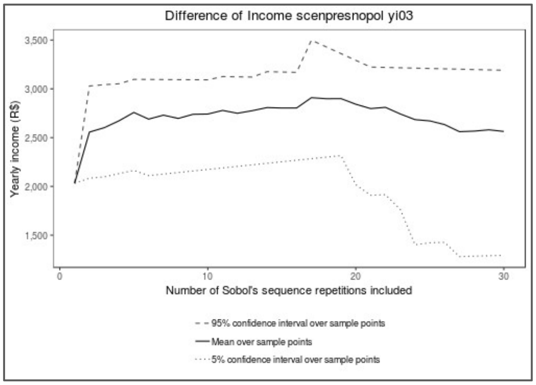

Difference of fallow medium scenpresnopol yi07

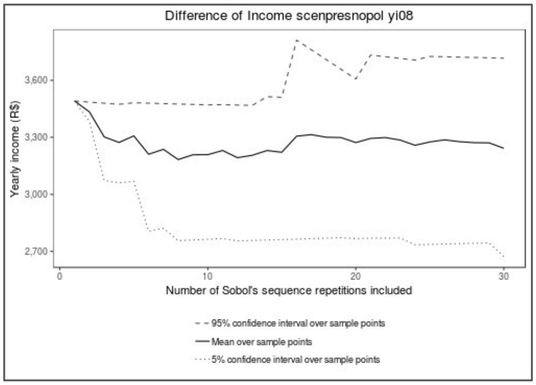

Difference of fallow medium scenpresoldpol yi03

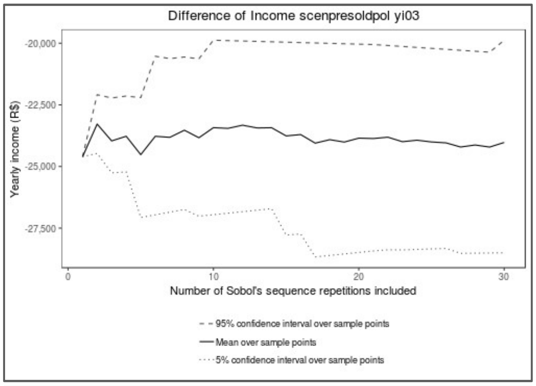

Difference of fallow medium scenpresoldpol yi04

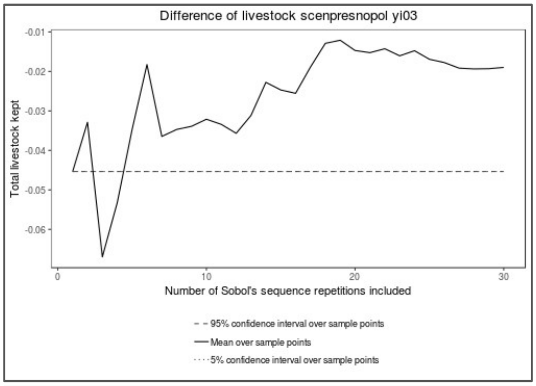

Difference of fallow medium scenpresoldpol yi07

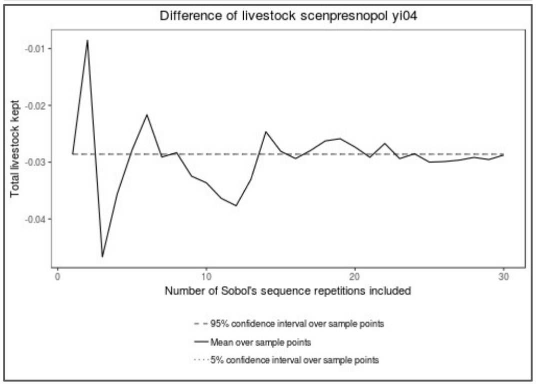

Difference of Income scenpast yi03

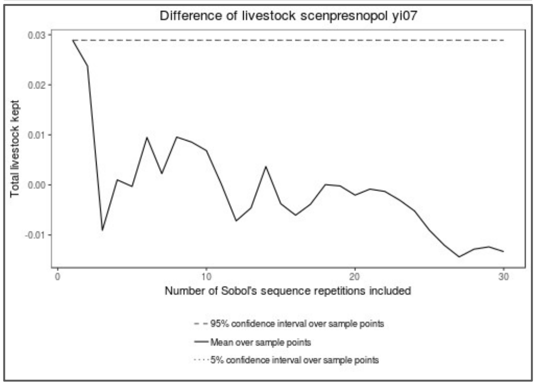

Difference of Income scenpresnopol yi03

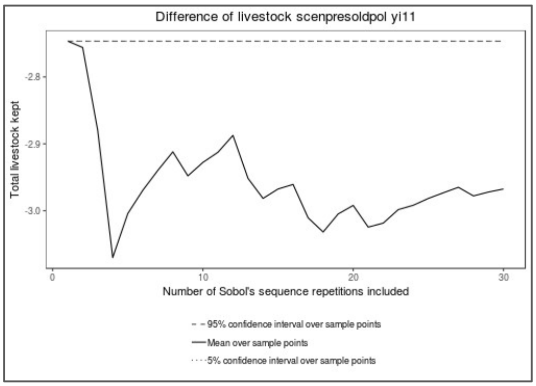

Difference of Income scenpresnopol yi08

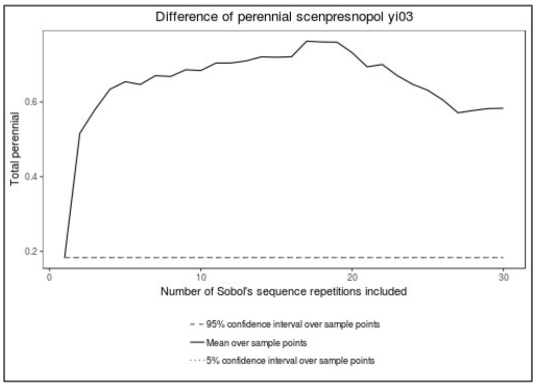

Difference of Income scenpresoldpol yi03

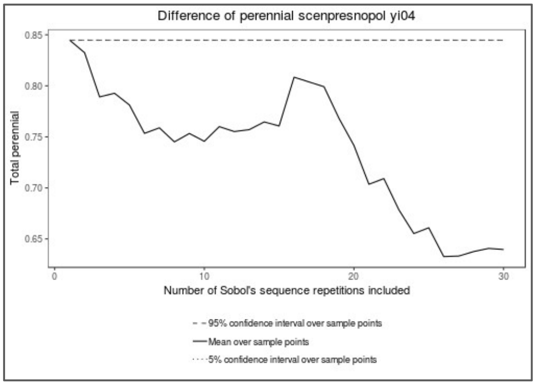

