ECONOMIC AND SPATIAL ASPECTS OF FOREST RESTORATION IN TROPICAL AGRICULTURAL LANDSCAPES: EVALUATING LANDOWNER INCENTIVE PROGRAMS IN THE ATLANTIC FOREST OF BRAZIL

by

Ryan Clark Richards
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Environmental Science and Public Policy

Committee:

____ Dr. Christopher Kennedy, Committee Co-chair

____ Dr. Francisco Dallmeier, Committee Co-chair

____ Dr. Thomas Lovejoy, Committee Member

____ Dr. Ragan Petrie, Committee Member

____ Dr. Albert Torzilli, Graduate Program Director

____ Dr. A. Alonso Aguirre, Department Chairperson

____ Dr. Donna Fox, Associate Dean, Student Affairs & Special Programs, College of Science

____ Dr. Peggy Agouris, Dean, College of Science

Date: ___________________________________ Spring 2017
George Mason University
Fairfax, VA

Economic and Spatial Aspects of Forest Restoration in Tropical Agricultural Landscapes: Evaluating Landowner Incentive Programs in the Atlantic Forest of Brazil

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

by

Ryan Clark Richards
Master of Science & Master of Public Policy
University of Maryland – College Park, 2010
Bachelor of Science
University of California, Davis, 2006

Director: Christopher J. Kennedy, Assistant Professor
Department of Environmental Science and Public Policy

Spring Semester 2017
George Mason University
Fairfax, VA

DEDICATION

I dedicate this dissertation to my parents, Ron and Robin, and to my grandparents, in recognition of the value they placed in education and their encouragement to pursue the things I loved.

ACKNOWLEDGEMENTS

I would like to thank my family for their support and love. I thank my friends for their help and companionship through the process, and Emily Kayser for her patience and compassion.

I also acknowledge the support of numerous people in Brazil who helped conduct this research. I thank Pedro Brancalion, Eduardo Ditt, Alexandre Uezu, and Clinton Jenkins for their help pursing funding and in the strategic and logistic planning that got the project to the finish line. Leticia Guimarães Marttinen was a great help in learning the policies and programs at the Ministério do Meio Ambiente and elsewhere. And thanks to Tom Lovejoy for his help directing me to his colleagues in Brazil and for early insights in shaping the research. My advisor, Chris Kennedy, was a great help in all aspects of the project, and he and Ragan Petrie were instrumental in organizing the methodology and analysis for the choice experiment.

I also acknowledge Lizandra Gasparro, Mauro Rufato, Ruan Gomes, Marcela Beraldo, César Godoy, and Day Paulino for their help interviewing landowners, and Ben Christ for his help in planning the survey and conducting interviews. Oscar Sarcinelli was a great help in acclimating to the culture and learning about the cattle production in the region, and Mbatuya Medina and Emanuel Haddad Perdão were gracious in their support of the project and sharing future government needs at the state and local level to help shape the project. I also acknowledge the support of Laury Cullen, both for the research ideas and the assistance in bridging the gap between rural American and rural Brazilian culture.

Finally, I thank Francisco Dallmeier, Marshall Jones, Steve Monfort, and John Berry, all of whom provided valuable advice on pursuing a PhD with Smithsonian and George Mason University.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

National Water Agency .... ANA
Area of Permanent Preservation .... APP
Rural Land Registry .... CAR
São Paulo Agricultural Extension Office .... CATI
Minas Gerais Office of Rural Extension and Technical Assistance .... EMATER
Agricultural Federation of Minas Gerais .... FAEMG
Federation of Agricultural Workers of Minas Gerais .... FETAEMG
Minas Gerais State Water Management Agency .... IGAM
Minas Gerais State Institute of Forests .... IEF-MG
Ecological Research Institute .... IPÊ
Minas Gerais State Land Institute .... ITER
Legal Reserve .... LR
Payments for Ecosystem Services .... PES
Payments for Watershed Services .... PWS
Water Producer Program .... PdA
Piracicaba-Capivari-Jundiaí .... PCJ
Program for Environmental Compliance .... PRA
Program for Riparian Forest Restoration .... PRMC
National Program to Strengthen Family Agriculture .... PRONAF
São Paulo State Water Utility Company .... SABESP
Agrarian Reform Secretary of Minas Gerais .... SEARA
National Rural Learning Service .... SENAR
National System of Conservation Units .... SNUC
The Nature Conservancy .... TNC

ABSTRACT

ECONOMIC AND SPATIAL ASPECTS OF FOREST RESTORATION IN TROPICAL AGRICULTURAL LANDSCAPES: EVALUATING LANDOWNER INCENTIVE PROGRAMS IN THE ATLANTIC FOREST OF BRAZIL

Ryan Clark Richards, Ph.D.

George Mason University, 2017

Dissertation Director: Dr. Christopher J. Kennedy

This dissertation describes the state of forest restoration on private land in the Cantareira region of São Paulo state, Brazil, specifically the municipalities of Nazaré Paulista, Piracaia, and Joanópolis. It includes separate analyses of forest restoration policies, landowner preferences and perceptions regarding forest restoration, and trends in forest regeneration in the region.

The Cantareira System is one of the largest drinking water reservoir systems in the world, with the potential to supply water to approximately 10 million people in the São Paulo metropolitan area. The basin stretches across two states (São Paulo and Minas Gerais) and several municipalities inhabited by over 180,000 people, many of whom maintain pasture where forests once grew. Recent droughts have raised concerns over land use and water stress, as both water quantity and quality issues have arisen in the region.

The Cantareira System lies completely within the highly threatened Atlantic Forest, and is valuable for conservation as a link between the Serra da Cantareira and Serra da Mantiqueira mountains. Because of its importance to São Paulo and its ecological value, government and civil society actors have piloted *payments for watershed services* (PWS) programs here. These incentive programs encourage reforestation through direct payments to landowners. However, there is little evidence that PWS incentives will encourage forest restoration at spatial scales to positively affect watershed services.

In **Chapter One**, a policy review and data from a survey of landowners are used to identify potential gaps between the incentives that have been offered in existing PWS programs and the preferences of farmers who would likely be targeted by active forest restoration efforts. The analysis suggests that the payments offered by many PWS programs may not be sufficient for participation by landowners who are heavily dependent on agriculture – the most likely target group for this type of program. In addition, penalties set by other legislation, such as restrictions on formal credit for farmers who are not in compliance with Brazilian land use law, may not affect these farmers. This suggests that better incentive design is needed at the regional level to encourage forest restoration.

Chapter Two uses discrete choice experiment methodology to elicit preferences for PWS contract attributes and examine how these preferences relate with property and household characteristics. Landowners show a preference for inclusion of in-kind payments (in this case, fencing material) in lieu of cash-only payments. Varied restoration levels reveal the importance of property-level characteristics to reforestation decisions, which will likely confound enforcement of land use laws that target riparian areas. Finally, a significant percentage (~20%) of the landowners opted for the status quo in all choice situations. In some cases this was related to property characteristics, but also reveals issues of trust in outside contracts that has potential to limit the success of PWS programs.

Finally, **Chapter Three** uses land cover data from 1990, 2000, and 2010 to identify trends in forest regeneration in the study municipalities. In addition to evaluating land cover change at a municipal scale, data from the landowner survey and the Brazilian CAR property registry are used to explore property-level dynamics. Analyses of land cover change from 1990-2000 and 2000-2010 reveal distinct patterns, driven by the expansion of eucalyptus plantations in the first period and transitions from pasture to forest in the second. Distance to watercourses and forests are observed to have large, positive effects on forest regeneration, while distance to urban areas have negative effects. These broad influences affect regeneration at the property-level as well, but regeneration is also observed to be more likely as property size increases.

A brief **Conclusion** summarizes the observations from the three chapters and considers their relevance to conservation strategies in the Cantareira region and areas of future research need.

CHAPTER ONE – CONSIDERING FARMER LAND USE DECISIONS IN EFFORTS TO 'SCALE UP' PAYMENTS FOR WATERSHED SERVICES

Introduction

Payments for ecosystem services (PES) programs are a policy approach to promote land uses that provide ecosystem services through payments to land managers by ecosystem service users (Wunder 2005). This concept of direct payments is more efficient than indirect approaches to shifting behavior, especially in situations where the desired provision of an ecosystem service involves coordinating large numbers of individuals (Ferraro and Kiss 2002). Watershed management is one field in which PES has been welcomed, as downstream service users (e.g., public drinking water utilities or hydroelectric power producers) often have a range of actors upstream that affect quality and quantity of water supplies (Landell-Mills and Porra 2002). The appeal of payments for watershed services (PWS) is reflected in the rapid emergence of programs over the past 20 years. Ecosystem Marketplace, a Forest Trends program that tracks market-based environmental programs, reports over 450 PES programs in operation solely to protect watershed services, with transactions totaling over $25 billion (Bennett et al., 2013).

This rapid growth in the number of programs has raised concerns about additionality – the outcomes of programs beyond what would have occurred in their absence (Pattanayak et al, 2010). Research into this issue has primarily been conducted *ex post*, frequently using experimental or quasi-experimental approaches to measure impacts of PES programs on land cover or other variables (Arrigiada et al., 2012; Sills et al. 2008; Robalino and Pfaff, 2013; Jayachandran et al. 2016). This has been useful, helping such programs as Costa Rica's national *Pagos por Servicios Ambientales* program address issues with targeting and other opportunities for improvement (Pagiola, 2008).

However, these evaluation approaches are not available in every context in which PES programs have operated. The scale of Costa Rica's PES program lends itself to quantitative evaluation using spatial data, and planning and partnerships were required to apply randomization of treatments during the implementation of other programs for evaluation purposes. Absent these conditions, other approaches are necessary to identify opportunities to program design and implementation.

Here we describe the results of a research project on challenges and opportunities for PWS to serve as a tool to increase forest cover on private land in the watersheds of the Cantareira System in southeastern Brazil. The area is the source of a significant portion of the drinking water for the São Paulo metropolitan area, but agricultural activities, in particular pasture for cattle, affect these resources and several PWS programs have been implemented in the region. Several PWS programs have already been implemented in the region, but they have experienced high startup costs and other challenges (The Nature Conservancy-Brasil 2015; Kfouri and Favero 2011). Despite these challenges, there is interest in expanding PWS efforts, and a clear need to identify and address potential obstacles to wider landowner participation to secure additional environmental benefits.

We draw from the literature on PWS programs in Brazil to identify the structure of contracts and incentives offered to landowners in the Cantareira watersheds. We then use past research on land use and technology adoption by Brazilian cattle farmers, as well as interviews with landowners and technical staff working in the São Paulo portion of the Cantareira System, to understand drivers of land use change on farms in the region. Using the model of PES adoption proposed by Pagiola et al. (2005), we discuss factors that may affect the additionality of future investments in PWS and lessons for development of this type of program elsewhere in the world.

Methods

Study site description

The Cantareira System is a large reservoir complex used to store drinking water for the São Paulo metropolitan area – the largest urban agglomeration in South America (Whately and Cunha 2007). The basins that drain into the reservoirs lie within the states of São Paulo and Minas Gerais, covering roughly 230,000 hectares (Figure 1). The entire system is located in the Atlantic Forest ecoregion, a biodiversity hotspot with globally significant levels of plant and animal diversity and endemism (Myers et al. 2000) and only 11-16% of its native vegetation cover (INPE and SOS Mata Atlântica 2015)). The Cantareira System is a focal area for forest restoration by the Atlantic Forest Restoration Pact (AFRP), which has a goal of restoring 15 million hectares of forest by 2050 (Melo et al. 2013; Banks-Leite et al 2014).

The Atlantic Forest is also home to over 125 million people (IBGE 2016) and produces roughly 70% of Brazilian GDP (Melo et al. 2013). Recent droughts have raised concerns over the state of the Atlantic Forest and the impacts of deforestation and land degradation on the drinking water and hydropower supplies that are critical to the country's economy (Nobre et al. 2016; Tafarello et al. 2016).

Although roughly 40% of the Cantareira region is still forested, native vegetation cover is highly fragmented by agriculture. Pasture for cattle and eucalyptus plantations are the dominant agricultural activities by land area, although some municipalities also have high concentrations of greenhouses for vegetable and seed production (São Paulo State Agricultural Extension Service 2008). The total population of the three study municipalities in São Paulo state (Nazaré Paulista, Piracaia, Joanópolis) was approximately 53,208 individuals as of 2013 (IBGE 2016), with 1,882 landowners raising cattle for dairy and beef during the last available state agricultural census (São Paulo State Agricultural Extension Service 2008). The municipalities are all close to the São Paulo metropolitan area and accessible by major highways, which has resulted in expansion of housing construction driven by urban demand. This combination of agricultural activity and rural development in an important catchment has made the region a priority for riparian restoration efforts, including PWS, to improve water quality.

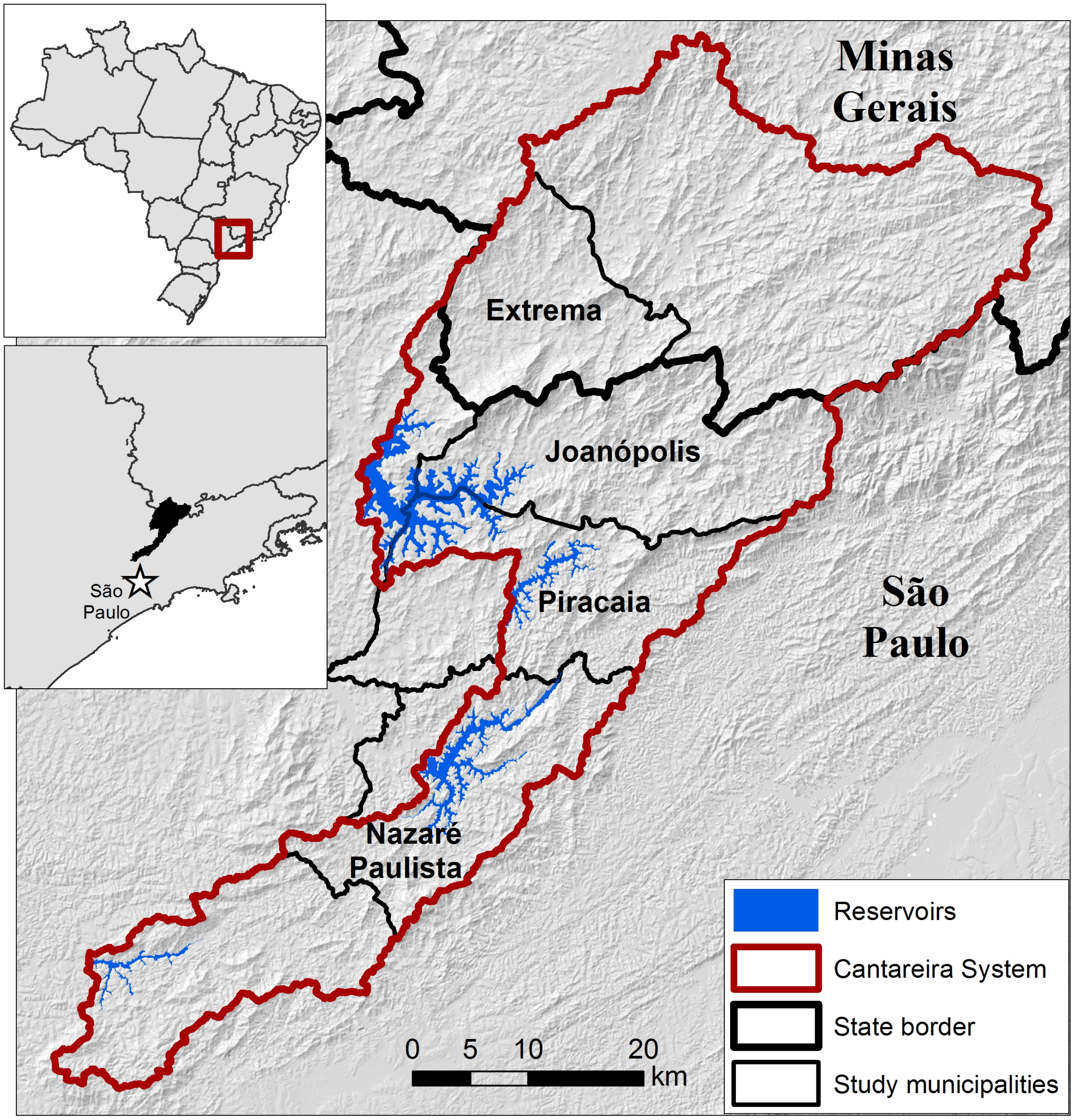


Figure 1. Map of the Cantareira System, including study municipalities

Review of policies affecting PWS in Brazil and of PWS programs in the Cantareira region

Information on environmental legislation was gathered through a review of the legislative history of Brazil and of several policy analyses published after the promulgation of the Native Vegetation Protection Law, which replaced the Forest Code in 2012 (Brancalion et al. 2016). Peer-reviewed publications were added through a purposive sampling process, drawing from the authors' libraries, discussions with government officials in Brazil, and in-depth reviews of material maintained by knowledge centers, in particular the World Bank. Additional information on PWS across Brazil, and specifically within the Cantareira region, was gathered from peer-reviewed literature, as well as grey literature on program development and implementation that is available through PWS partner websites (see Appendix 1 for full reference list).