Difference of livestock scenpresnopol yi03

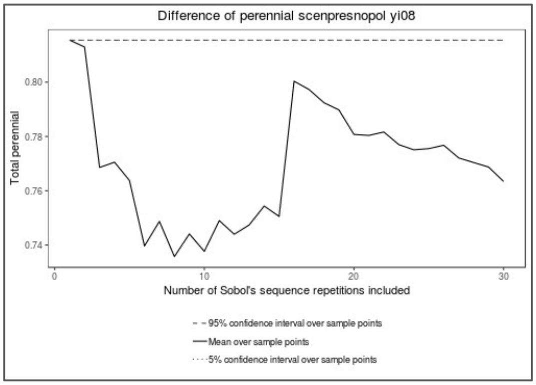

Difference of livestock scenpresnopol yi04

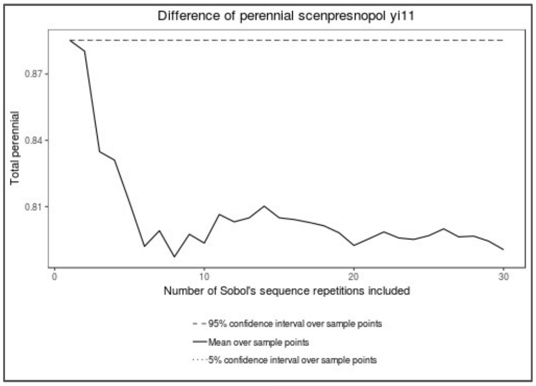

Difference of livestock scenpresnopol yi07

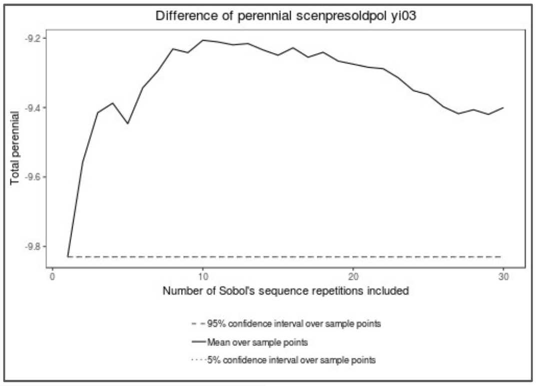

Difference of livestock scenpresoldpol yi11

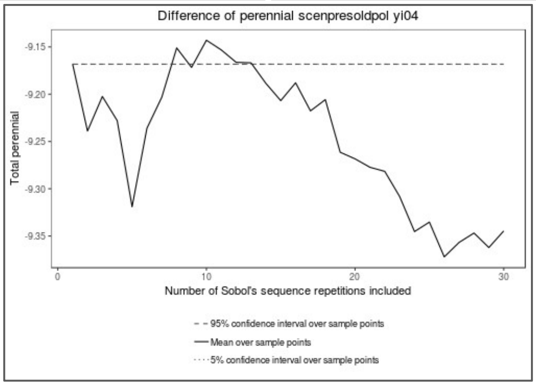

Difference of perennial scenpresnopol yi03


Difference of perennial scenpresnopol yi04


Difference of perennial scenpresnopol yi08


Difference of perennial scenpresnopol yi11

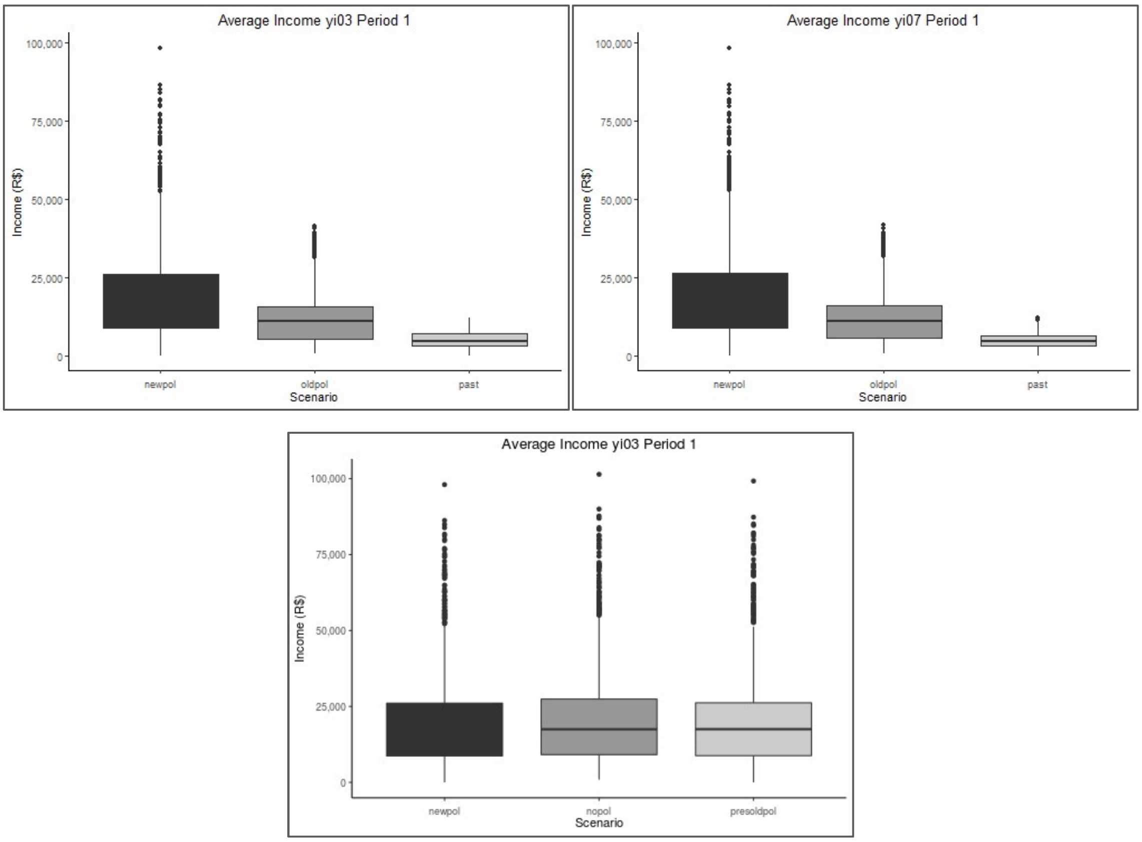

Difference of perennial scenpresoldpol yi03


Difference of perennial scenpresoldpol yi04

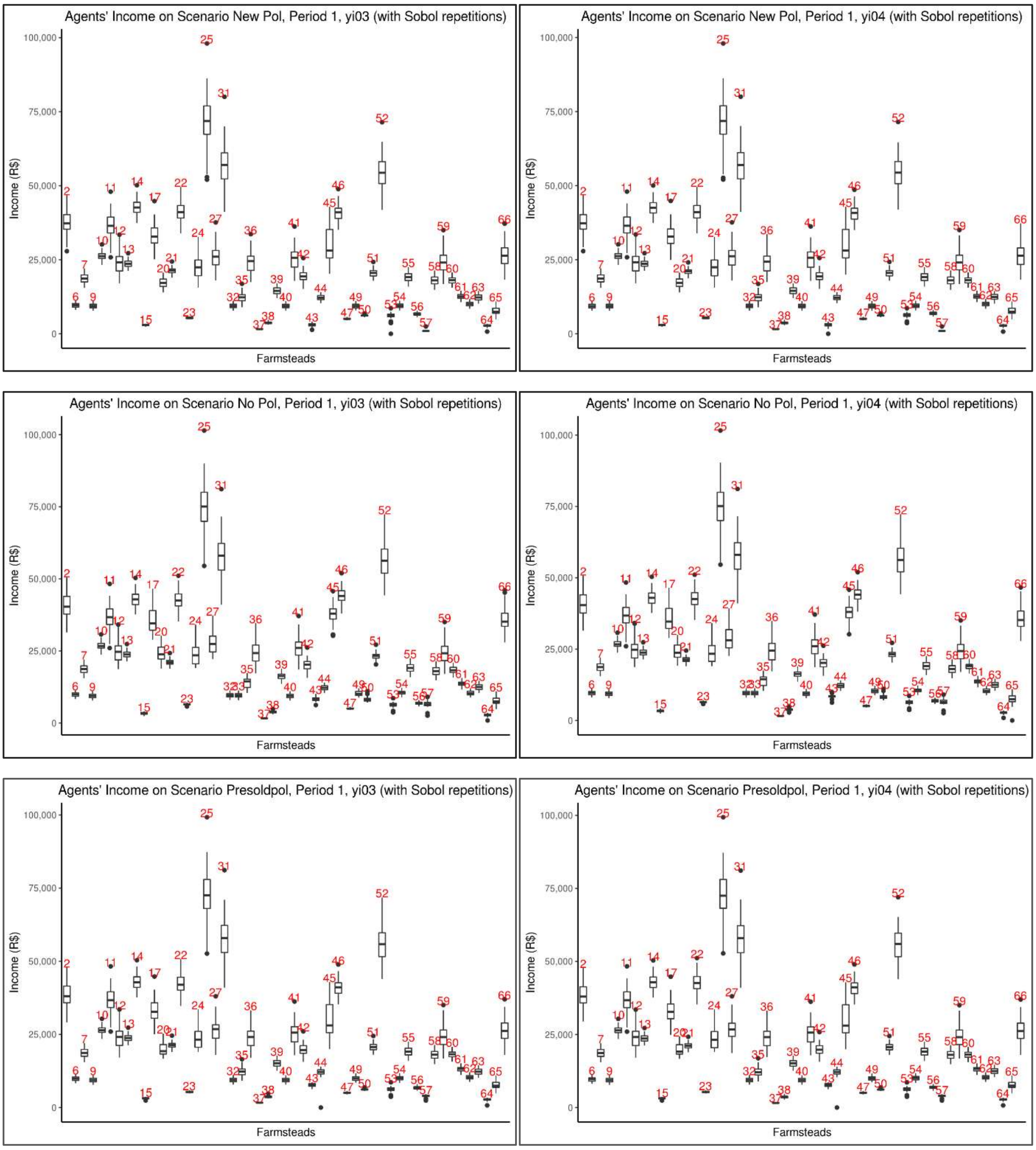
Appendix E: Plots from MPMAS results analyses

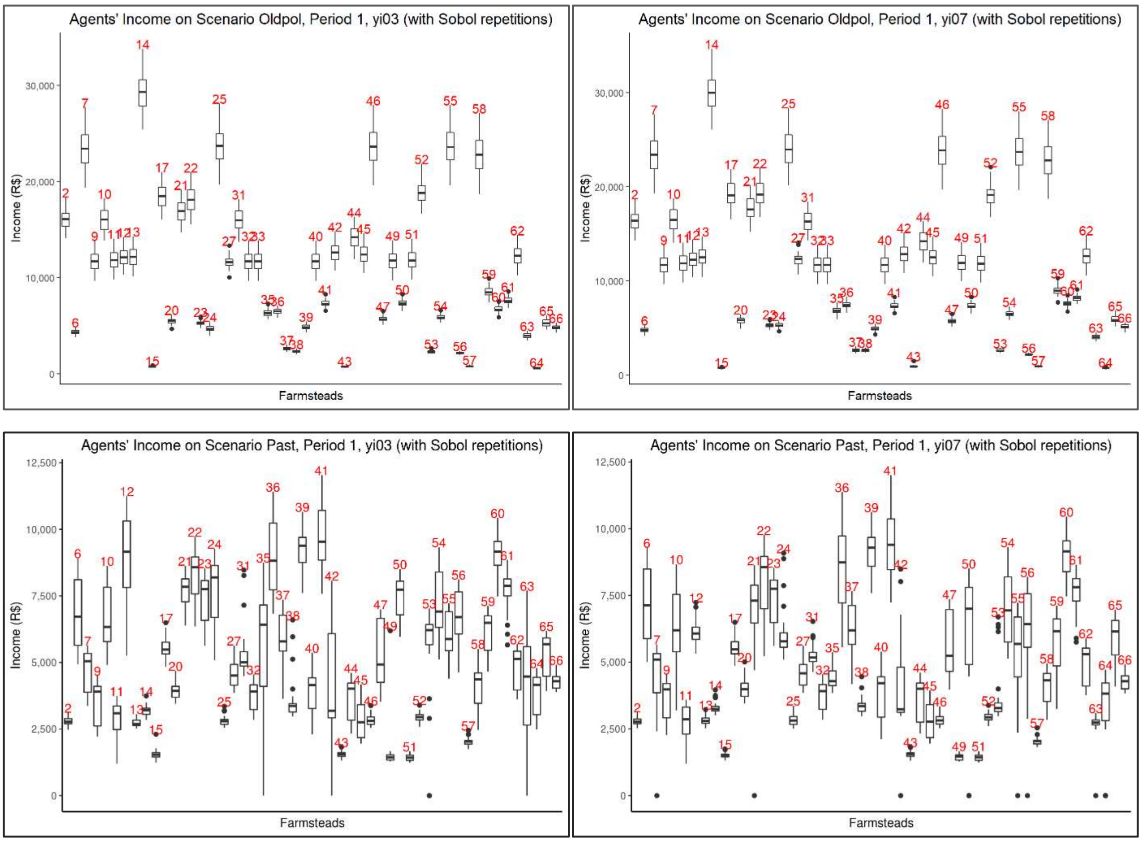
In most cases, different yield curves show the same values and are not presented here but in the supplementary material. They follow the same order as presented in Chapters 6 and 7.

Income Boxplot

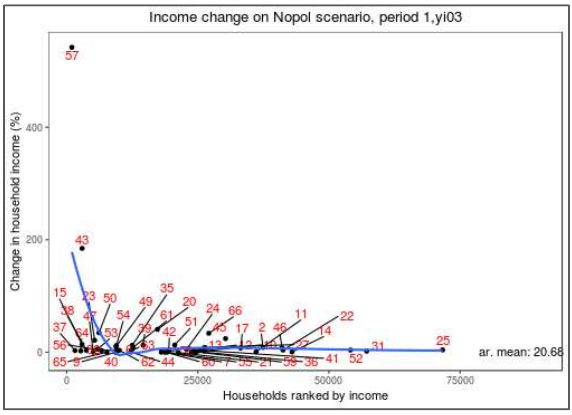


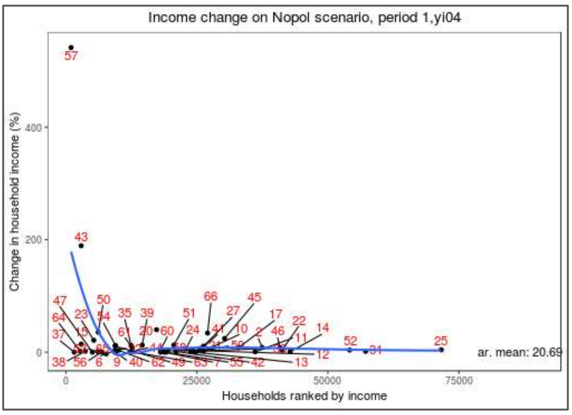
Total agents’ income on each political scenario

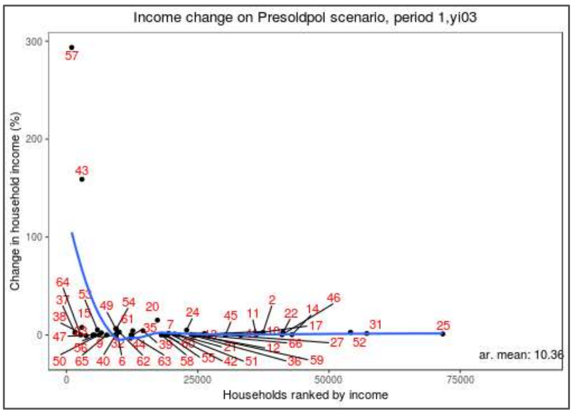


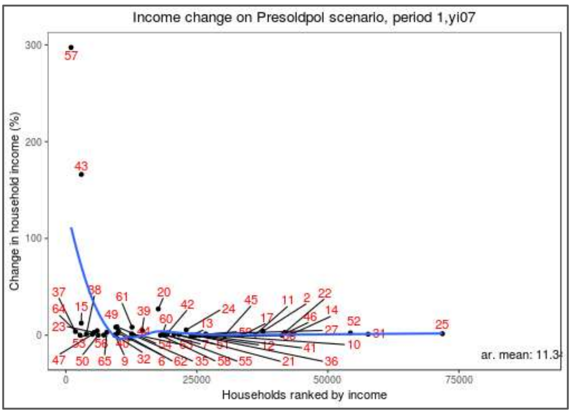


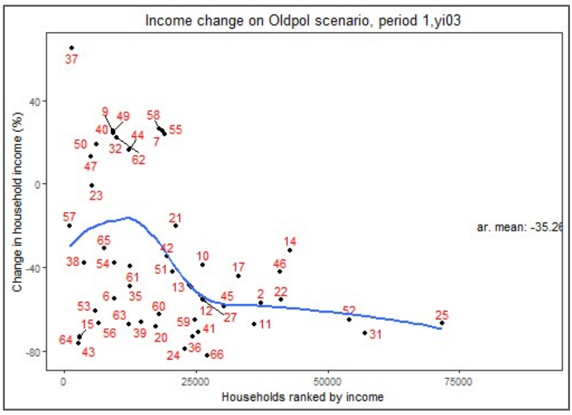
Income variation between political scenarios