Literature review of drivers affecting land use and technology adoption by cattle ranchers in Brazil

Following these interviews, a literature review was conducted to capture in greater detail the issues affecting land use decisions by small-scale beef and dairy producers typical of the São Paulo portion of the Cantareira watersheds. Search terms on the Brazilian cattle industry (Brazil AND agricultur* AND cattle) were used to collect articles published between January 2000 and April 2016 using the Web of Science database. Initial searches returned 1390 publications, of which just 88 were related to farmer decisions (the majority of the results reported on epidemiological and biological research). Of these 88 articles, only 21 explicitly addressed issues (e.g., economic factors) that affected land use. Additional references were drawn from the literature cited by these articles, and from the authors' personal libraries, for a total of 27 articles for review (see Appendix 2).

Field assessments with farmers and agronomists

To understand the factors that may affect landowner participation in PWS, focus groups on challenges facing those involved in agricultural production were conducted with farmers in the Cantareira region as a part of pasture management courses run by a Brazilian NGO (Instituto de Pesquisas Ecológicas – IPÊ) during June and July 2015. Two focus groups were held, with a total of 7 participants (see Appendix 3 for survey questions). In order to augment the low number of participants, individual in-person and Skype interviews were conducted with agricultural extension officials (N=4) working in this region of São Paulo state, and with individual farmers who had partnered with IPÊ on past projects.

Individual interviews with farmers in the Cantareira

Data from the individual interviews with landowners and agronomists and the literature review were complemented by survey data from 189 individual interviews with landowners from September to November 2015. These data were collected in the study municipalities of Nazaré Paulista, Piracaia, and Joanópolis, in each municipality's rural zones. To minimize bias in sample selection, researchers did not rely on existing social networks or contacts to arrange interviews. Instead, landowners were approached during neighborhood visits. Surveys lasted approximately 45 minutes and included questions on household and property characteristics (see Appendix 4).

Results

Development of PWS in the Cantareira Region

There is a long history of environmental legislation in Brazil (Dean, 1997), including some of the world's first decrees to restore native forests and several iterations of national land laws (referred to as the "Forest Code") that mandate retention of areas of native vegetation on private land. The current Native Vegetation Protection Law, commonly referred to as the "New Forest Code", is the primary major legal instrument for addressing land degradation and promoting ecosystem services in Brazil.

The earliest version of this legislation (1934) was intended to secure fuelwood reserves close to cities and industry and maintain ecosystem services mediated by native vegetation in riparian buffers. The 1965 Forest Code mandated conservation and restoration of riparian and other environmentally fragile areas, such as steep slopes and mountaintops (Brancalion et al. 2016). These land use mandates were categorized as either Legal Reserves (LR), (i.e., a minimum percentage of farm area to be maintained with native vegetation) or as Areas of Permanent Preservation (APP), (i.e., environmentally fragile areas that must be protected) in addition to LR. Landowners are required to conserve or restore native vegetation on portions of their property categorized as LR and/or APP or face legal repercussions.[1]

Historically, the enforcement of the Forest Code has been weak, due in part to gaps in legal instruments (see Hirakuri, 2003) and enforcement capacity (e.g., monitoring compliance and subsequent administration of fines) (Sparovek et al., 2012; Hirakuri, 2003). For larger landowners and businesses, enforcement has become more frequent as the Environmental Crimes Law (Lei nº9605/1998) and public pressure and attention has increased. The 2012 law has sought to improve compliance for smaller landowners through the introduction of a rural land registration system (CAR), mandatory for rural properties, that includes spatial data for a property including its environmental

[1] The relative sizes of the Legal Reserve and Area of Permanent Protection vary by ecoregion and characteristics of an individual property. A good summary of these requirements can be found in the supplementary material of Soares-Filho et al., 2014, in Garcia et al., 2013, and Brancalion et al. 2016.

information (Garcia et al., 2013). Enrollment is being coordinated by the environmental secretariat in each municipality, and registration closes in May 2017. However, restoration costs remain a major obstacle for many landowners (Pinto et al., 2014). On a per-hectare basis, seedlings and maintenance can cost roughly R$17,000/hectare (US$4,800/ha) in the Cantareira region,[2] which is higher than upfront investments for most agricultural products.

Payments for ecosystem services have been proposed as a means to foster legal compliance by small- and medium-sized landholdings through reductions in compliance costs, and to date several PWS programs have been implemented in the Brazilian Atlantic Forest, ranging in scale from watershed sub-basins to states (Brancalion et al., 2012; Pagiola et al. 2013; Banks-Leite et al., 2014). The new Forest Code includes a chapter – the Program for Environmental Compliance (*Programa de Regularização Ambiental* – PRA) on financial incentives for restoration, with an emphasis on payment programs (Packer, 2015; Garcia et al., 2013). This chapter, in conjunction with other environmental legislation, enables development of PES contracts with landowners who have registered in the CAR.

Funding for PES for restoration can originate from a range of sources. The National Water Law of 1997 established a framework to facilitate creation of watershed committees to manage water resources (Veiga and Magrini, 2013). This framework recognizes water as a public good, which users must compensate producers for, and notes

[2] Conversion used the USD-BRL exchange rate as of 4 June 2016. Cost estimates are from the Insituto de Pesquisas Ecológicas (IPÊ, Ecological Research Institute), a Brazilian NGO that owns a nursery and works with landowners on restoration projects in the Atlantic Forest, and include material and labor for both planting and 3 years of site maintenance to improve survival.

that user fees should be used to protect water sources. Each watershed committee is comprised of government representatives (either state or federal, depending on the jurisdiction for a given river), civil society representatives, and stakeholders, such as landowners and water users. These committees collectively decide how to (i) allocate water; (ii) implement new development projects; (iii) arbitrate conflicts among stakeholders; and (iv) impose pollution control restrictions (Porto and Kelman, 2000). National level actors still exert heavy influence on water management, and these committees provide a voice for local actors in project management and implementation. To date, three committees in the state of São Paulo already collect usage fees – Paraíba do Sul, Sorocaba/mid-Tietê, Piracicaba-Capivari-Jundiaí – which have been used in part to support pilot PWS (Padovezi et al., 2012).

PWS programs in the Cantareira

The Cantareira Region has been the focus of the earliest efforts to develop PWS in Brazil, and four programs have been implemented within the watersheds. These include the municipal Water Conservator (*Conservador das Águas*) program in Extrema, Minas Gerais, the Water Producer (*Produtor de Água*) program in the Piracicaba-Capivari-Jundíai watersheds, the state-level Water Mine (*Mina d'Água*) program in São Paulo state, and the state-level Green Bag (*Bolsa Verde*) program in Minas Gerais (Table 1).

Table 1. Attributes of PWS within the Cantareira System

	Year Founded *(First Contract)*	Focal Activities	Funding Sources	Program Watersheds	Stakeholders
Conservador das Águas	2005 *(2007)*	• Forest restoration • Erosion control • Soil Conservation	Municipality through city taxes; TNC	Posses and Salto (Extrema)	• Municipality of Extrema • Mina Gerais State Institute of Forests (IEF) • PCJ Watershed Committee • The Nature Conservancy • SOS Mata Atlântica
Produtor de Água - PCJ	2009 *(2010)*	• Soil conservation • Forest restoration • Forest conservation	PCJ committee	Cancã (Joanópolis); Moinho (Nazaré Paulista)	• National Water Agency (ANA) • São Paulo State Secretariat of the Environment (SMA) • São Paulo State Agricultural Extension Service (CATI) • Municipal governments (Joanópolis, Nazaré Paulista) • The Nature Conservancy • Associação Mata Ciliar (NGO)
Mina d'Água	2010 *(2012)*	• Spring protection through forest restoration or conservation	Paid through the state of SP	Piracaia (city-wide)	• São Paulo State Secretariat of the Environment • São Paulo State Agricultural Extension Service (CATI) • São Paulo Fund to Combat Poverty (FECOP) • Municipality of Piracaia
Bolsa Verde	2008 *(2010)*	• Forest conservation • Forest restoration	MG government (8 sources)	Camanducaia, Extrema, Itapeva (state-wide program)	• Minas Gerais State Institute of Forests (IEF) • Minas Gerais Water Management Agency (IGAM) • Minas Gerais Office of Rural Extension and Technical Assistance (EMATER) • Agrarian Reform Secretary (SEARA) • Minas Gerais Land Institute (ITER) • Agricultural Federation of Minas Gerais (FAEMG) • Federation of Agricultural Workers of Minas Gerais (FETAEMG)

The development of PWS in Brazil was initiated in 2001, when the National Water Agency (ANA) developed a country-wide Water Producer program (*Produtor de Água*) to support incentives for sustainable land use and restoration by watershed committees (Pereira et al., 2010). The initial task for the program was the development of legal and administrative frameworks to propose financial incentives to improve land use, and demonstrate their practicality in a field setting (Padovezi et al., 2012; Agência Nacional de Águas, 2011).

Following the creation of the conceptual frameworks, pilot Water Producer projects were developed in several municipalities. The first of these was the Water Conservator (*Conservador das Águas*) program in Extrema. Launched in 2005, contracts were first implemented in one small basin (Posses) in the municipality in 2007 (Pereira et al. 2010). The program expanded to an additional basin (Salto) in 2009 and as of 2015 has produced contracts with 53 landowners that have resulted in a 60% increase in forest cover in the program areas (Richards et al. 2015).

A second project was launched in the São Paulo state portion of the Cantareira System, called the Water Producer – Piracicaba-Capivari-Jundiaí program (*Produtor de Água – Piracicaba-Capivari-Jundíai*, or PdA-PCJ). Planned in 2005, the PCJ watershed committee secured fees to finance pilot PdA-PCJ contracts with landowners, beginning in 2009 (Padovezi et al., 2012). Two subwatersheds in the Cantareira System were selected for the PdA-PCJ project, in the municipalities of Nazaré Paulista and Joanópolis. The Moinho (Nazaré Paulista) and Cancã (Joanópolis) microbasins collectively cover 4,212ha, and as of 2016 320 hectares had been enrolled in the PdA-PCJ program as part of over 40 contracts (Tafarello et al. 2016).

The state of São Paulo advanced its commitment to PWS through its 2009 State Climate Change Policy (PEMC – Política Estadual de Mudanças Climáticas). In 2010, the São Paulo Environment Secretariat adopted Resolution No. 61, building on a series of riparian restoration and sustainable land use programs to create a framework for PWS to conserve or restore springs that supply drinking water (Pagiola et al., 2013). Implementation began in 2010 with the development of municipal legislation enabling financial transfers from public entities to private landowners. This enabled the first round of contracts with five landowners in Piracaia in 2012 (von Glehn, 2012; São Paulo Environment Secretariat, 2015).

The government of Minas Gerais created its own PES program in 2008, with a focus on restoration of riparian areas to improve water supplies and improve connectivity for biodiversity (de Oliveira et al., 2013). Small agricultural operations are the priority audience for participation in the Green Bag *(Bolsa Verde)* program, in particular family farms and properties of less than 4 'fiscal modules'[3] (Santos et al. 2012). Enrollment proposals may be submitted by property owners individually or in groups, and are awarded based on point scores that consider current levels of forest cover on a property, existing conservation activities, agricultural practices, and other socioeconomic factors.[4] As a statewide program, the enrollment in this program is much larger than the other programs in the Cantareira (Pagiola et al. 2013), but the majority of the enrolled areas are elsewhere in the state.

[3] A fiscal module is measured in land area and comprised the minimum area needed to be under agricultural production to support a family using the dominant crop/livestock type in a given municipality. As a result there can be high levels of variation in the size of a fiscal module across states and regions.

[4] For a full scorecard, see de Oliveira et al. (2013), p. 149.

Details of enrollment requirements and contract incentives offered by the PWS programs are described in Table 2. All contracts had relatively short lengths (2-5 years) and provided both legal and technical assistance to the participating landowners. Payments varied in their complexity, ranging from Extrema's CdA program paying landowners a fixed rate for every hectare of an enrolled property to the more complicated formulas of the Water Mine (*Mina d'Água*) program to calculate per-hectare payments for specific management actions. In each program, civil society organizations and other groups were involved in design and implementation activities to assist landowners in conducting PWS practices. All programs shared common requirements, such as legal documentation, to enter into contracts, but several restricted eligibility based on agricultural practices or farm size. This targeted the types of landowners that were unlikely to maintain forest on their property without some form of support.

Table 2. Enrollment requirements and contract features for PWS in the Cantareira System.

Eligibility requirement	Enrollment requirements	Contract length	Payments
Produtor de Água - PCJ	• Minimum portion of APP must be forested • Legal documentation of property	3 years	Set using 3 factors: 1) Relative use of soil conservation practices (25-50/50-75/75-100% of recommended), R$25-75 per ha/yr. 2) Riparian forest restoration (2 classes) with either R$83 or 125 per ha/yr. 3) Conservation of riparian forest, with payment by the class of forest and engagement of landowner, R$43-125 per ha/yr.
Conservador das Águas	• >2 hectares • Landowner must reside on property • Legal documentation of property	4 years, renewable	Fixed payment of R$176/ha/yr (opportunity cost of pasture)
Mina d'Água	• Family farms only • Active agricultural practices • Legal documentation of property • Owner may not be in arrears to the state	2-5 years	Based on a reference value with a maximum of R$150/ha and the following formula: Payment = $0.2V_{ref}$ x (protection factor) x (importance factor)[1]
Bolsa Verde	• < 4 fiscal modules • Landowner must reside on property • Legal documentation of property	5 years	R$200/ha/yr (for both the conservation and restoration of native vegetation)

Literature on behavior of cattle producers in Brazil

Literature in agricultural economics and international development identifies a range of factors affecting production and land use (Mendola, 2007). Economic issues, such as distance to markets, infrastructure, price fluctuations, technology adoption, credit access, and labor constraints, affect production potential. In addition, social, political, and cultural factors, including trust in institutions, education, and social networks, interact with each other and with economic factors to influence land use decisions.