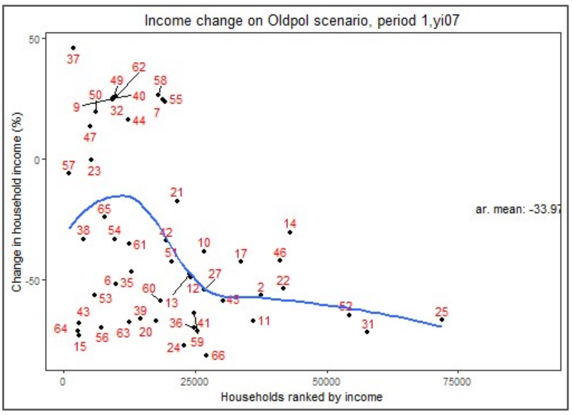


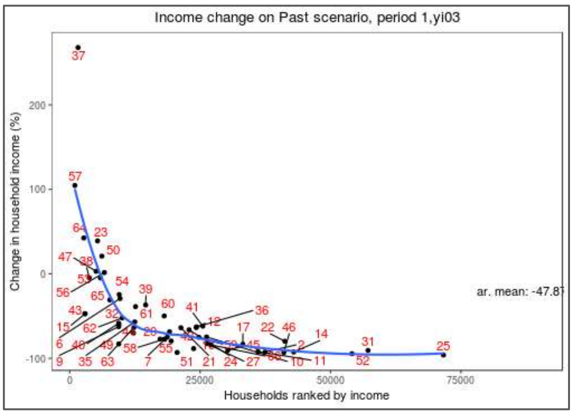


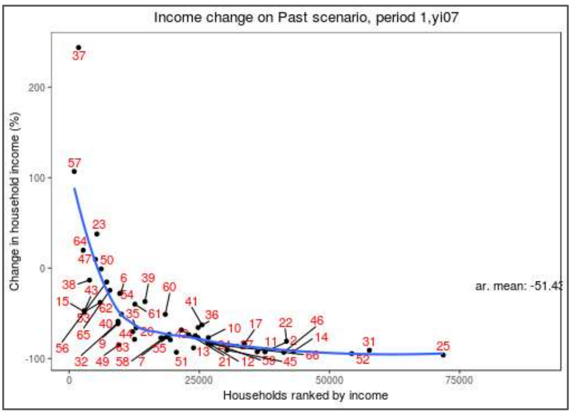

Income change on Presoldpol scenario, period 1,yi03
Change in household income (%)
300
200
100
0
0
25000
50000
75000
Households ranked by income
ar. mean: 10.36


Income change on Presoldpol scenario, period 1,yi07
Change in household income (%)
300
200
100
0
0
25000
50000
75000
Households ranked by income
ar. mean: 11.34


Income change on Oldpol scenario, period 1,yi03
Change in household income (%)
40
0
-40
-80
0
25000
50000
75000
Households ranked by income
ar. mean: -35.26


Income change on Oldpol scenario, period 1,yi07
Change in household income (%)
50
0
-50
0
25000
50000
75000
Households ranked by income
ar. mean: -33.97


Income change on Past scenario, period 1,yi03
Change in household income (%)
200
100
0
-100
0
25000
50000
75000
Households ranked by income
ar. mean: -47.87


Income change on Past scenario, period 1,yi07
Change in household income (%)
200
100
0
-100
0
25000
50000
75000
Households ranked by income
ar. mean: -51.43

Economic class position change

Scenario	Yield curve	A	B1	B2	C1	C2	D & E
Newpol	yi03	0 (0-1)	6 (3-8)	9 (8-10)	9 (10-10)	21 (16-19)	6 (14-3)
	yi13	0 (0-1)	6 (3-8)	9 (8-10)	10 (10-11)	21 (17-18)	5 (13-3)
Nopol	yi03	1 (0-1)	6 (4-8)	10 (9-10)	12 (9-13)	20 (21-18)	3 (9-2)
	yi11	1 (0-1)	6 (4-8)	11 (10-11)	12 (11-12)	20 (18-18)	2 (9-2)
	yi13	1 (0-1)	6 (4-8)	10 (9-11)	13 (12-12)	20 (18-18)	2 (9-2)
Presoldpol	yi03	0 (0-1)	7 (3-8)	9 (8-10)	11 (10-11)	19 (19-18)	5 (11-3)
	yi13	0 (0-1)	7 (3-8)	9 (8-10)	12 (11-11)	19 (18-18)	4 (11-3)
Oldpol	yi03				8 (4-10)	23 (24-24)	21 (24-18)
	yi04				8 (4-10)	22 (24-23)	22 (24-19)
	yi07			0 (0-1)	9 (4-10)	26 (25-26)	17 (23-15)
	yi13			0 (0-1)	10 (4-11)	25 (26-25)	17 (22-15)
Past	yi03					31 (16-37)	20 (35-14)
	yi04					30 (18-37)	21 (33-14)
	yi11				1 (0-2)	36 (19-40)	14 (32-9)
	yi13					35 (18-40)	16 (33-11)

Headcount ratio

Yield curve	Scenario	N of agents under the poverty line
yi03	Newpol	4 (9-2)
yi03	Nopol	2 (4-2)
yi03	Oldpol	3 (3-3)
yi07	Oldpol	2 (3-2)
yi03	Past	1 (10-1)
yi03	Presoldpol	3 (7-2)

Poverty position evaluation table

Yield curve	Scenario	World Bank	*Bolsa Família*	*Bolsa Família* extrema pobreza
yi03	Newpol	13 (20-11)	4 (6)	1 (3-1)
yi07	Newpol	12 (20-11)	4 (6)	1 (3-1)
yi11	Newpol	12 (16-12)	5 (5)	1 (2-1)
yi03	Nopol	12 (16-11)	2 (3)	1 (1-1)
yi07	Nopol	11 (14-11)	2 (2)	1 (1-1)
yi03	Oldpol	16 (19-12)	0 (1)	0 (0-0)

yi07	Oldpol	13 (15-9)	0 (0)	0 (0-0)
yi12	Oldpol	15 (17-13)	0 (1)	0 (0-0)
yi03	Past	50 (51-45)	24 (37)	1 (5-0)
yi07	Past	48 (51-45)	23 (36)	0 (10-0)
yi08	Past	47 (49-46)	23 (32)	0 (3-0)
yi11	Past	46 (50-40)	21 (31)	0 (5-0)
yi12	Past	49 (51-44)	24 (35)	1 (6-0)
yi03	Presoldpol	12 (17-11)	4 (5)	1 (2-1)
yi07	Presoldpol	11 (16-11)	4 (5)	1 (2-1)