Brazilian cattle production is generally characterized by relatively low per hectare stocking rates, and the potential for intensification is considered an opportunity to create space for large-scale forest restoration (Latawiec et al., 2015). However, both dairy and beef production require significant upfront investment in livestock and infrastructure, and sensitivity to these costs varies with household and property characteristics. For example, Haddade et al. (2005) modeled profitability of intensive pasture management (e.g., rotational grazing) for dairy production, and found it to be highly sensitive to fluctuation in prices for milk and production inputs, leading to high risks of losses that may be unacceptable for some landowners. Mendes (2006) observed that ear tagging, a monitoring tool, was adopted mainly by large landowners in Santa Catarina state, which was attributed to the high cost of the system and financial restrictions faced by smaller operations. In Extrema, many enrollees in *Conservador das Águas* are retired, and conducting only limited agricultural operations as they draw pensions (Richards et al., 2015). This may, in addition to the larger PWS payments offered through the program, make management practices required by PWS more tolerable for participants.

Policies to improve credit access for smaller agricultural operations are relatively recent, with a historical focus on large-scale agriculture (Carrer et al. 2013). PRONAF, a government support program that extends credit to family farmers[5] for infrastructure, technology, and market access (e.g., the creation of cooperatives), has yet to achieve broad impacts on production for smallholders, including investments in on-farm milk cooling equipment or other infrastructure that would aid farmers in improved their outputs (Guanziroli et al., 2013). Barbosa et al. (2013) find that access to credit is a significant factor affecting returns to scale in a review of agricultural efficiency throughout Brazil. Merry et al. (2004) notes that farmers in the Brazilian Amazon frequently used informal contracts instead of formal credit to establish cattle herds, despite the fact that small ranchers typically lost money and bore most of the risk.

The 2007/2008 Agricultural Census in the state of São Paulo (referred to as LUPA in Portuguese), reports only 15.38% of agricultural producers using rural credit programs (São Paulo State Agricultural Extension Service 2008). Considering credit usage at this scale includes large agricultural operations producing sugarcane or cattle, which are common in the interior of São Paulo state. Selecting data only from the three municipalities that cover the majority of the São Paulo portion of the Cantareira watersheds reveals that only 4.3% of the landowners involved in agricultural activities reported usage of rural credit programs. This does not include informal credit and may be

[5] "Family farmer" is an official classification, defined by the Brazilian government using property size, on-farm labor, and household dependence on agricultural income.

confounded by the smaller size of operations in the region, but suggests that barriers to usage of credit remain.

Labor constraints also have a strong effect on cattle production at different scales. Many family farms depend on labor from the household or from extended family, with farm managers and additional permanent workers only present on larger operations (Hostiou et al., 2015). The quantity and capacity of available labor affects production costs, as many efficiency measures (e.g., use of milk cooling equipment and record-keeping practices) require significant labor investments (Dill et al., 2015; Diniz et al., 2013).

Social and cultural factors affect capacity to adopt new practices and land uses. Rural family agriculture is deeply rooted in Brazilian cultural history, and the appeal of the profession plays an important role in farmer identity and the avenues through which information and technology enter communities (Hostiou et al., 2015; Gil et al., 2015). Social networks have been observed to positively affect intentions to alter pasture management (Borges and Lansink, 2015), adoption of economic management practices (Dill et al., 2015), and capacity for bargaining and negotiating contracts (de Brito et al., 2015). Dill et al. (2015) observe the adoption of accounting and other management practices among dairy farmers in Rio Grande do Sul to be correlated with association membership, and with internet access.

Beyond social networks, perceptions of government also affect land use decisions. Despite Brazil's long history of land use regulations, many properties remain out of compliance with APP and LR mandates. This may be attributable to restoration costs, but low probability of enforcement, economic benefits of grazing in riparian areas, and barriers to working with government and civil society groups also likely play a role. Entry into a PWS contract with a government entity depends on the reliability of the fulfillment of contract terms. Although some of the benefits of PWS contracts are delivered early in the contract (e.g., forest restoration and legal documentation), payments are typically contingent on monitoring and paid annually or semi-annually, and so participating landowners would need to be confident in their eventual delivery. Zanella et al. (2014) identify prior connections with environmental NGOs to be correlated with PWS participation, which may reflect landowner values, or higher trust in PWS administration and objectives.

Biophysical characteristics of a property also affect landowner decisions in a number of ways. Chief among these is the productivity of land as pasture, which varies with characteristics such as water availability, soil type, and slope. Although most of the Cantareira is hilly and relatively inefficient for cattle, especially compared to other regions in Brazil, eucalyptus is the main alternative (Ditt et al. 2008). Plantations do not generate income as quickly as cattle, and so lose appeal for some landowners. However, some portions of land are highly sloped and require higher labor or generate production risk (through the loss of cattle to falls), making intensification of pasture management untenable and shifts to eucalyptus or abandonment more likely. Distance also restricts development options on some properties, as infrastructure in the region is poor and dominated by dirt roads on steep slopes that are difficult to traverse during wet periods.

A final issue is perceived risk associated with forest cover near a property. In a pilot study on the potential use of auctions to allocate PWS contracts in São Paulo state, Hercowitz and Figueiredo (2011) note that security concerns affected perceptions of forest restoration, in particular poaching of native palms and robbers using forests as cover to steal livestock. Security services are relatively weak in rural Brazil, with farmers relying on neighbors to monitor threats, and so maintaining open sightlines to mitigate the potential for loss of stock to theft is a serious consideration for small-scale farmers.

Field assessments and farmer interviews

Descriptive statistics of demographic variables for survey participants are included in Table 3. All of the surveyed individuals maintained pasture for livestock, which was a requirement to participate in the survey. The population is relatively old, with an average age just below the minimum for pension collection. Education and income levels are highly variable. Across the population roughly 60% of income was reported from off-farm sources, but the distribution was highly varied. Eighteen percent of farmers are wholly reliant on on-farm activities for income, while nearly 40% reported less than 10% of their earnings from agriculture on their property. Other farmers reported a more equal mix of on- and off-farm income streams, which was attributed to dual income households as well as pensioners, as retirement benefits were considered off-farm income in the survey questions.

Table 3. Descriptive statistics of surveyed landowners.

	Mean	Std. Dev.	Min	Max
Gender (proportion male)	0.842	--	--	--
Age (years)	54.15	13.73	18	88
Education (years)	7.59	5.49	0	30
Monthly income[1] (% of sample)				
<1	5.29	--	--	--
1-3	49.74	--	--	--
4-10	33.86	--	--	--
>10	11.11	--	--	--
Off-farm income (%)	59.02	37.85	0	100
CAR registration (% of sample, Nov. 2015)	56.08	--	--	--
Property Size (hectares)	41.98	61.56	0.6	453
Pasture (% of property	65.17	26.52	7	100
Forest (% of property)	16.04	15.51	0	70
All APP forested	25.40	--	--	--

Over half (56%) of households reported having completed the CAR registration process for their property. However, only 25% of households reported that the APPs on their land were fully forested. A variety of factors were suggested during interviews for the lack of forest cover, including the specific orientations of springs and streams on properties, and the presence of forest cover elsewhere on the property or on other properties owned by the landowner. The density of streams on properties (meters/hectare) was highly variable (mean = 30.41, std. dev. = 56.92), with several farmers expressing skepticism about the possibility of maintaining cattle production and complying with land use laws, despite the maximum restoration requirements established under the 2012 law.

The surveyed population reported little usage of formal credit sources, with many individuals complaining either of paperwork or risk involved in working with banks. Only 27% of farmers (51) reported the use of credit within the past 5 years, while 76% (143) reported having invested in physical improvements on the property in the same time period. Focus group participants mentioned the use of social and family networks to procure informal loans during crises, and reluctance among many of their peers to utilize PRONAF or other lines of formal credit. The reasoning behind this preference for informal or formal credit is unclear, but it was suggested that the bureaucracy required for formal credit presents challenges to farmers with lower levels of education, and that some landowners were skeptical of financial institutions.

Focus group participants observed that adoption of improved pasture management in Nazaré Paulista has spread through specific landowners in the municipality who have close familial ties to other farmers and rent tank space to neighbors for milk storage. Informal training sessions have also been organized with neighbors and extended family to demonstrate pasture management techniques. Participation in agricultural extension programs is low, only 26% of the survey participants reported attending a course offered by government agricultural extension offices, NGOs, or rural producers' associations.

The proximity of the Cantareira to some of the country's largest urban areas has affected labor supply for landowners. Contracting day laborers (*mão-de-obra* in Portuguese) is preferred for construction and infrequent maintenance tasks, but urban expansion has contributed to labor market constraints. The factories of Guarulhos and the greater São Paulo area are relatively close, and farmers have commented that the labor pool for daily contracts appears to have been negatively affected by this urban expansion and more lucrative employment opportunities. Migration away from cities is also having an impact, as the construction of second homes and infrastructure for tourism around the reservoirs and rivers of the region has resulted in increased subdivision and sale of agricultural land.

It was not clear that political and economic crises in Brazil affected perceptions of the validity of PWS contracts with the government, but it was apparent that historical political issues continue to affect landowner opinions. In addition to negative perceptions of agricultural extension programs and wariness to seek credit, trust in government institutions in the Cantareira region is further complicated by the development of reservoirs in the 1970s. When the Atibainha reservoir was completed in 1973, the government relocated many families in the municipality of Nazaré Paulista to less productive land in the hills around the reservoir, which limited family farmers' capacity to support themselves and created a lasting legacy of distrust of government (Ditt et al., 2008).

Discussion

Brazil has developed a legal framework for PWS, including governance structures to manage watersheds, generate financing, and identify ecologically beneficial activities. This framework has been augmented by state and municipal laws, which have, in turn, spurred development of a range of small-scale and pilot programs. In some instances these programs have targeted priority areas for ecosystem services provision, while others allow for interested participants to enroll across broader geographic scales. However, much of the participation in PWS programs in the Cantareira has been a product of focused recruitment and support from government and civil society actors (The Nature Conservancy-Brasil 2015; Zanella et al. 2014; Kfouri and Favero 2011). This type of recruitment is expensive, and results from the Cantareira suggest that several factors will need to be addressed if development of PWS participation is to become a cost-effective.[6]

The first obstacle that may affect recruitment of eligible landowners into PWS is the structure of contract incentives (see Figure 2). All of the PWS programs in the Cantareira have payments that are lower than the annual land rental rate for pasture (~R$450/ha), and this has been cited in program evaluations as an opportunity for improvement (The Nature Conservancy-Brasil 2015). This is likely to affect the landowners who participate, selecting for those individuals with stronger off-farm income sources or diversified on-farm activities (e.g., horticulture or eucalyptus as well as pasture). In Extrema's Water Conservator program, which offers higher payments, many enrollees are retired and cattle production is infrequently the sole source of income (Richards et al., 2015). For individuals who are highly dependent on cattle production, or who are interested in maintaining open pasture for future use, the overall payoff of PWS may not be sufficient.

[6] The costs and benefits of using PES to encourage ecologically-significant biome-wide restoration in the Atlantic Forest has recently been debated in the literature. See: Banks-Leite, et al. 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science* 345 (6200), 1041-1045; Finney, C. 2015. Comment on "Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot". *Science* 347(6223), 731-a.; Banks-Leite et al. 2015. Response to Comment on "Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot". *Science* 347(6223), 731b.

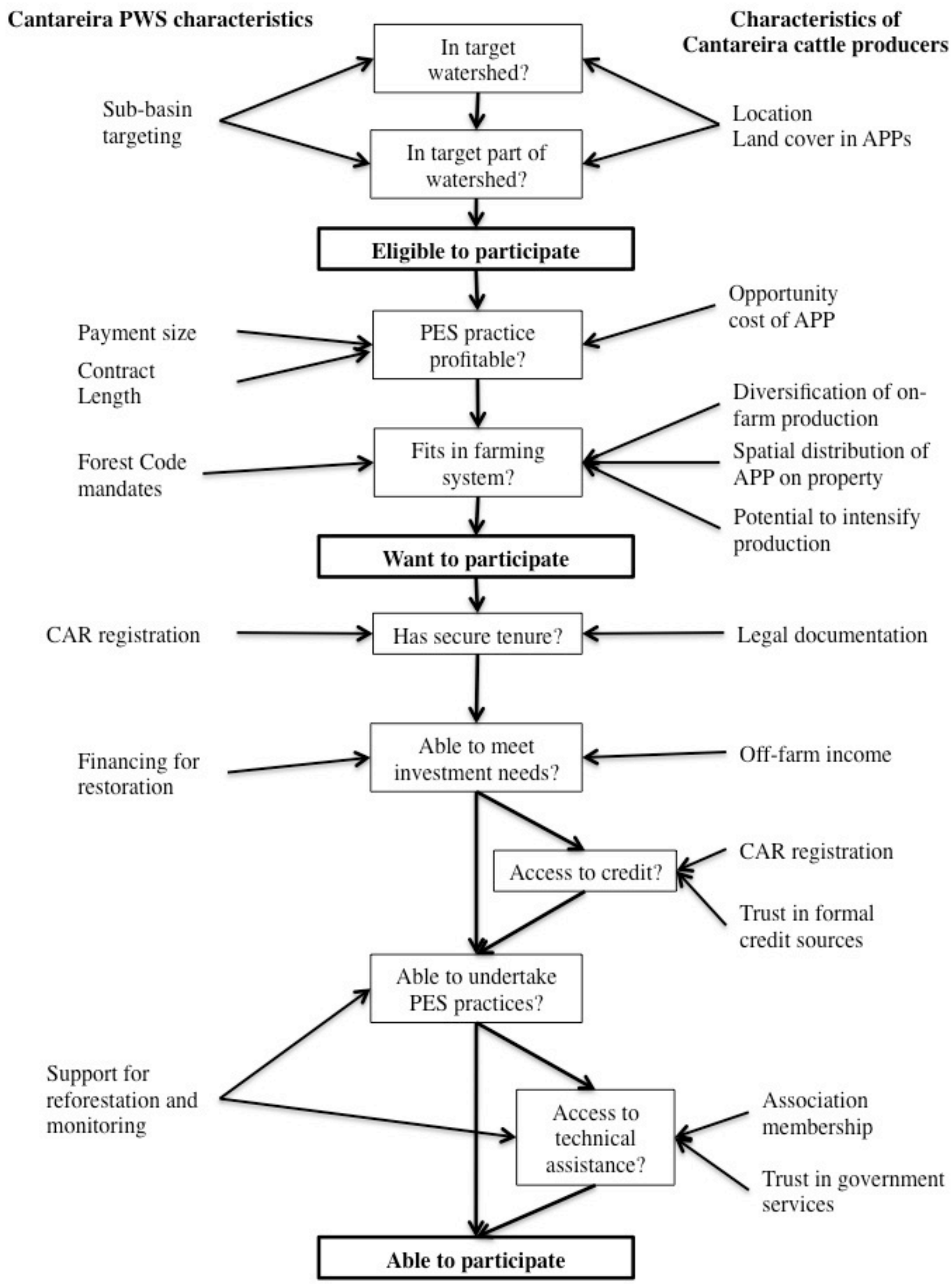


Figure 2. Factors affecting participation in PWS programs. (Adapted from Pagiola et al. 2005)

Almost all contracts that have been implemented in the Cantareira region are short-term (2-5 years). In the early stages of program development this shorter length provides both landowners and program staff an opportunity for evaluation while minimizing long-term costs. However, the Native Vegetation Protection Law mandates long-term (permanent) conservation, and program staff may need to establish opportunities for either longer-term contracts or contract renewals to avoid the potentially negative consequences of lost funding for participants after only a few years. Renewals with shorter terms may be more appealing, as evidence from an attempt in Extrema to enroll participants in 30-year carbon sequestration contracts were unsuccessful (Richards et al. 2015).