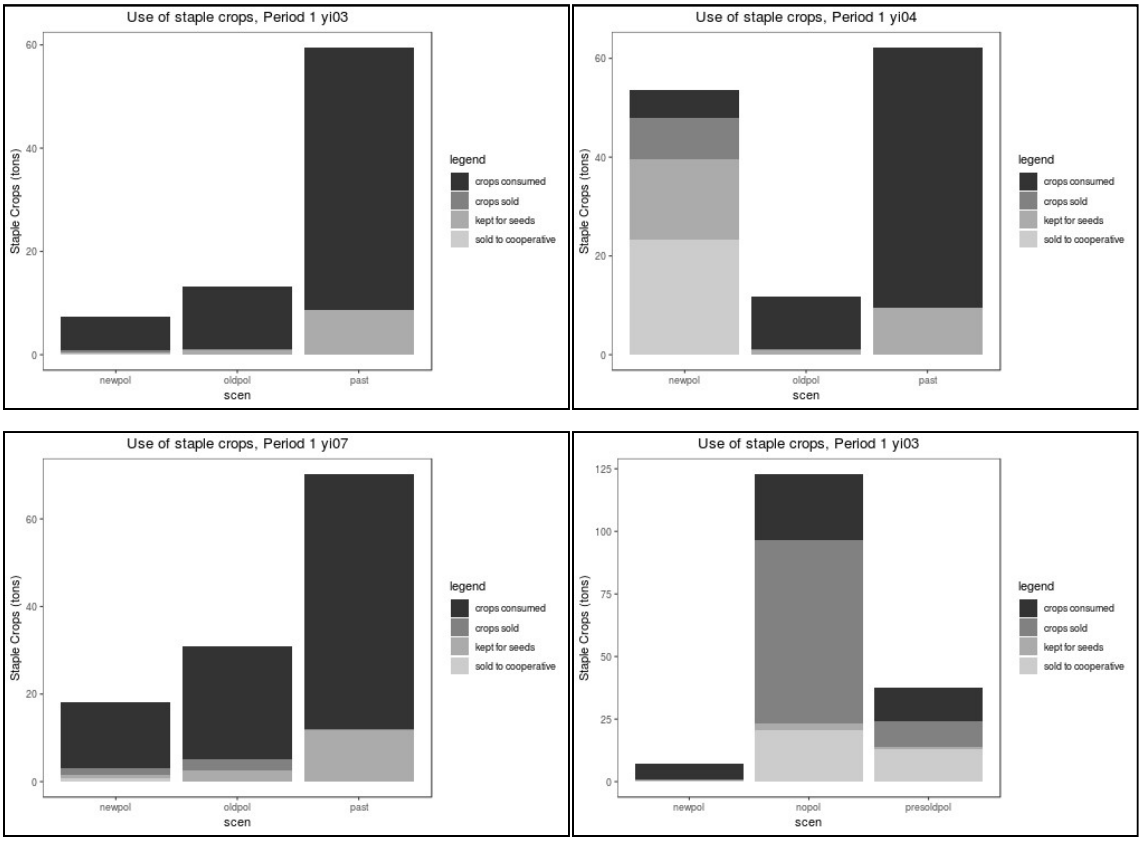
Number of events of food consumption unmet

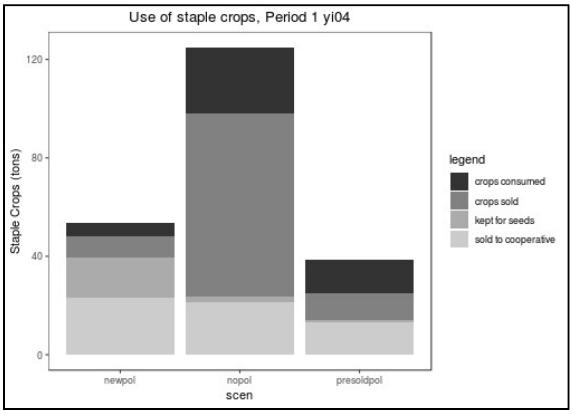
Scenario	Yield curve	N of times (average)	N of times (minimum)	N of times (maximum)
Newpol	yi03	0	28	0
	yi07	0	40	0
	yi08	0	21	0
	yi11	2	16	2
	yi12	1	54	1
Nopol	yi03	0	28	0
	yi04	0	29	0
	yi12	1	0	1
Past	yi03	85	28	85
	yi04	85	29	85
	yi07	66	0	66
	yi08	65	42	65
	yi11	48	32	48
	yi12	79	27	79
	yi13	47	51	47
Presoldpol	yi04	1	29	1
	yi07	0	20	0
	yi12	1	0	1

Number of events of other consumption unmet

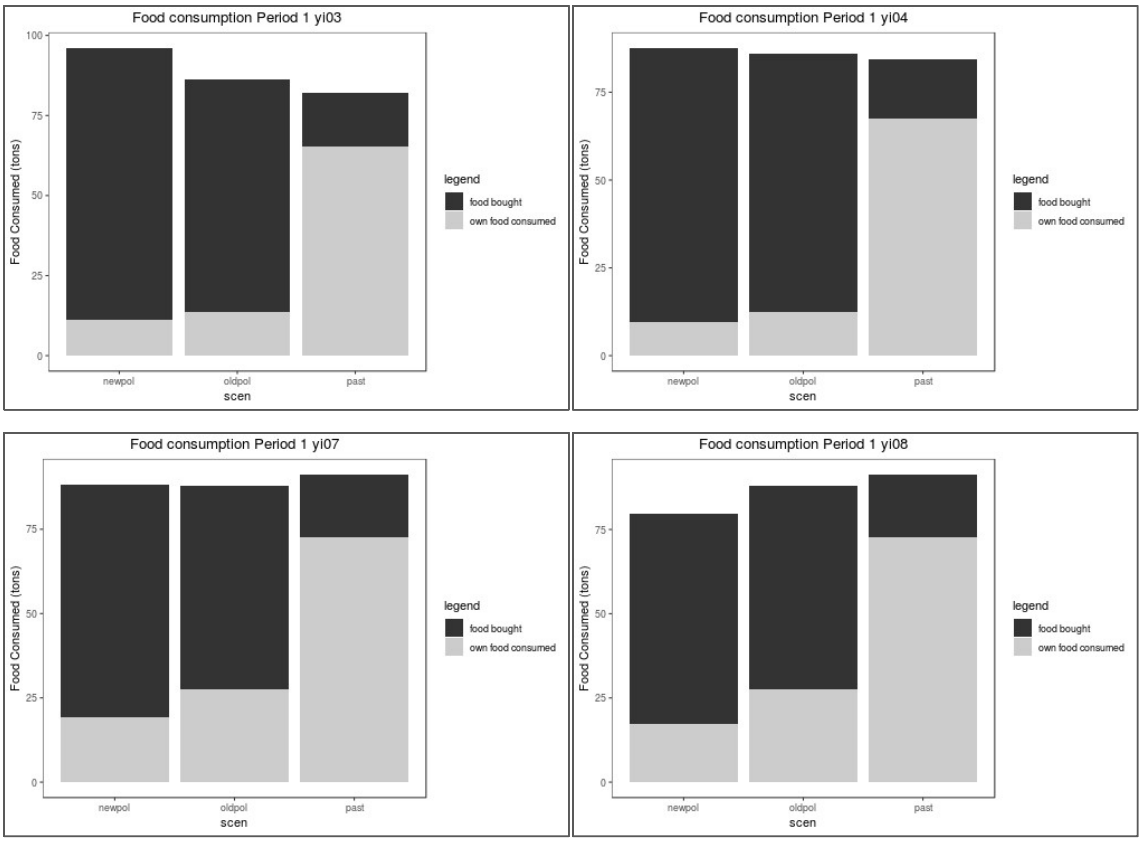
Scenario	Yield curve	N of times (average)	N of times (minimum)	N of times (maximum)
Newpol	yi03	34	3	34
Nopol	yi03	32	4	32
Nopol	yi04	31	4	31
Nopol	yi07	33	5	33
Nopol	yi12	32	5	32
Oldpol	yi03	5	1	5
Oldpol	yi11	4	1	4
Past	yi03	102	74	102
Past	yi07	101	58	101
Past	yi11	100	58	100
Presoldpol	yi03	33	2	33
Presoldpol	yi07	33	3	33
Presoldpol	yi13	32	3	32

Use of staple crops production





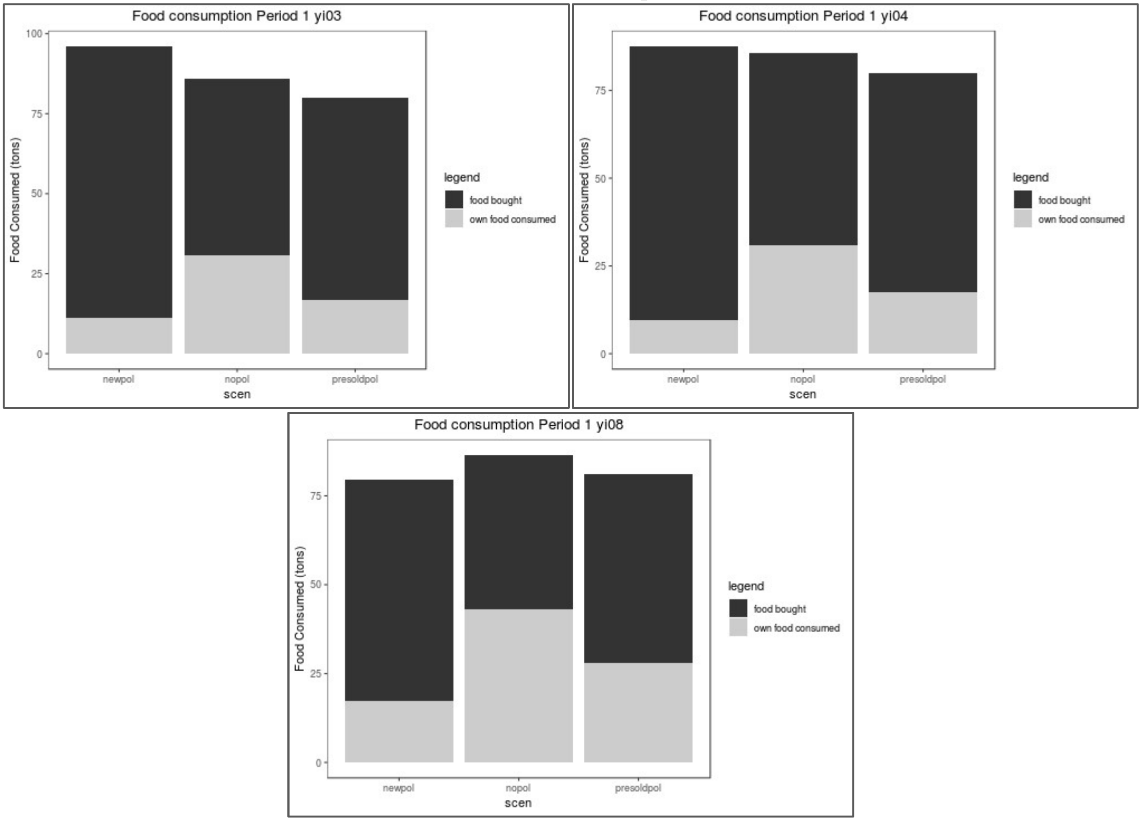
Comparison of the amount of food consumed to the amount of food bought



Total food consumption

		Newpol			Oldpol			Past		
Yield		aver	min	max	aver	min	max	aver	min	max
yi03	Food bought	85.09	60.45	232.94	72.55	60.65	84.71	16.74	14.22	19.46
yi04		77.99	59.96	160.46	73.62	61.26	85.65	16.95	13.61	28.86
yi07		68.75	53.51	142.39	60.28	50.25	69.68	18.60	14.87	34.94
yi08		62.25	53.47	71.24	60.41	50.24	69.98	18.64	14.88	34.83
yi03	Own food consumed	11.04	6.67	37.33	13.77	8.52	17.91	65.34	57.30	75.13
yi04		9.67	6.45	23.76	12.46	8.33	16.46	67.53	57.49	127.17
yi07		19.33	14.51	43.34	27.62	22.94	33.07	72.69	59.67	154.28
yi08		17.42	14.07	21.71	27.47	22.64	32.95	72.73	59.44	154.76

Total food consumption



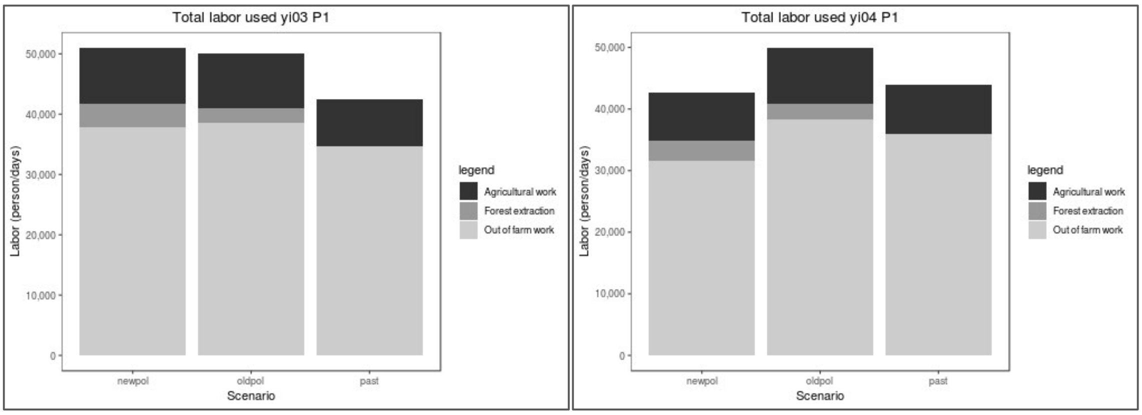
Total food consumption

		Newpol			Nopol			Presoldpol		
	Yield	aver	min	max	aver	min	max	aver	min	max
Food bought	yi03	85.09	60.45	232.94	55.20	44.40	102.79	63.02	53.61	71.83
	yi04	77.99	59.96	160.46	54.73	44.26	93.75	62.56	53.22	71.32
	yi08	62.25	53.47	71.24	43.54	36.68	77.86	52.96	46.08	60.39
Own food consumed	yi03	11.04	6.67	37.33	30.58	24.49	60.23	16.82	12.79	21.73
	yi04	9.67	6.45	23.76	30.88	25.50	50.38	17.44	13.78	21.63
	yi08	17.42	14.07	21.71	43.00	36.32	71.92	28.14	23.67	33.57

Number of agents

		yi03			yi04			yi07			yi12		
	Scenario	aver	min	max	aver	min	max	aver	min	max	aver	min	max
Annuals	Newpol	29	26	31	26	24	28	34	34	34	31	29	33
	Nopol	44	42	46	45	44	46	48	48	48			
	Oldpol	39	37	40	38	36	39	41	41	41			
	Past	50	49	51	51	49	51						
	Presoldpol	39	38	40				43	43	43	40	39	41
Cooperativ	Newpol	1	0	4									
	Nopol	1	0	2									
	Presoldpol	1	0	2									
For extraction	Newpol	23	23	23									
	Nopol	23	23	23									
	Oldpol	23	23	23									
	Presoldpol	23	22	23									
Livestock	Newpol	49	45	51	yi11								
	Nopol	49	47	52	50	47	52						
	Oldpol	2	0	15									
	Presoldpol	49	47	51	49	46	51						
Perennials	Newpol	38	37	38									
	Nopol	38	38	38									
	Oldpol	7	7	7									
	Presoldpol	38	38	38									