Some environmental NGOs have attempted to train farmers pasture management strategies, such as the Voisin grazing system, to help compensate for the conversion of APPs to reforestation. However, adoption of these alternative methods has been limited, and varied by municipality and neighborhood. Farmers in Nazaré Paulista reported reliance on *ad hoc* associations with neighbors for information on farming practices, while farmers from Extrema and other municipalities in Minas Gerais have more active farmer associations, in particular SENAR (National Agricultural Learning Service). Other municipalities in the Cantareira devoted greater resources to agricultural extension offices, including equipment rentals, which cultivated greater interactions among farmers and agronomists. Evidence from other regions with PES programs suggest that these social contexts will also affect enrollment (Zanella et al. 2014; Chen et al. 2009)

Taken together, PWS incentives that currently exist in the Cantareira would be expected to enroll landowners with diversified on-farm or high off-farm income, with connections to and trust in institutions, such as government agencies and NGOs, and an intrinsic desire to comply with the APP mandates of the Forest Code to motivate participation. Evidence from an analysis in Extrema (as well as PES projects elsewhere in the Atlantic Forest) suggests that connections to civil society organizations involved in PWS programs are especially important (Richards et al. 2015; Zanella et al. 2014). However, these landowners may also be more willing to replant forest on their own, either through their own investments or mitigation-type programs such as the São Paulo Springs program (*Programa Nascentes*) that link landowners interested in forest restoration with others who need to 'purchase' restoration elsewhere to comply with land use laws. Recruitment of landowners who are unlikely to plant forests on their own would require higher overall payments, greater investment in developing social connectedness, or – absent changes in incentive structures – greater perceived risks to non-compliance through legal enforcement of the 2012 law.

Improving incentives would require actions to address two major administrative challenges – financing and governance. Restoration targets for the Atlantic Forest are large, and will likely require investments from multiple sources (Pinto et al., 2014). The New Forest Law has enabled the use of funding mechanisms to support reforestation, but thus far there are limited examples (such as Extrema) in which resource users have joined permanent fee or tax systems to fund these types of project. In the Cantareira, one source of funding that has yet to engage in PWS is the state water utility company (Companhia de Saneamento Básico do Estado de São Paulo – SABESP), which manages the reservoirs in the Cantareira System. To date, the company has focused on reforestation within the buffer areas of its reservoirs, but declined to support PWS programs.

Although governance frameworks are legally defined, and both national and state governments have invested in pilot programs to refine management structures and regulations, the watersheds in the Cantareira still fall under the responsibility of multiple authorities, including several municipalities and watershed committees (Padovezi et al. 2013). This complicates planning and decision making, including development of funding mechanisms and support for technical assistance. This is not insurmountable, as evidenced by the existence of several PWS programs already, but it may affect the capacity to modify incentives and financial support to better attract landowners who would not otherwise participate in provision of watershed services.

Conclusion

Despite substantial effort to develop PWS programs in Brazil, there have been limited environmental gains. This is due, in part, to the slow process of developing legal frameworks and pilot projects to implement PWS and validate its model. However, observations from the Cantareira suggest that the structure of existing incentives may not be sufficient to encourage enrollment by landowners who are unlikely to reforest portions of their land on their own. This supports a growing body of research on the economic, social, and environmental factors that affect decision making. A better understanding of the preferences and motivations of these landowners is necessary, both to target the landowners who would provide the greatest environmental gains through participation and to better use limited resources.

CHAPTER TWO – FARMER PREFERENCES FOR REFORESTATION CONTRACTS IN BRAZIL'S ATLANTIC FOREST: EVIDENCE FROM A CHOICE EXPERIMENT

Introduction

Payments for ecosystem services (PES) programs have become an increasingly common policy tool for encouraging socially desired land management practices on private property through direct payments from users of ecosystem services to landowners who can provide services through land management (Bennett and Carroll, 2014; Ferraro and Kiss, 2002). Payments for watershed services (PWS), which pay upstream landowners to adopt practices that improve downstream water quality, have become especially widespread (Bennett and Ruef, 2016).

However, there is evidence that the additionality of PWS is limited in certain contexts (Arrigiada et al., 2012; Pattanayak et al., 2010). Research suggests that enrollment decisions are affected by a wide range of factors, including credit constraints, social norms, and the structure of payments, and these, in turn, affect the environmental gains created by a program (Kaczan et al., 2014; Chen et al., 2009; Jayachandran et al., 2016).

Addressing incentive design and targeting issues is challenging and potentially expensive. Procurement auctions are considered the optimal approach to eliciting participation at the lowest overall cost, eliminating the need to design incentives with broad appeal and enrolling only the most willing landowners (Ferraro, 2008). This is not feasible in some contexts, for logistical purposes or due to transaction costs or familiarity issues that would affect participation (Hercowitz and Figueiredo 2011). In these cases, clearly defined sets of incentives are necessary, and their design requires understanding of the range of preferences of the target population.

Here we report of the results of a choice experiment on PES contracts in the Cantareira region of the state of São Paulo, Brazil. The region is a critical source of drinking water supply for the São Paulo metropolitan region, and PWS have been piloted in several municipalities with the goal of improving water quality.

Payments for environmental services

PES programs are a transactional system in which landowners are contracted by external actors to manage land in a way that provides some agreed upon level of environmental service (for a thorough overview of program design and implementation, see Morrison and Aubrey (2010) and Engel et al., (2008)). They have become increasingly popular in the past two decades, in particular in Latin America (Bremer et al., 2016; Balvanera et al., 2012). In Brazil, the PES concept has been promoted as an opportunity to leverage the services provided by the country's ecosystems to encourage conservation and restoration (Pagiola et al., 2012). Seventy-nine PES programs had been implemented or planned in the Brazilian Atlantic Forest ecoregion through 2011, with the majority (41) targeting watershed services and the remainder focusing on either carbon (33) or biodiversity (5) (Guedes and Seehusen, 2011).

Despite the proliferation of PES programs, the land area enrolled in Brazil has lagged behind countries with national programs, such as Mexico and Costa Rica (Pagiola et al., 2012). This is largely due to the complex process of developing policy mechanisms to manage programs, including promulgation of national, state, and local regulation to enable financing and payments (Richards et al., 2015). In addition, many programs have only implemented pilot projects with constrained areas of operation.

The slow process of increasing enrollment in PES in Brazil has important policy implications in the Atlantic Forest, a largely deforested biodiversity hotspot that is also home to most of the country's metropolitan areas (IBGE, 2010; Myers et al, 2000). In addition to the water crisis in the Cantareira region, the Atlantic Forest Restoration Pact – a partnership of NGOs, government agencies, private firms, and research institutions – has set a target of restoring 15 million hectares of native vegetation in the ecoregion by 2050 (Pinto et al., 2014). The new Native Vegetation Protection Law, which was passed in 2012 to replace the Brazilian Forest Code, intends to improve enforcement of land use mandates requiring ecological restoration of riparian areas (Soares-Filho et al., 2014). Financial mechanisms enabling PES are explicitly included in the new law to alleviate economic costs of converting land from agriculture to native vegetation, and to offset high per-hectare costs of planting and maintaining restoration sites (Brancalion et al., 2016; Packer, 2015).

A great deal of attention has been paid to administration of PES programs (Guedes and Seehusen, 2011), but there is limited research on factors affecting enrollment (see, for example, Zanella et al., 2014) and, specifically, how PES contract attributes may influence participation. Several PWS programs have been implemented in the Cantareira region, but only one (*Conservador das Águas*) has continued beyond the pilot stage to expand enrollment and renew contracts (Richards et al., 2015; also see Supplementary Table S1 for contract attributes of the Cantareira PES programs). Understanding the relative appeal of these contract attributes will help refine PWS incentive design in the Cantareira region.

Methods

Study site description

The Cantareira System is the largest drinking water supply for the São Paulo metropolitan area. The catchment stretches across portions of the states of São Paulo and Minas Gerais, and is comprised of five interconnected reservoirs that capture water from the Serra da Cantareira and the Serra da Mantiqueira ranges (Figures 1 & 3). The entire system lies within the Atlantic Forest ecoregion, which is considered to be one of the world's biodiversity hotspots (Myers et al., 2000), with globally significant levels of species diversity and endemism. The Atlantic Forest has been heavily influenced by human development – of the 1.5 million km^2 of original forest cover, only 11-16% remains, often in highly fragmented patches (Ribeiro et al., 2009).

Some successional stage of native Atlantic Forest vegetation covers approximately 40% of the Cantareira catchment's 230,000 hectares, but the landscape is highly fragmented by agricultural land (Ditt et al., 2008). The predominant agricultural land uses in the region are eucalyptus and pasture for dairy and beef cattle production. Over the past several years, low levels of rainfall and infrastructure problems have resulted in a prolonged water shortage in the Cantareira System, and deforestation and degradation of springs and riparian areas for cattle production have likely exacerbated the problem (Taffarello et al., 2016). As a result, there have been significant investments in programs to encourage reforestation and stream protection in the region.

This study focused on the three municipalities in the state of São Paulo that lie almost completely within the Cantareira catchment: Nazaré Paulista, Piracaia, and Joanópolis (Figure 1). These municipalities are home to 53,298 people (IGBE, 2010), and the most recent agricultural census (2008) recorded 1,882 properties on which pasture was used for agricultural production (Table 4).

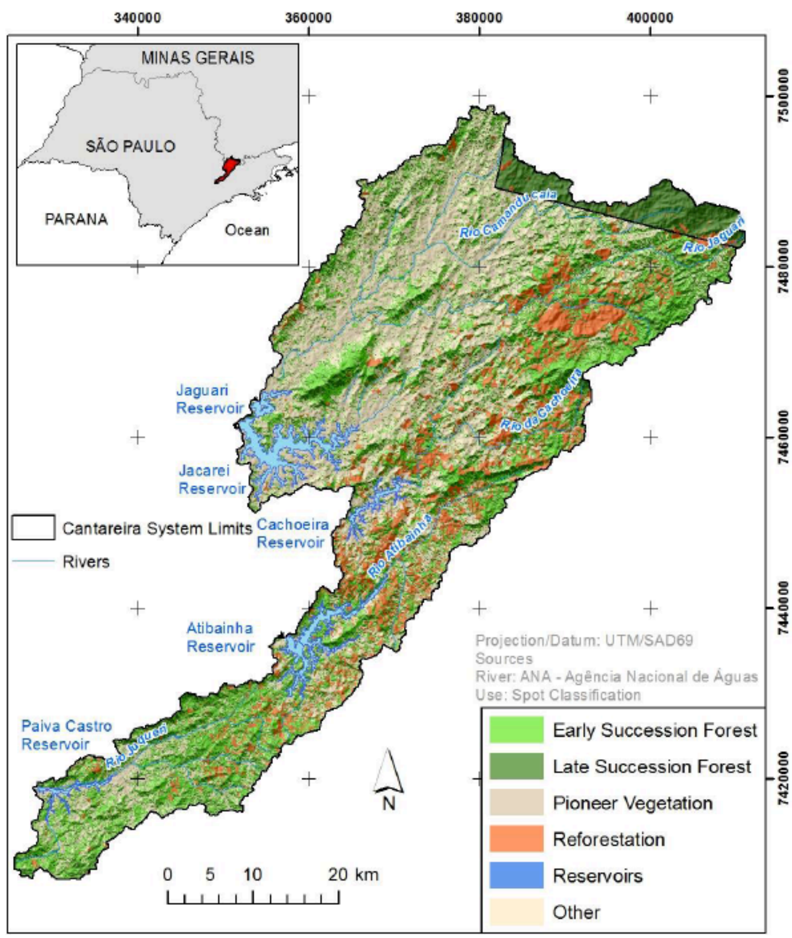


Figure 3. Land cover map of the Cantareira region.

Table 4. Population data for study municipalities (Source: IBGE Census 2010, State of São Paulo Agricultural Cesnsus, 2008)

	Population	Cattle Farmers
Joanópolis	11,768	745
Nazaré Paulista	16,414	488
Piracaia	25,116	649

Data collection

A discrete choice experiment (CE) was used to quantify preferences for PES contracts and identify tradeoffs between the size of restoration areas and payouts that vary in size and type (e.g., cash and in-kind returns). The choice experiment approach is used to understand preferences for different attributes of a good by asking participants to choose between hypothetical goods as part of a questionnaire. These goods are comprised of attributes, each with a number of different levels.

Theoretical framework

Several behavioral models have been developed in economics and other social sciences to understand the decision-making process for participation in policy programs. In this study, we assume a utility-maximization framework for landowner decisions. Because a landowner faces a loss in utility due to the reforestation requirements of a PES contract, they will be expected to enroll when payments and other contract attributes result in a net utility gain.

Consider the utility function of a landowner i when faced with choice of contracts in situation j:

Equation 1

$$U_{ij} = V(z_i, x_j) + \varepsilon_{ij}$$

Where *V* is an observable, known utility component comprised of individual-specific characteristics z_i and contract-specific characteristics x_j. ε_i is a random error term comprised of unobservable factors affecting choices, which for analytical purposes is assumed to be IID extreme value type I (McFadden 1974).

An individual is expected to select the alternative *k* from a set of alternatives *C* when the utility of *k* is greater than any other alternative *j* in the set. This is expressed as:

Equation 2

$$U_{ik} > U_{ij} \Rightarrow V_{ik} + \varepsilon_{ik} > V_{ij} + \varepsilon_{ij} \; \forall \, j \neq k, k \in C$$

as described in Adamowicz et al. (1998a). The probability that an individual chooses alternative *k* matches the probability that the utility of alternative *k* exceeds the utility of the other alternatives in the choice situation/set (Adamowicz et al., 1998a). Given the use of three alternatives in each choice set in this study, the utility can be rewritten as:

Equation 3

$$U_{kin} = \begin{cases} V(\text{ASC}, x_{kin}, \beta_i, \varepsilon_i) + \varepsilon_{kin}, & \text{if } k = 1; \\ V(\text{ASC}, x_{kin}, \beta_i, \varepsilon_i) + \varepsilon_{kin}, & \text{if } k = 2; \\ \varepsilon_{kin}, & \text{if } k = 3 \text{ (status quo)}; \end{cases}$$

where utility of individual i for an alternative k in choice situation n is a product of the indirect utility V and the unobservable characteristics of the choice situation and individual captured by the error term ε_{kin}. Indirect utility is a function of the vector of variables x_{kin} that describe the contract attributes, and the vector β_i, which describe individual preferences. The component z_i from Eq. 1 is expressed here as an attribute-specific constant (ASC).

The selection of an attribute k can be described probabilistically by rewriting Equation 2:

Equation 4

$$\begin{aligned} P_{ik} &= \Pr\,(U_{ik} > U_{ij})\ \forall\, j \neq k \\ &= \Pr\,(V_{ik} + \varepsilon_{ik} > V_{ij} + \varepsilon_{ij})\ \forall\, j \neq k \\ &= \Pr\,(\varepsilon_{ij} - \varepsilon_{ik} < V_{ik} - V_{ij})\ \forall\, j \neq k \end{aligned}$$

This equation serves as the basis for a set of logit models that can be used to predict preferences, which are differentiated by their assumptions regarding the distributions of the error terms.

Assuming error terms are IID Type-I extreme value distributed is the basis for the conditional logit model (McFadden 1974):

Equation 5

$$P_{ik} = \frac{\exp(V_{ik})}{\sum_{j=1}^{J} \exp(V_{ij})}$$

The indirect utility vectors for contract and individual attributes introduced in Eq. 3 can be included to create the following model:

Equation 6

$$P_{ik} = \frac{\exp(\beta_i' x_{ik})}{\sum_{j=1}^{J} \exp(\beta_i' x_{ij})}$$

The conditional logit model assumes that individuals share the same characteristics, which is unlikely to be observed in field settings. The mixed logit (or random parameters logit) relaxes this assumption by allowing for variation in individual characteristics (Hole 2007):

Equation 7

$$P_{ik} = \int \frac{\exp(\beta_i' x_{ik})}{\sum_{j=1}^{J} \exp(\beta_i' x_{ij})} f(\beta|\theta) d\beta$$

where $f(\beta|\theta)$ is a density function of β. Assuming that choices are independent when individuals make selections in more than one choice situation, the probability of individual *i* choosing alternative *k* in situation *n* is then described as:

Equation 8

$$P_{ikn} = \int \left(\prod_{n=1}^{N} \left[\frac{\exp(\beta_i' x_{ik})}{\sum_{j=1}^{J} \exp(\beta_i' x_{ij})} \right] \right) f(\beta|\theta) d\beta$$

Log-likelihoods for P_{ikn} can then be simulated using maximum likelihood estimations in Stata (Hole, 2007).

Experimental design

Attributes for the choice experiment were developed from incentives used in existing PWS and agricultural extension programs in the region (Table 1), and from reforestation requirements along springs and watercourses, as defined by the 2012 Native Vegetation Protection Law (See Soares-Filho et al., 2014 – Supplementary Material). Initial scoping interviews were conducted in June and July 2015 with local farmers and agronomists to gather information on the appropriate ranges of attribute levels, and in early September 2015 pilot surveys were conducted with 15 rural landowners to refine the composition of the choice sets (see sample choice card in Figure 4).

Three payment attributes were used, all as per-hectare, annual payouts for proposed restoration areas on the property. The typical land rental price for grazing on one hectare of pasture was R$450/year in 2015, and so all three payment levels were set below this mark (Table 5). In addition to the value of the payment attribute, the overall payout for a farmer would vary by the width of the area to be restored, the structure of riparian areas on the property, and the length of the contract. Three widths were used, drawn from the Forest Code for APP mandates for properties of different sizes (5m, 15m, 20m). The survey team explained the restoration component of the hypothetical contracts during interviews by recording the number of springs and the length of watercourses on the property, then consulting a table with the participant to calculate the total area of restoration under the three different scenarios. These were referred to during the survey as the choices were presented.

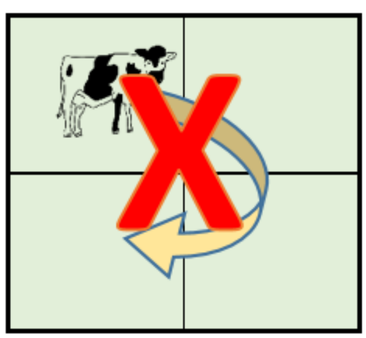
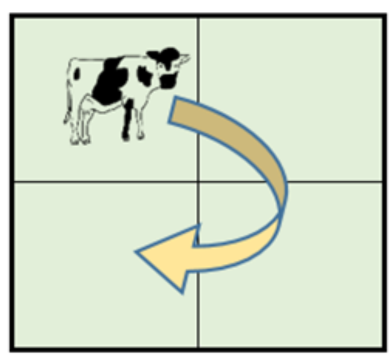
Atributo de programa	Opção A	Opção B
Duração de contrato (anos)	20anos	10anos
Valor do pagamento (por hectare, por ano)	R$350	R$250
Área de restauração	 15 metros	 20 metros
Sistema Voisin	 Não	 Sim

Figure 4. Example choice set (in Portuguese).

The temporal attribute of the contract options included terms of 5, 10, and 20 years. For simplicity, contracts were described as lacking penalties for early exit. The purpose of this variable was to understand how contract duration affected utility, as current PES initiatives use shorter terms (typically 3-5 years) and it is unclear whether there is demand for recurring payouts over a longer period of time (Richards et al., 2015). One PES project in the Minas Gerais portion of the Cantareira System, *Conservador das Águas*, has attempted to adopt 30-year carbon agreements, but has received little interest.

Table 5. Choice attributes and levels

Attribute	Description	Levels
Duration	The length of the contract (years). There is no penalty for early exit.	• 5 • 10 • 20
Payment	Compensation for the restored area on the property (per-hectare, in Brazilian reais, R$)	• R$150 • R$250 • R$350
Restoration Width	The width of restoration around all springs on the property, and along all watercourses.	• 5m • 15m • 20m
Pasture Material (Voisin System)	A donation of fencing material and day labor to install paddocks for rotational grazing on all pasture on the property.	• Yes • No

The final attribute was the donation of fencing material and labor to install the Voisin system of rotational grazing on all pastureland on the property, which has a value of approximately R$1000/ha (US$305 in August 2016). This variable was included to explore the relative importance of material and labor (*mão-de-obra*) for landowners.

A D-*efficient* design algorithm included in the SAS software package was used to construct 24 choice situations, which were then divided into 4 sets of 6 choice situations. This approach is considered beneficial in a choice experiment setting because it minimizes the errors created through the construction of the choice situations (Rose and Bliemer 2009). Error minimization allows for estimation of the marginal effects of attributes with a smaller sample size.

Surveys included two sections, which were conducted during one session if the participant met certain criteria. The choice experiment was applied when the participant owned the property being considered, maintained pasture, and had springs and/or permanent watercourses on the property, so that all contract attributes were relevant to land use on the property. Participants were presented with two sets of 6 choice situations, and each choice situation included two contract options and a 'none of the above' option to prevent a forced choice (see section below on biases).

Following the choice experiment section of the survey, all participants were asked a series of demographic and socioeconomic questions about the household, as well as questions about property characteristics (Supplementary Material S1). Questions about reliance on media sources and recent drought conditions were also included. Only a brief set of qualifying questions about agriculture on the property, ownership status, and watercourses were presented prior to choices to avoid fatigue in the next part of the survey.

Hypothetical and social desirability bias

Stated preference techniques are susceptible to various biases, including both hypothetical and social desirability biases. Hypothetical bias is expressed as the difference between the preferences stated in a survey context and those expressed in a real-life situation. This includes strategic responses to skew results or appease survey responses, also known as a social desirability bias. Cheap talk, or scripts delivered prior to the choice situation to emphasize the importance of realistic answers, has been effective in some situations (Carlsson et al., 2005), including choice experiments to study PES (Kaczan et al., 2014). A cheap talk script was included in the initial version of the survey, but was dropped after pilot respondents suggested the encouragement of honest responses would alarm participants who are not complying with the Forest Code, as they may fear ramifications for their land use.

Social desirability bias describes the effect on survey responses of social norms and context. For example, respondents in a survey with interviewers from an environmental NGO may consider it beneficial to skew their responses to environmentally-favorable choices, while in reality this does not reflect their preferences. To address this, respondents were presented with a series of 6 choices and asked to consider their own property, followed by an ‘inferred valuation’ set of 6 choices, in which farmers were asked to select the option that they believed would be most popular for other farmers living in the area.

Survey data collection

Surveys were conducted from September-November 2015. All interviews were conducted by pairs of researchers, with one team member reading the script to the landowner and the other entering data. Magpi (http://www.magpi.org), a free mobile app for survey data collection, was used to record data in most interviews. When this tool was unavailable, data were recorded on paper copies of the response form and entered that evening in Magpi for online storage on secure servers.

Landowners were contacted principally through 'cold' approaches on their property, although a small number of respondents were referred to the researchers by neighbors or social contacts.[7] Surveys were conducted on the farm and locations were recorded using GPS units. Maps of the municipalities were consulted to ensure survey effort was distributed across the full extents of the municipalities and to avoid repeat visits to properties post-interview.

Data analysis

Preference data were analyzed using conditional and mixed logit models. The conditional logit model was used to evaluate preferences for the entire sample, and to compare the preferences from the direct and inferred valuation data.

Mixed logit models were used to explore the potential interactions between preferences and the property and household characteristics gathered in the survey, and to calculate preferences for groups that may be the target of future PES in the region. Several mixed logit models were constructed, including a model used the full direct

[7] Seven interviews were arranged through the Joanópolis environmental secretariat and an owner of a local dairy and cheese processor. The participants regularly sold him milk.

valuation dataset, models that interacted contract attributes with household and property characteristics, and one that split the sample into two groups based on the participants' status as family farmers.

Results

Sample descriptive statistics

Interviews were conducted with 202 farmers, of whom 189 met the participation criteria and were interviewed using the full choice experiment methodology (Table 6). Descriptive statistics for the socio-economic characteristics of the participants and the biophysical traits of the properties are listed in Tables 7 and 8, respectively.

Table 6. Number of respondents by municipality.

	No. of respondents
Joanópolis	85
Nazaré Paulista	41
Piracaia	63
Total	189

The average age of surveyed landowners was slightly above 54 years, just shy of the retirement age in Brazil (55). On average participants had received close to 8 years of education, although the range was quite large (from <1 year of formal schooling to multiple post-baccalaureate-level years of study). Income was reported only categories relative to the Brazilian monthly minimum salary. Income was almost always generated through agricultural activities, but many individuals also earned from outside sources, either professions or pensions. The latter form of income is quite common, due to the age of the population and the generous pension policies adopted by the Brazilian government.

Property characteristics varied widely. Although all properties contained some pasture that was used for livestock, the relative size of the pasture on the property, and its value to household earnings, ranged from hobby-type farms for pensioners to multi-employee dairy operations. Eucalyptus was present on some properties as an alternative revenue source. Nearly all properties had some native vegetation, although only 25% of the surveyed properties held sufficient forest cover and distribution to comply with the Native Vegetation Protection Law. In many cases at least some of the watercourses on the property were not lined with forest as required by law. Although the overall forest cover was estimated during the survey, compliance with land use laws was reported only as a yes/no response.

Table 7. Summary statistics of socio-economic characteristics

	Mean	Std. Dev.
Gender (proportion male)	0.842	--
Age (years)	54.15	13.73
Education (years)	7.59	5.49
Household Size	3.94	3.93
No. children/retired	1.54	1.77
Monthly income[8]		
<1	0.05	--
1-3	0.498	--
4-10	0.339	--
>10	0.111	--
Off-farm income (%)	59.02	37.85

[8] Categories relative to monthly minimum wage, R$788 (approx. US$230)

Conditional logit (Direct and inferred valuation)

Preference data were analyzed in separate steps. Direct and inferred preference data were modeled as conditional logit models, following McFadden (1974) (see Table 9). The 189 survey respondents resulted in 1134 choice situations for the two separate analyses. As mentioned previously, each choice situation included two hypothetical contract options (A & B), and an option C, in which no contract would be selected and the landowner would maintain the status quo. Distributions of choices for each choice set are listed in Appendices 4 and 5. No single choice in any set was selected over 64% of the total responses. Instances in which the status quo option was the most commonly selected corresponded with choice sets in which both contracts included high levels of restoration.

In the direct valuation portion of the survey 20.88% of the participants selected C for each of the choice situations, and in the inferred valuation portion 17.88% of the participants selected option C for all situations. In some situations participants selected option C for each choice situation in both direct and inferred sections, but frequently participants expressed specific reasons (e.g., property-specific characteristics, poor knowledge of the preferences of neighboring farmers) for opting out. Appendix 6 contains summary statistics for socioeconomic and property characteristics of participants who elected the status quo in every choice situation.

In each conditional logit model, the provision of material for pasture fencing (Voisin) had a large positive effect on contract selection, and larger restoration areas had a negative effect on contract utility. The effect of payment size was small but significant, unsurprising given the wide range, and the length of the contract did not have a significant effect on probability of selection. In the direct valuation model, the coefficient for the alternative specific constant (status quo) variable was positive, and in the inferred valuation it was negative (significant at alpha = 0.1 for both). This indicates that there was a preference for the status quo when choosing a contract for one's own property, but not necessarily when participants estimated the preferences of nearby landowners.

Table 8. Summary statistics of property characteristics.

	Mean	**Std. Dev.**
Hectares	41.99	61.56
Spring Density (no./ha)	0.12	0.195
River Density (meters/ha)	30.41	56.92
Pasture Cover (%)	65.17	26.5
Forest Cover (%)	16.04	15.51
Area with slope >30°		
<30%	69.31	--
30-60%	16.4	--
60-90%	10.58	--
>90%	3.7	--

Mixed logit

Mixed logit models were also constructed using the direct valuation responses from the choice experiment, with preferences for the length of the contract, the width of restoration, the fencing variable, and the ASC assumed to be heterogeneous across the population. The models were estimated using the *mixlogit* package in Stata 13, using 500 Halton draws for the simulations.

Table 9. Results of multinomial (conditional) logit regression for direct and inferred valuation choice data.

VARIABLES	(1) Direct Valuation	(2) Inferred Valuation
Years	-0.00758	-0.00923
	(0.00710)	(0.00666)
Payment	0.00210***	0.00107**
	(0.000545)	(0.000510)
Restoration	-0.0530***	-0.0497***
	(0.00692)	(0.00646)
Voisin	0.389***	0.266***
	(0.0817)	(0.0752)
ASC	0.357*	-0.326*
	(0.191)	(0.178)
Observations	3,402	3,402
McFadden's pseudo-R^2	0.0520	0.0303
Log-likelihood	-1181	-1208
AIC	2372.08	2426.14
BIC	2402.75	2456.8

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In main effects model (Table 10 – Model 1), payments had a small, positive effect on farmer contract selection. As expected, the inclusion of fencing had a large and positive effect. However, the standard deviation was large, suggesting that there was a great deal of heterogeneity in the perceived utility of fencing and Voisin pasture management for landowners. Participants showed a preference for lower restoration widths. The coefficient for the ASC was negative, and significant only at the 10% level.

Models 2 and 3 incorporate interaction effects between contract attributes and property characteristics. These include an interaction variable representing the absolute value of the payment (Payment * Restoration, *PayRest*), the percentage of a property that is to be planted in a contract (*RestImpact*), the presumed importance of fencing to income (*FencePotential* – the percentage of on-farm income * Voisin fencing dummy variable), and a dummy variable when the combination of the existing forest on a property and the proposed restoration area exceeded the legal requirement under Brazilian law (*LegalMax*). Both models were created through an iterative process in which different interactions were added to the base model (Model 1) and compared using their log-likelihood values and Akaike and Bayesian information criteria.