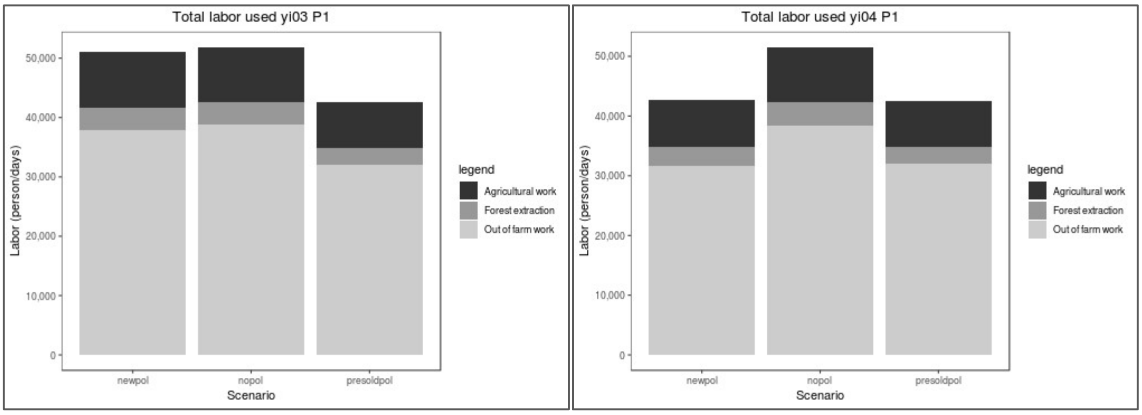
Use of household labor



Use of household labor

		Newpol			Oldpol			Past		
Econ acts	Yield	aver	min	max	aver	min	max	aver	min	max
Agricultural	yi03	9369.06	7775.09	23336.15	9071.27	9068	9072	7741.61	7539.11	7847.02
	yi04	7814.07	7776	7856	9071.30	9068.04	9072	7991.36	7471.03	15383.59
Out of farm	yi03	37902.57	24549.69	95503.93	38509.74	29312.57	47228.75	34646.90	26384.02	42548.26
	yi04	31598.19	25330.13	37763.26	38270.65	29261.40	47520.62	35986.63	26388.69	81103.58
Forest extractio	yi03	3765.29	2104.66	11422.28	2397.89	1235	4231.29	0	0	0
	yi04	3191.56	2233.54	5299.29	2636.95	1858.14	4584.79	0	0	0

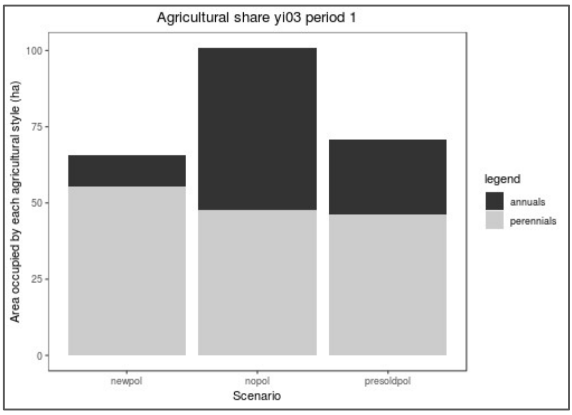
Use of household labor

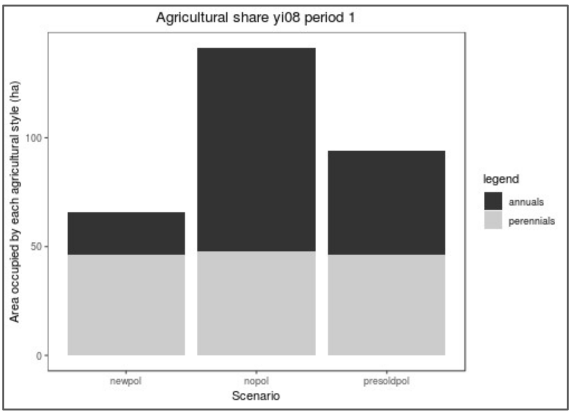


Use of household labor

Econ acts		Newpol			Nopol			Presoldpol		
	Yield	aver	min	max	aver	min	max	aver	min	max
Agricultural work	yi03	9369.06	7775.09	23336.15	9315.58	9000.65	18040.11	7807.89	7765.99	7853.64
	yi04	7814.07	7776	7856	9304.21	8993.23	17721.37	7808.16	7766.71	7853.39
Out of farm work	yi03	37902.57	24549.69	95503.93	38746.19	29168.34	83746.81	32002.41	24899.14	38536.92
	yi04	31598.19	25330.13	37763.26	38447.28	29367.16	70719.43	32018.11	24912.17	38531.92
Forest extraction	yi03	3765.29	2104.66	11422.28	3813.90	1984.01	12018.59	2779.07	1440.66	4649.65
	yi04	3191.56	2233.54	5299.29	3792.70	2125.66	7127.21	2763.11	1380.66	4772.15

Share of plots for annuals and perennials

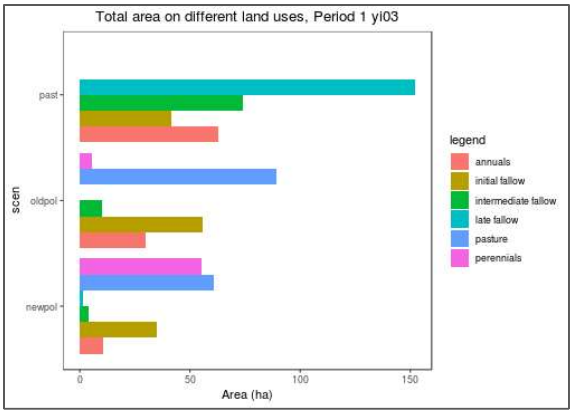


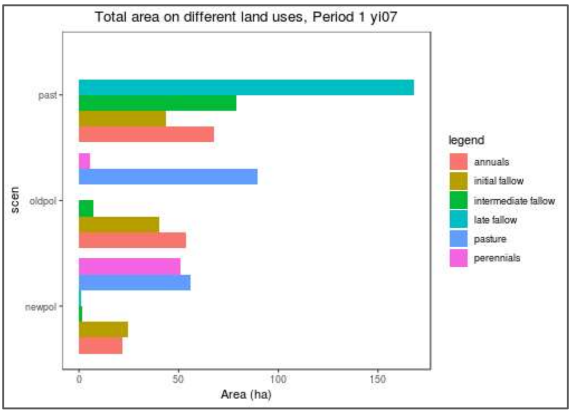


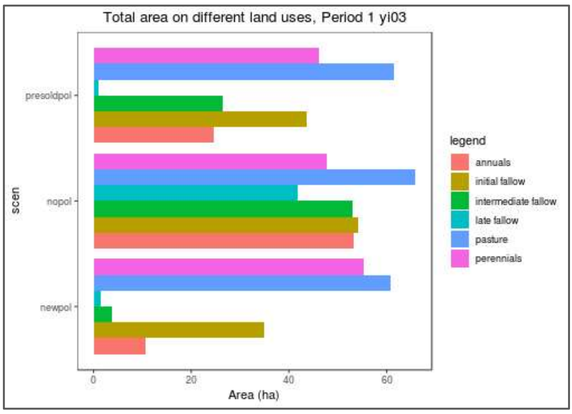
Share of plots for annuals and perennials

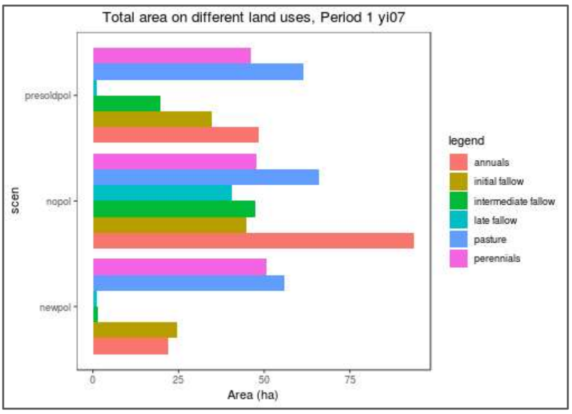
Scenario	Yield curve	Ann aver	Ann min	Ann max	Per aver	Per min	Per max
Newpol	yi03	169.1	112	480	884.67	738	2214
	yi08	315.03	292	365	738	738	738
Nopol	yi03	853.17	714	1651	762.6	738	1476
	yi08	1500.3	1209	2835	762.6	738	1476
Presoldpol	yi03	395.37	320	521	738	738	738
	yi08	764.47	710	819	737.9	735	738

Landscape structure






Total area on different land uses, Period 1 yi03
scen
presoldpol
nopol
newpol
0
20
40
60
Area (ha)
legend
annuals
initial fallow
intermediate fallow
late fallow
pasture
perennials


Total area on different land uses, Period 1 yi07
scen
presoldpol
nopol
newpol
0
25
50
75
Area (ha)
legend
annuals
initial fallow
intermediate fallow
late fallow
pasture
perennials

Annex 3

Declaration in lieu of an oath on independent work

according to Sec. 18(3) sentence 5 of the University of Hohenheim's Doctoral Regulations for the Faculties of Agricultural Sciences, Natural Sciences, and Business, Economics and Social Sciences

1. The dissertation submitted on the topic

Agent-based modeling of human-environment interactions in a smallholder agricultural system in the Atlantic Forest (Ribeira Valley, SP, Brazil)

is work done independently by me.