Results for Models 2 and 3 are included in Table 10. Model 2 included two interactions related to the impact of the proposed forest restoration – the variables *RestImpact* and *LegalMax*. The magnitude and direction of the contract attributes did not change much with the inclusion of these attributes. *RestImpact* had a strong and negative association with the selection of a contract, but there was not a significant relationship between the dummy variable *LegalMax* and contract selection.

Model 3 was constructed without the legal compliance variable and incorporated both an interaction term for the total sum of the payment under the contract (*PayRest*) and a proxy for the relative importance of on-farm activities to household income (*FencePotential*) to examine the effect of preferences for fencing on contract selection. The dummy variable for the fencing had a much larger positive coefficient in this model, and the proxy for the importance of fence to income was also positive but significant only at the 0.1 level. The effect of the overall payment size was very small and not significant, and likely captured by payment variable itself. The negative effect of the proportion of a property to be forested was even larger than in Model 2.

Models 1-3 suggest that property and household characteristics have a large influence on the propensity to select a particular contract. This is very relevant for targeting landowners, as it is suggested that PWS be tailored to appeal to landowners that face high compliance costs and would be unlikely to reforest riparian areas without additional resources. Two separate models were constructed to explore the incentives that may be appropriate for this PWS strategy by splitting the full sample based on participants' status as family farmers (Table 11).

Family farms are codified in Brazilian national law as landowners who own no more than four "fiscal modules"[9], use primarily family labor, derive over 80% of income from the family property, and directly manage on-farm agricultural activity (Guanziroli 2013; Government of Brazil, 2006).[10] Given their dependence on their property for income, these landowners are logical targets for PWS programs. Thirty-four participants met the criteria for 'family farmer' and mixed logit models were estimated for this sub-group and the subgroup of landowners who did not meet the criteria (N=155). Demographic traits for the two subgroups are listed in Table 12.

---

[9] A fiscal module is described in hectares and defined by municipality as the minimum amount of land required to support a family in the predominant agricultural activity in a municipality -

[10] Cattle are the predominant agricultural activity in the study municipalities, and a 'fiscal module' is 24 hectares in both Piracaia and Joanópolis, and 16 hectares in Nazaré Paulista.

Table 10. Results of mixed (random parameters) logit regression.

	Model 1		Model 2		Model 3	
VARIABLES	Coefficient	S.D.	Coefficient	S.D.	Coefficient	S.D.
Payment	0.00542***		0.00616***		0.00545***	
	(0.00121)		(0.00138)		(0.0015)	
Years	-0.0224	-0.0469	-0.019	0.095***	-0.0198	-0.057**
	(0.016)	(0.033)	(0.0188)	(0.0271)	(0.0169)	(0.0255)
Restoration	-0.315***	0.3898***	-0.213***	0.381***	-0.210***	0.378***
	(0.0476)	(0.0479)	(0.0409)	(0.0523)	(0.0472)	(0.0497)
Voisin	0.987**	4.948***	1.005**	6.166***	2.478***	4.289***
	(0.398)	(0.622)	(0.445)	(0.879)	(0.734)	(0.606)
ASC	-0.618*	5.029***	-0.645	6.168***	-1.096*	6.014***
	(0.576)	(0.663)	(0.669)	(0.892)	(0.652)	(0.875)
RestImpact			-8.707***	7.052***	-12.539***	19.469***
			(3.16)	(1.876)	(4.702)	(4.69)
PayRest					-0.000204	0.0009
					(0.000565)	(0.0009)
FencePotential					0.031*	0.052***
					(0.011)	(0.009)
LegalMax			-0.98	3.715***		
			(0.845)	(0.82)		
Observations	3,402		3,402		3,402	
Log-likelihood	-746.27		-740.58		-741.28	
AIC	1510.54		1507.16		1512.55	
BIC	1565.73		1586.87		1604.53	

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
Model 1 = Main effects of contract variables, Model 2 = Contract variables and property-specific restoration, Model 3 = Contract, property-specific restoration (impact and relative payment size), and relative importance of fencing/dependence on on-farm income

The inclusion of fencing material was observed to have a much stronger positive effect for family farmers than the rest of the sample, and the magnitude of the negative utility of restoration widths is larger. Both of these observations align with the results of Models 2 and 3.

Table 11. Results of mixed (random parameters) logit regression for family farm and non-family farm subgroups.

	Family Farms		"Non-family Farm" Properties	
VARIABLES	**Coefficient**	**S.D.**	**Coefficient**	**S.D.**
Payment	0.00926***		0.00421***	
	(0.00329)		(0.00124)	
Years	0.0336	0.0445	-0.0332*	0.0735***
	(0.0384)	(0.0469)	(0.0178)	(0.0215)
Restoration	-0.335***	0.514***	-0.201***	0.303***
	(0.0957)	(0.124)	(0.0283)	(0.0316)
Voisin	3.598***	4.981***	-0.116	4.145***
	(1.000)	(1.483)	(0.388)	(0.482)
ASC	0.977	5.363***	-0.834	3.197***
	(1.439)	(1.356)	(0.511)	(0.333)
Observations	612		2,790	
Log-likelihood	-126.52		-625.5	
AIC	271.04		1268.91	
BIC	310.79		1322.31	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Discussion

Results from the choice experiment provide several insights for PES practitioners regarding incentive design and targeting of landowners in the Cantareira region. Chief among these is that contract structures used in pilot projects in the Cantareira may not provide sufficient incentives for farmers to enroll if they are highly dependent on agricultural activities. This challenge is compounded by the heterogeneous effects of land use mandates on properties and the complicated history of governance in the region.

Table 12. Comparison of household characteristics by status as a "family farm"

	Family Farm	Non-family Farm
Gender (proportion male)	0.91	0.826
Age	51.09 (10.37)	54.82 (14.24)
Household Size	3.59 (2.80)	4.28 (3.97)
Off-farm income (%)	2.65 (6.09)	71.39 (29.67)
Hectares	26.39 (22.09)	45.41 (66.53)
Spring density (#/ha)	0.105 (0.124)	0.122 (0.208)
River density (m/ha)	25.30 (31.26)	31.53 (60.91)
Pasture area (%)	70.39 (30.02)	64.03 (25.46)
APP fully forested (% of subgroup)	26.47	25.16
CAR registration complete (% of subgroup)	0.62	0.56

The lack of a significant effect of contract length in any of the models may be an effect of the survey design, as contracts were stated to be voluntary and lack penalties for early exit. However, this topic should be further explored, as other sources of reforestation funding are likely to develop through carbon finance, which requires long-term (~30 year) guarantees for credits. This type of agreement was attempted in Extrema by the municipal government, in partnership with The Nature Conservancy, but received limited interest due to concerns about generational transfer of land (Richards et al., 2015).

Upfront, in-kind payments in the form of fencing material had a much stronger effect on choice selection for family farmers, which is unsurprising given the importance of pasture for household income. Trust in institutions may also influence these preferences, as it has been recognized as a challenge in other domestic development programs. As an example, Brazil has attempted to expand specialized government credit programs that include small-scale producers, such as PRONAF, but participation has been limited (Guanziroli, 2013). Only 27% of participants in this choice experiment reported utilizing credit within the past five years, and data from the 2008 agricultural census shows only 4% of farmers in the study municipalities using formal credit sources (Government of São Paulo, 2008). Participants frequently expressed distrust in banks and government loans during interviews, and there is anecdotal evidence that many farmers rely instead on social networks for emergency credit lines. Brazil has frequently experienced economic turbulence, including a serious economic crisis during this research project (June-November 2015), and this may be another reason for aversion to deferred or staggered payments.

Trust and perception of institutions may have broader effects on enrollment in PWS in Brazil. In roughly 21% (39/189) of the interviews, participants selected 'none of the above' for all of their choices, preferring instead the status quo. These individuals were frequently out of compliance with land use mandates. Following the choice experiment portion of the survey they expressed knowledge of the existence of these land use laws and news related to forest conservation, which suggests there is little concern that non-compliance will incur any penalty. In the inferred valuation section of the survey, several participants stated that other farmers in the area had little or no interest in reforestation, so they could not guess about the preferences of other landowners.

Property characteristics also played an important role in landowner decisions. The distribution of APPs, in particular riparian areas, in the study area was heterogeneous (mean on-farm stream density = 30.41m/ha, std. dev. = 56.92). In many instances the areas that contained springs and streams were also the most important areas for pasture production, or the position of streams bisected the property such that reforestation would require significant shifts in herd management. The importance of these areas is especially evident in the addition of a restoration impact variable in Models 2 and 3. It should be noted that the contract attributes for forest restoration sometimes exceeded the legal obligations for the property (see Soares-Filho et al., 2014, for a summary of the requirements for different property sizes).

Most landowners agreed to participate in the survey when approached, although in some instances they did decline the invitation. Typically this was due to farmers being occupied with other activities when approached by researchers, and in some cases these attempted interviews were re-scheduled. In other instances landowners stated that they were unavailable, which could be due to fluid schedules or to a lack of interest in participating in the survey. Landowners did occasionally express concern with sharing information about their properties and their land use decisions, despite being presented with information about the partner NGO and the declaration that the survey was solely for research purposes.

Conclusion

Recent efforts to develop PWS programs in the Cantareira region have utilized short-term contracts with a range of incentive structures to encourage reforestation. These efforts have occurred in parallel with legislative changes intended to reduce the costs of compliance with land use laws for landowners, and to enable greater enforcement of these laws. PWS programs offer additional incentives for landowners in environmentally-important areas when costs of reforestation limit conservation.

However, there is little evidence to suggest that the incentives utilized by existing PWS programs will encourage reforestation without significant recruitment effort, which incurs high upfront transaction costs for government agencies and civil society organizations that have been involved in PWS. Some PWS, such as the *Conservador das Águas* program in Extrema, have opted for simpler incentive structures that pay larger lump sums to reduce these upfront costs. Evidence from this choice experiment suggests that another strategy that may also improve provision of desired ecosystem services is the inclusion of in-kind payments (e.g., fencing) at the start of the contract to alleviate the loss of pasture. This is likely to be especially relevant to projects that seek to increase forest restoration by family farmers.

In light of the projected completion of the CAR database in May 2017 and the ongoing political and economic turmoil in Brazil, it is difficult to predict how land use trends will change in the Cantareira and throughout the Atlantic Forest in the near-term. This will have an effect on the future of PWS in the region. Despite this uncertainty, the importance of watershed management following the 2013-2014 drought events suggests that investment in reforestation efforts will continue. This research suggests that any such effort should carefully target specific landowner types or offer higher payouts to account for the heterogeneity in preferences and property characteristics affecting land use choices.

CHAPTER THREE – LANDSCAPE AND PROPERTY-LEVEL FACTORS AFFECTING ATLANTIC FOREST REGENERATION IN RURAL SÃO PAULO STATE, BRAZIL

Introduction

Deforestation of tropical forests is a persistent global conservation challenge, but rates of forest loss are not homogeneous across the tropics. In some areas recovery has been observed (Sloan and Sayer, 2015). This forest regrowth can be attributed to abandonment of agricultural land and other social and economic changes, or to land use reforms. A great deal of political capital has been directed toward land use reform, including the endorsement of the Bonn Challenge by the United Nations in 2014, which encourages national-level restoration through a commitment to restoration of 350 million hectares of forest by 2030 (IUCN-GPFLR, 2014). However, a great deal of work remains to organize on-the-ground implementation.

Brazil, which consistently ranks near the top of the list the countries with high absolute deforestation levels, has committed to restoring 12 million hectares as its contribution to the challenge. This national commitment is driven by regional efforts, including the Atlantic Forest Restoration Pact, which committed restoration of 15 million hectares in the ecoregion by 2050 (Pinto et al., 2014).

Reforms to the country's land management laws – the Forest Code and its successor legislation – have resulted in measurable reductions in deforestation rates in the Amazon region (Assunção et al., 2013), although broader economic conditions in the country have contributed to a recent reversal in this trend. The conclusion of a national effort to complete a rural land registry in 2017 is intended to stem further losses as well, and provide a platform for coordinating large-scale restoration in other regions, such as the Cerrado and the Atlantic Forest.

The Atlantic Forest, a biodiversity hotspot and center of most of Brazil's economic activity, retains only a small portion (11-16%) of its original vegetation, primarily in small fragments (INPE and SOS Mata Atlântica, 2015). Reforestation efforts must therefore accompany reforms aimed at minimizing deforestation. Active restoration has been widely attempted in Brazil, but seed production and site maintenance are expensive (Brancalion et al., 2012). Passive restoration – the recovery of native vegetation through natural dispersal processes – is necessary to achieve national targets for forest restoration. Research has provided some insight into the likelihood of forest regeneration at the landscape-level (Rodrigues et al., 2011) and at finer spatial scales (Rezende et al., 2015; Uezu et al., 2015), but information gaps remain with regard to property-level factors that are difficult to observe but affect landscape dynamics.

Here we present the results of a spatial analysis of land cover change in three municipalities in the Cantareira System of São Paulo state, Brazil. In addition to examining changes in land cover, we incorporate property maps from the newly-available Rural Land Registry (*Cadastro Ambiental Rural* – CAR, in Portuguese) using data from a landowner survey conducted in 2015. These new data allow for examination of the factors affecting natural regeneration at a finer-scale than has been previously attempted.

Methods and Data

Drivers of forest loss and regeneration

Understanding the biophysical and anthropogenic factors that influence forest cover, especially natural regeneration on degraded land, is necessary to plan context-appropriate management actions. Ecological restoration is an emerging field, and early lessons suggest that top-down and standardized approaches are unlikely to succeed (Holl 2017). This raises questions about whether active or passive approaches are best suited to restore ecological function and ecosystem services (Chazdon, 2008) and provide cost reductions while improving outcomes for biodiversity (Holl and Aide, 2011). Active restoration approaches have high labor and material costs, which constrain project scale, but are necessary where the intensity of past degradation or current land use will prevent natural regeneration processes.

However, global reviews of restoration approaches using both active and passive restoration approaches find that active restoration does not consistently result in a better or more complete recovery on agricultural land (Meli et al., 2017). This has important implications for restoration strategies in the Atlantic Forest. Rezende et al. (2015) observed natural spontaneous regeneration of over 3,000ha in an agricultural landscape in Rio de Janeiro state over a 36-year period. An equivalent area would require over US$15 million over several years if active restoration approaches were used.

A great deal of research has been devoted to the biophysical and anthropogenic drivers of land cover change, especially to deforestation in tropical regions. Geist and Lambin (2002) examined over 150 case studies of deforestation, and identified five broad categories of drivers. Economic factors were the most frequently identified driver, with institutions and policies, technological drivers, and cultural and demographic factors playing varied roles in deforestation. Subsequent research suggests that these drivers continue to influence land cover change at national (Rudel et al., 2005) and local scales (Freitas et al., 2010; Michalski et al., 2010).

There are a wide range of mechanisms through which socioeconomic and cultural factors influence forest loss and regeneration. Laurance et al. (2002) identify proximity to roads as an enabling factor for deforestation in the Brazilian Amazon, providing access for conversion to pasture or crops. Quezada et al. (2014) observe similar patterns of deforestation near roads in Guatemala, and note that rates of loss correlate with advancement of public policies and economic forces that promoted expansion of agriculture. Studies of natural regeneration note that proximity to roads is also correlated with lower probabilities of expanding forest cover (Molin et al., 2017; Rezende et al., 2015; Freitas et al., 2010).

Similarly, abandonment of agricultural activities was more likely to be observed with increasing distance from roads and urban areas, leaving open opportunities for regeneration of native vegetation. Newman et al. (2014) finds that while deforestation rates in the Cockpit Country of Jamaica are highest where fragmentation has already occurred due to roads and existing agriculture, reforestation is more likely to occur in remote portions of the landscape. Similar spatial patterns of regeneration have been observed in Brazil (Uezu et al., 2015; Rezende et al., 2015)

The geographic patterns are frequently correlated with socioeconomic factors. In Jamaica, Newman et al. (2014) observe that wealthier properties are frequently closer to roads and on gentle terrain that is better suited for crops, and that the highly-sloped portions of the landscapes that are more likely to show regeneration are occupied by households with observable signs of lower wealth. They posit that land abandonment in these areas, due to marginal production or more promising employment elsewhere, is one explanation for forest regeneration.

However, smaller property sizes and lower wealth and status do not always show similar effects on land cover change. In a field experiment of uptake of PES contracts in Uganda, landowners with greater credit constraints were more likely to maintain trees as a liquidity source for times of need (Jayachandran et al., 2016). Smaller properties in the Brazilian Amazon were observed to have lower levels of forest cover than large properties. Forest was maintained when it suited the suite of on-farm economic activity or was located on unusable land (Michalski et al., 2010). This range of land cover patterns suggest that there is an interplay between the productivity of land, household characteristics, and access costs that affect the probability of natural regeneration.

Biophysical characteristics of land also influence patterns of forest regeneration. Chief among these is the position of land within a matrix of various land cover types, especially its proximity to existing native vegetation (Rezende et al., 2015; Newman et al., 2014; Rodrigues and Gandolfi, 2007). Proximity to rivers is another important factor (Molin et al., 2017), as are slope, solar radiation, and soil type (Uezu et al., 2015; Rezende et al., 2015).

It is also important to note that trends in forest regeneration at the local level are dynamic over time. These changes are frequently associated with shifts in agriculture, such as policies to encourage expansion or abandonment of marginal lands, and may be difficult to forecast.

Study area

The Cantareira System is the primary drinking water reservoir system for the São Paulo metropolitan area – the largest urban agglomeration in South America (Whately and Cunha, 2007). The basin comprises 230,000 hectares in the states of São Paulo and Minas Gerais (Figures 1 and 3), and has the capacity to store water for over 10 million people (Tafarello et al., 2016).

The Cantareira System lies entirely within the Atlantic Forest ecoregion, a biodiversity hotspot that extends along the eastern coast of Brazil and harbors globally significant levels of plant and animal diversity (Myers et al., 2000). Only 11-16% of the native vegetation of the Atlantic Forest remains (INPE and SOS Mata Atlântica, 2015). Over 80% of this forest cover is found in fragments of less than 50 hectares (Ribeiro et al., 2011).

Land cover change was analyzed for three municipalities – Nazaré Paulista, Piracaia, and Joanópolis – that contain the majority of the Cantareira's extent within São Paulo state (Figure 2). All of the municipalities have low populations and large rural areas, with a high percentage of the population engaged in agricultural production (Table 13). Pasture for cattle and eucalyptus for pulp and charcoal comprise the majority of agricultural activity in the study municipalities (São Paulo State Agricultural Extension Service, 2008).

Table 13. Population data for study municipalities (Source: IBGE Census 2010, State of São Paulo Agricultural Census, 2008)

	Population	Cattle Farmers	Eucalyptus Growers
Joanópolis	11,768	745	431
Nazaré Paulista	16,414	488	377
Piracaia	25,116	649	349

Data Sources

Land cover was drawn from Landsat 5 TM imagery from the years 1990, 2000, and 2010, with a pixel size of 30m (Molin et al., 2015). These images were classified into seven classes: 1) crops, 2) native vegetation, 3) forest plantations, 4) water bodies, 5) pasture, 6) urban areas, and 7) perennial crops. Classifications of Landsat imagery were verified through field visits in 2015. In addition to identifying land cover type, three age classes of native vegetation were determined for the 2010 observation (2 years, 22 years, and 32 years). Other data sources on biophysical and anthropogenic factors used in the analysis are summarized in Table 14.

Spatial data for registered properties was accessed through the Rural Land Registry database for the state of São Paulo. The Rural Land Registry (*Cadastro Ambiental Rural – CAR*) has been incrementally expanded to enforce the land use mandates of the Forest Code, and under the 2012 Native Vegetation Protection Law penalties are incurred for unregistered properties (Brancalion et al., 2016). Data on property location, size, and land cover are publicly available through the state ministries responsible for registration (SIGAM-SP, 2016).

Table 14. Variables used for analyzing land cover change.

Variable	Data set	Type	Source
Land use	1990, 2000, 2010 LANDSAT	Anthropic/biophysical	Molin et al. (2015)
Soil type	Map of soils	Biophysical	de Oliveira (1999)
Distance to water (m)	Hydrology map	Biophysical	IBGE (2010, 2013)
Distance to forest (m)	1990, 2000, 2010 LANDSAT	Biophysical	Molin et al. (2015)
Mean annual rainfall (mm)	Pluviometric map	Biophysical	Woltzenlogel (1990)
Slope (degrees)	ASTER DEM	Biophysical	NASA and METI (2011)
Altitude (m)	ASTER DEM	Biophysical	NASA and METI (2011)
Distance to urban areas	Raster data	Anthropic	Converted from Molin et al. (2015)
Distance to highways	Raster data	Anthropic	Converted from IBGE data

Socioeconomic data was collected through in-person interviews with 202 landowners from September-November 2015. The interviews included questions about property characteristics, agricultural production, and household characteristics, including whether the property was registered in the CAR system and the length of tenure (for full questionnaire, see Appendix 3). Property locations were recorded using GPS as part of the interview process, and later matched with CAR data downloaded from the SIGAM system. Of the original 202 interviews, 105 reported registration in the CAR and were matched with corresponding properties in the online system. Interview data was linked to the land cover data described above to analyze natural regeneration at the property level.

Research Questions and Methods

Evaluation of land cover change and associated factors was conducted in several steps. An overall analysis of land cover change, including forest regeneration, was run for the study municipalities over 2 time periods (1990-2000, 2000-2010) in ArcGIS and Stata 13 to determine the overall characteristics of the study area and the net transitions across the land use types over the study period.

Following this analysis, generalized linear models were constructed to evaluate factors associated with forest regeneration. There is no standardized approach for evaluating the determinants of forest regeneration. The literature includes a range of methods for identification of variables and for analysis (Moreno-Fernández et al., 2015). Frequently used analyses include non-parametric approaches (e.g., Weights of Evidence (WoE) or regression trees) (Soares-Filho et al., 2002; Rezende et al., 2015; Molin et al., 2017) and regression models (Moreno-Fernández et al., 2015; Michalski et al., 2010).

We used logistic regression to examine the relationships between biophysical and anthropogenic factors and the likelihood of forest regeneration. A regeneration variable was created for both time periods by generating a dummy variable in Stata for pixels that transitioned to forest from non-forest land uses across time periods. Raster data on the age of a forest at the end of the period was used to verify that forest was in a regrowth stage appropriate to the ten-year time periods. Pixels classified as urban areas and water bodies were omitted from the analysis.

Regression models were evaluated based on their log-likelihood values and information criteria (AIC and BIC). Tests of linearity resulted in three distance variables (to watercourses, native forests, and transportation) being log-transformed for the model runs. Three models were ultimately constructed for each time period. The first restricted variables to biophysical factors, the second used only anthropogenic variables, and the third combined all variables.

Results

Land cover dynamics in the study period

Land cover distributions are presented in Table 15 and Figure 5 for each of the three years in which observations occurred. Pasture area declined substantially over the study period, and the spatial extent of commercially-managed plantations increased by more than 100%. Crop cover showed very little change in area. Urban areas expanded by approximately 25%, although their footprint remained small (~1% of the study area). Native vegetation cover in the study area in much higher than average for the Atlantic Forest, and it was not observed in less than 37% of the study region at any time period.

Over the full 20-year study period, native vegetation underwent a reduction in area, followed by a recovery. This trend is complicated somewhat by the age of the native vegetation. Regenerated vegetation (trees > 2 years old) covered 13.41% of the study area in the 2010 LANDSAT imagery. The absolute gain over the 2000-2010 period is smaller (8.1% of the total area), and so some of this observed regrowth is also the product of deforestation at some point during the 2000-2008 time period when data is unavailable.

Links between biophysical factors and native vegetation regeneration

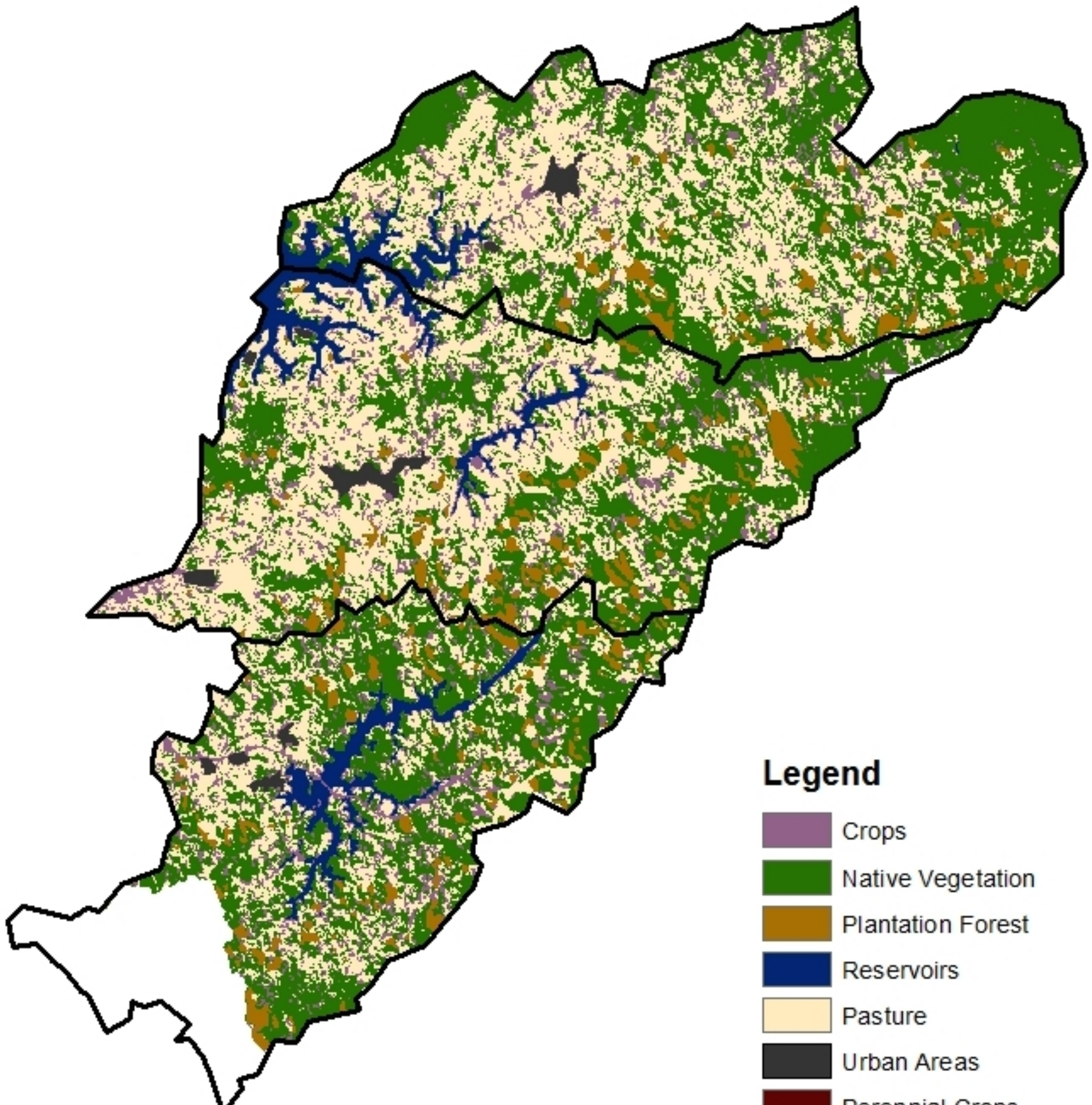
Results of the logistic regression are presented in Table 16 for the 2000-2010 period and Table 17 for the 1990-2000 period. Three models are shown for both time periods: 1) a model including all biophysical variables, 2) a model using the two coarse distance-to-anthropogenic feature variables, and 3) a joint model including all of the variables. Log-transformations of some distance variables are noted in table descriptions.

Table 15. Land cover (% of total) in the study area in 1990, 2000, and 2010.

	1990	2000	2010
Crops	10.25	10.12	10.41
Native Vegetation	42.03	37.25	45.35
Commercial Forest (eucalyptus/pine)	5.23	11.42	13.81
Water bodies	4.37	4.67	5.29
Pasture	37.13	35.26	23.84
Urban	0.99	1.21	1.24

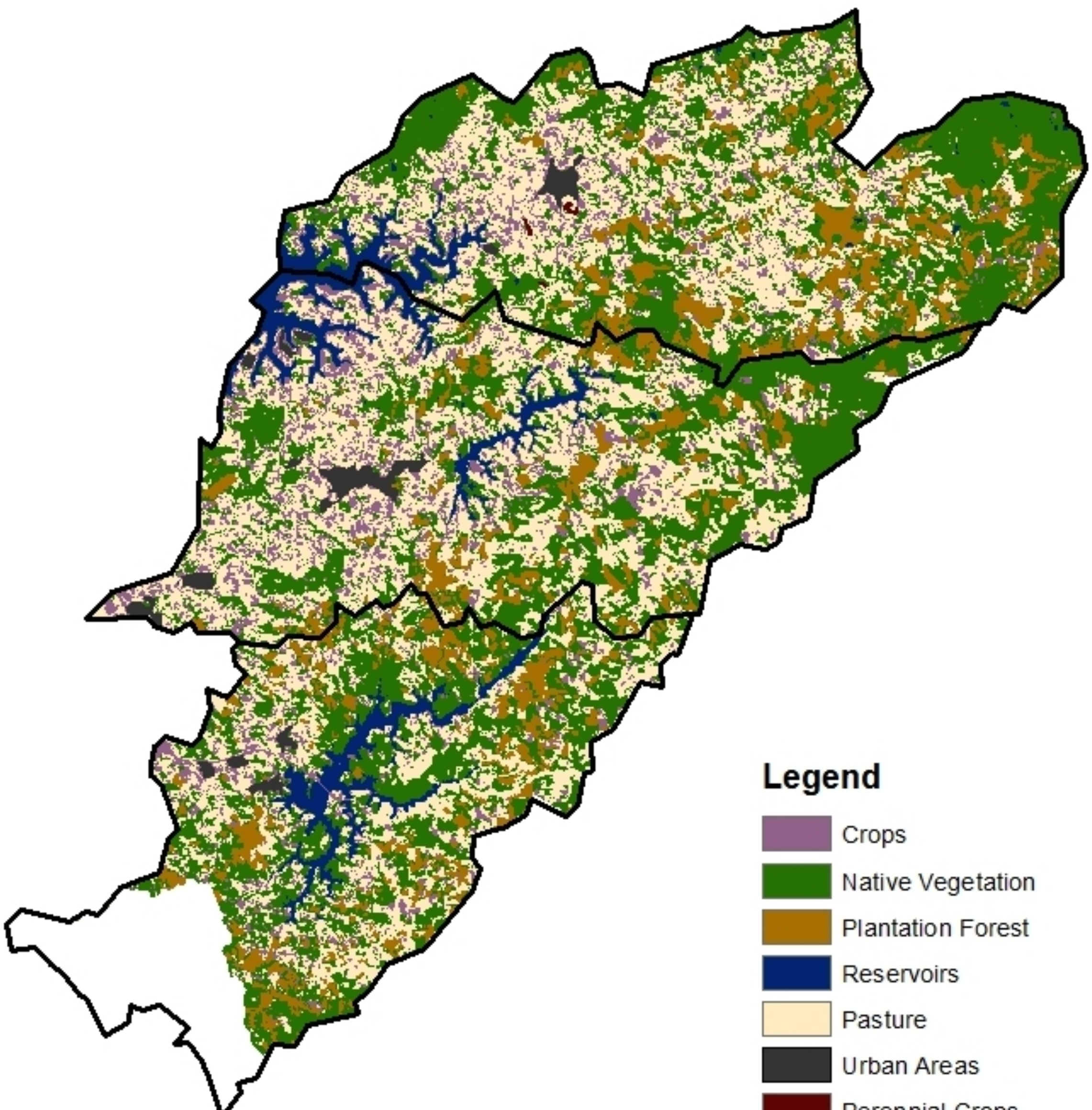
Increasing distance from watercourses had strong negative effects on the likelihood of regeneration in both time periods. The effect of Soil types 5 and 8 were negatively associated with the likelihood of regeneration relative to the base (Type 1). Although type 2 was negatively associated with regeneration in the 2000-2010 time period relative to type 1, but was positively associated with regeneration the 1990-2000 biophysical model. However, the distribution of soils across the landscape may confound the results, as types 5 and 8 are much more common in the study area (41.5% and 50.6% of the land area, respectively).