2. I only used the sources and aids listed and did not make use of any impermissible assistance from third parties. In particular, I marked all content taken word-for-word or paraphrased from other works.

3. I did not use the assistance of a commercial doctoral placement or advising agency.

4. I am aware of the importance of the declaration in lieu of oath and the criminal consequences of false or incomplete declarations in lieu of oath.

I confirm that the declaration above is correct. I declare in lieu of oath that I have declared only the truth to the best of my knowledge and have not omitted anything.

Santos, 30 October 2020

Place, Date

Signature

Curriculum Vitae

Lucia Chamlian Munari

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Education

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Ph.D. candidate at the Department of Land Use Economics in the Tropics and Subtropics
Universität Hohenheim (UHOH), Stuttgart, Germany
Title: Agent-based modeling of human-environment interactions in a smallholder agricultural system in the Atlantic Forest (Ribeira Valley, SP, Brazil)
Supervisor: Thomas Berger
Scholarship from: Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)

01.2007 – 01.2010

Master's in Ecology
University of São Paulo (USP), São Paulo, Brazil
Title: Social memory and historical ecology: the shifting cultivation system practiced by Quilombolas and the relationship with the formation of the Atlantic Forest
Supervisor: Dr. Rui Sérgo Sereni Murrieta

02.2000 – 12.2005

Bachelor in Biology
University of São Paulo (USP), São Paulo, Brazil

Professional experience

05.2017 – 11.2017

Freelance consultant– Socioenvironmental institute
(Instituto Socioambiental -ISA). This job included a research with fieldwork, interviews and visitations to agricultural areas. It also included results analysis and results presentation to farmers, agricultural estate institutions and policy makers. The research focused on the traditional agricultural practices in Quilombos of Ribeira Valley, and the different aspects involved on conservation policies implementation, including the reasons for conflict generation.

08.2010 – 04.2011	**Freelance consultant– Socioenvironmental institute** (Instituto Socioambiental -ISA). Land use classification through GIS methods. This job was part of the São Paulo state master plan for forest restauration and conservation of the hydrological resources in the Ribeira Valley. Funding: FEHIDRO (São Paulo State Fund for Hydrological resources)
02.2000 – 12.2005	**Freelance consultant– Ambiental Consulting, environmental solutions, AC S.A.** I supported the fieldwork, data collection and interviews in this job. The work was to develop socioeconomic studies for the creation o protected areas in the Dunes of the São Francisco river, in the municipalities of Barra and Xique-Xique, Bahia, Brazil.
08.2008 – 08.2010	**Research project coordination** Project title: Social memory and historical ecology: the shifting cultivation system practiced by Quilombolas and the relationship with the formation of the Atlantic Forest. The two years research project supported the fieldwork and research of the scientific projects of two Bachelor students, two Master students and one PhD candidate. Funding: FAPESP (The São Paulo Research Foundation)

List of publications

Journal contributions

Ribeiro Filho, A.A., Adams, C., Manfredini, S., **Munari, L.C.,** Barbosa, J.M., Barreiros, A.M., Neves, W.A., 2018. Dynamics of the soil fertility in quilombola shifting cultivation communities of the Atlantic Rainforest, Brazil Dinâmica da fertilidade do solo na agricultura itinerante de comunidades quilombolas na Mata Atlântica, Brasil. Bol. Mus. Para. Emílio Goeldi Ciênc. Nat. 13, 79–106.

Futemma, C., **Munari, L.C.,** Adams, C., 2015. The Afro-Brazilian Collective Land: Analyzing Institutional Changes in the Past Two Hundred Years. Lat. Am. Res. Rev. 50, 26–48.

Adams, C., **Munari, L.C**., Van Vliet, N., Sereni Murrieta, R.S., Piperata, B.A., Futemma, C., Novaes Pedroso, N., Santos Taqueda, C., Abrahão Crevelaro, M., Spressola-Prado, V.L., 2013. Diversifying Incomes and Losing Landscape Complexity in Quilombola Shifting Cultivation Communities of the Atlantic Rainforest (Brazil). Hum. Ecol. 41, 119–137. https://doi.org/10.1007/s10745-012-9529-9

Adams, C., **Munari, L.C**, Sereni Murrieta, R.S., Santos Taqueda, C, Novaes Pedroso, N; Gomes, E. P.C., Sugiyama, M., Oliveira Jr, C.J.F. 2010. Land-use/land-cover change in the Atlantic Rainforest (Brazil) - The historical ecology of the Quilombola shifting cultivation system. GLP News: newsletter of the Global Land Project international office, p. 10 - 11.

Conference contributions

Munari L.C., Troost, C., Marohn, C.; Adams, C., Ribeiro-Filho, A.; Berger, T. Coupling biophysical and socioeconomic models: assessing the consequences of conservation policies on smallholder livelihoods in the Atlantic rainforest (Brazil). *8th International Congress on Environmental Modelling and Software*, Toulouse, France, 2016. Oral presentation.

Munari L.C., Adams, C., Marohn, C.; Troost, C., Cadish, G.; Berger, T. Modeling human-environment interactions in a smallholder agricultural system in the Atlantic Rainforest, using a coupled socio-ecological model. *7th German-Brazilian Symposium on Sustainable Development. Heidelberg, October, 2015.* Poster presentation.

Munari, L.C, Adams, C., Sereni Murrieta, R.S., Futemma, C. Social memory and landscape: agriculture and landscape change in Quilombola communities, in Atlantic Rainforest areas of the Ribeira Valley, Brazil. *2nd Global Land project Open Science Meeting*. Berlin, Germany, 2014. Oral presentation.

Munari, L.C, Adams, C., Sereni Murrieta, R.S., Gomes, E.P.C., Novaes Pedroso, N, Oliveira Jr, C.J.F, Sugiyama, M. Social memory and landscape: slash-and-burn agriculture in the formation of an Atlantic rainforest area inhabited by quilombola communities, Ribeira Valley, Brazil. *1st World Congress of Environmental History*, 2009, Copenhagen, Denmark. Oral presentation.

Munari, L. C., R. S. S. Murrieta, N. N. Pedroso Jr and C. Adams. Social memory and landscape: slash-and-burn agriculture in the formation of an atlantic rainforest area inhabited by a quilombola community, Ribeira Valley, Brazil. In: 11th International Congress of Ethnobiology, 2008, Cusco, Peru. Oral presentation.

Munari, L. C., Novaes Pedroso, N, Murrieta, R.S.S. Taqueda, C.S.; Navazinas, N.D.; Ruivo, A.P. Agricultural intensification and demise of shifting cultivation system among quilombola populations in the Ribeira valley, Brazil. In: XV International Conference of the Society for Human Ecology, 2007, Rio de Janeiro RJ. Abstracts. Bar Harbor, USA: Society for Human Ecology, 2007. Poster presentation.

Book chapters

Munari, L.C.; Crevellaro, M. A. ; Spressola-Prado, V. L. ; da Silva, H.A. ; Taqueda, C. S. ; Novaes Pedroso, N., Angeli, C.B. ; Netto, R. C. M. 2010. Do escravo ao quilombola: a história e a transformação do modo de vida dos remanescentes de Quilomobo do Vale do Ribeira. In: Reginaldo Barboza da Silva; Lin Chau Ming. (Org.). Polo de Biotecnologia da Mata Atlântica: relatos de pesquisas e outras experiências vividas no Vale do Ribeira. Jaboticabal: Gráfica Multipress Ltda, p. 225-244.

Santos, 30 October 2020

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