A) 1990



Legend
Crops
Native Vegetation
Plantation Forest
Reservoirs
Pasture
Urban Areas
Perennial Crops

B) 2000


Legend
Crops
Native Vegetation
Plantation Forest
Reservoirs
Pasture
Urban Areas
Perennial Crops

C) 2010

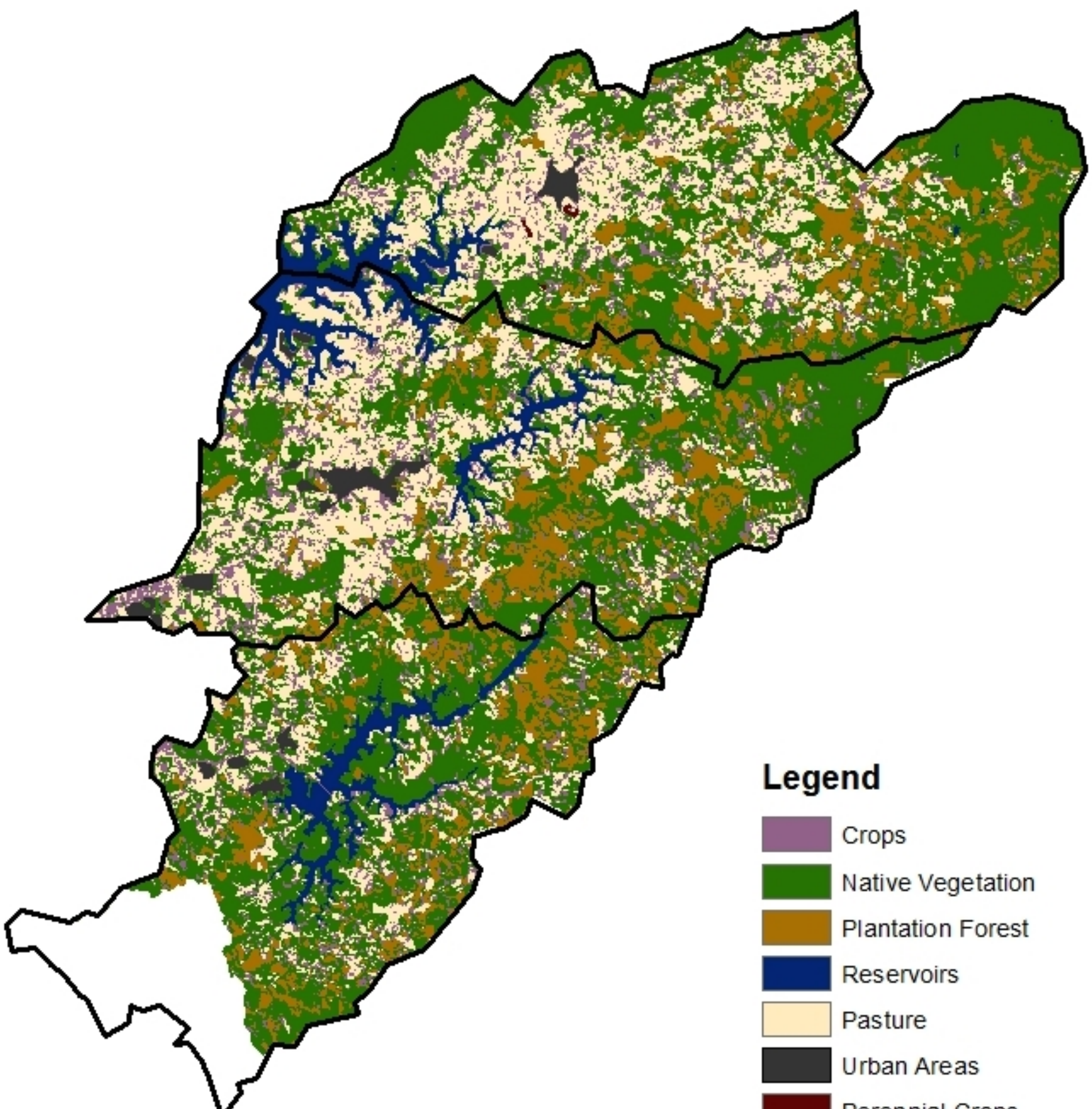


Figure 5. Land cover maps from the study periods.

Slope showed a positive effect on regeneration in the 1990-2000 model, but negative for 2000-2010. Coefficients for precipitation were small for both models (and not significant at the .05 level for 2000-2010). Altitude was positively associated with regeneration from 2000-2010, and negatively associated during the 1990-2000 period.

Potential effects and data limitations regarding anthropogenic factors

Regeneration is less likely to occur in close proximity to drivers of development and deforestation, such as roads and towns (Uezu et al., 2015; Michalski et al., 2010). However, a model solely comprised of these two factors provides little explanatory power regarding the probability of forest regeneration in the study area. In the anthropogenic model only distance to highways and urban areas are included, and as distances increase the probability of regeneration declines. However, it should be noted that the urban areas in the study municipalities are small, and the highways layer used in this analysis was limited, which may homogenize effect at a landscape level.

Suitability of a joint model

Results from the joint model are listed in column 3 of Tables 4 and 5. Generally, they are similar in scope and magnitude to the other models in the same time period. The combination of biophysical and anthropogenic variables into a single model improved the quality of the model, as measured by log-likelihood, AIC, and BIC. The Stata postestimation package for receiver operating characteristics (ROC) also reported the greatest explanatory power for the joint model. As in the biophysical and anthropogenic models, this indicator was relatively low. The area under the ROC curve was 0.633 for the joint model, which was greater than the areas for the biophysical model (0.616) and anthropogenic factor model (0.568). Values using this metric range from 0.5 to 1.

Table 16. Regression results for the 2000-2010 time period.

VARIABLES	(1) Biophysical	(2) Anthropogenic	(3) Joint
D_{Hydro}	-0.383***		-0.348***
	(0.00443)		(0.00452)
$D_{Forest2000}$	-0.245***		-0.204***
	(0.00455)		(0.00463)
Soils			
Type 2	-0.450***		-0.800***
	(0.0304)		(0.0307)
Type 5	-0.0198		-0.327***
	(0.0199)		(0.0204)
Type 8	-0.172***		-0.278***
	(0.0196)		(0.0197)
Slope	-0.00259***		-0.00577***
	(0.000218)		(0.000222)
Precipitation	-0.000698***		-0.00137***
	(3.41e-05)		(3.52e-05)
Altitude	0.000101***		-0.000308***
	(3.00e-05)		(3.05e-05)
$D_{urban2000}$		5.77e-05***	8.00e-05***
		(7.83e-07)	(9.35e-07)
D_{roads}		-0.0640***	0.0443***
		(0.00528)	(0.00578)
Constant	0.779***	-1.628***	1.696***
	(0.0466)	(0.0158)	(0.0478)
Observations	694,489	694,489	694,489
Log-likelihood	-329699	-333207	-325538
AIC	659416.9	666419.4	651098.5
BIC	659520	666453.7	651224.4

Standard errors in parentheses[11]
*** p<0.01, ** p<0.05, * p<0.1

[11] For the variables, D_{Hydro} is the $\log_{10}$ distance to the nearest watercourse, $D_{Forest2000}$ is the $\log_{10}$ distance to the nearest native vegetation at the start of the time period, Soils are dummy variables of the soil types from Woltzenlogel (1990), with the coefficient for Type 1 constrained to 0, $D_{Urban2000}$ and D_{Roads} indicate distances to urban areas (m) at the start of the time period and $\log_{10}$-transformed distance to highways, respectively.

Table 17. Regression results for the 1990-2000 time period.

VARIABLES	(1) Biophysical	(2) Anthropogenic	(3) Joint
D_{Hydro}	-0.372***		-0.347***
	(0.00493)		(0.00500)
$D_{Forest1990}$	0.462***		0.498***
	(0.00497)		(0.00503)
Soils			
Type 2	-0.617***		-0.862***
	(0.0342)		(0.0347)
Type 5	-0.281***		-0.505***
	(0.0226)		(0.0232)
Type 8	-0.173***		-0.238***
	(0.0221)		(0.0221)
Slope	0.00921***		0.00700***
	(0.000238)		(0.000242)
Precipitation	-0.000650***		-0.00125***
	(3.90e-05)		(4.02e-05)
Altitude	0.00185***		0.00163***
	(3.30e-05)		(3.30e-05)
$D_{urban1990}$		3.21e-05***	5.31e-05***
		(9.04e-07)	(1.12e-06)
D_{roads}		0.117***	0.123***
		(0.00642)	(0.00688)
Constant	-2.843***	-2.571***	-2.348***
	(0.0527)	(0.0195)	(0.0537)
Observations	775,976	775,976	775,976
Log-likelihood	-276820	-284123	-275226
AIC	553658.7	568251.2	550474.3
BIC	553762.8	568285.9	550601.5

Standard errors in parentheses[12]
*** p<0.01, ** p<0.05, * p<0.1

[12] For the variables, D_{Hydro} is the $\log_{10}$ distance to the nearest watercourse, $D_{Forest1990}$ is the $\log_{10}$ distance to the nearest native vegetation at the start of the time period, Soils are dummy variables of the soil types from Woltzenlogel (1990), with the coefficient for Type 1 constrained to 0, $D_{Urban1990}$ and D_{Roads} indicate distances to urban areas (m) at the start of the time period and $\log_{10}$-transformed distance to highways, respectively.

Evaluation at the property level

Following the analysis of the full extent of the study municipalities, the sample was restricted to the properties where interviews had been conducted in 2015. A total of 105 properties were included, covering 4,118 hectares. Properties were included in the analysis if the owner of the property reported ownership for over 15 years in the survey. The distribution of land cover types in the property-only sample is described in Table 18. Compared to the entire study region, CAR-registered properties contained significantly lower levels of native vegetation, and much higher levels of crop and pasture cover.

Table 18. Land cover in the surveyed CAR-registered properties in 2010.

	% of total
Crops	14.93
Native Vegetation	29.33
Commercial Forest (eucalyptus/pine)	9.53
Water bodies	0.24
Pasture	45.96
Urban	0.02

The effects of biophysical and anthropogenic variables on the probability of regeneration within the surveyed properties was not substantially different from the 2000-2010 output, despite the much smaller sample size (Table 19). The inclusion of property size resulted in only small changes in the magnitude of the coefficients of the landscape-level variables. Increasing property sizes had a positive and significant effect at the $\alpha=0.05$ level.

Evaluating forest age and extent across different property sizes suggests that other unobservable property-level factors may be affecting regeneration. Dividing the sample of properties at the median (~68 hectares) reveals that the subset of large properties has a higher proportion of forest cover (33% vs. 25%), and the distribution of forest ages is skewed heavily toward the highest age class (32 years) that could be classified using the LANDSAT images.

Discussion

These results raise several issues regarding the history of land use in the study region, the challenges of using regression models to analyze land use change, and the potential value of property-level data to guide research and policy related to restoration ecology.

Changing patterns of land cover

Patterns of land use in the study municipalities have been dynamic throughout the study period (Figure 5). Chief among these shifts in land use are the expansion of commercial eucalyptus plantations and the more recent transition of large amounts of pasture to native vegetation. Unlike pasture, which has low productivity on steep slopes and at high altitudes in the Cantareira region, eucalyptus grows rapidly in most landscapes within the study area. The limited labor requirements for maintenance and the relatively low transportation costs to urban consumer markets in São Paulo made plantations attractive investments, and likely depressed regeneration success during the

1990-2000 time period on slopes and high altitudes where land abandonment would be expected to facilitate regrowth (Uezu et al., 2015).

The decline in pasture is likely correlated with demographic and economic trends within the basin. Many interviewed landowners, all of whom maintained pasture, were at or near retirement age in Brazil. Labor constraints were frequently reported, as younger generations sought opportunities in growing industries in the nearby cities of the São Paulo and Campinas metropolitan areas (Richards et al., 2017). Development of *chácaras* – weekend or retirement properties for residents of the major metropolitan areas of São Paulo state – is increasingly common in the study area as cattle producers sell or subdivide properties. This demand for rural property, along with an aging agricultural workforce, is likely to affect land use in the future, with uncertain consequences for natural regeneration processes.

Omitted variables and data constraints

Evaluative measures (log-likelihood, AIC, and BIC) and postestimation procedures (receiver operating characteristic (ROC) analysis and specification link tests) suggest that the models described above have limited explanatory power. This is attributable to data constraints, the complexity of landscape level analysis, and the limits of regression models for explaining stochastic events.

Table 19. Regression results for models using the surveyed CAR properties sample in the 2000-2010 time period.

VARIABLES	(1) Biophysical	(2) Anthropogenic	(3) Joint	(4) Joint + Area
D_{Hydro}	-0.554***		-0.518***	-0.515***
	(0.0218)		(0.0221)	(0.0222)
$D_{Forest2000}$	-0.506***		-0.488***	-0.485***
	(0.0241)		(0.0244)	(0.0244)
Soils				
Type 2	-1.346***		-1.440***	-1.437***
	(0.233)		(0.236)	(0.236)
Type 5	-0.862***		-0.933***	-0.930***
	(0.135)		(0.138)	(0.138)
Type 8	-1.230***		-1.128***	-1.146***
	(0.134)		(0.136)	(0.137)
Slope	0.000835		-0.00188	-0.00200*
	(0.00117)		(0.00119)	(0.00119)
Precipitation	-0.00267***		-0.00392***	-0.00395***
	(0.000197)		(0.000224)	(0.000225)
Altitude	0.00318***		0.00224***	0.00219***
	(0.000185)		(0.000195)	(0.000198)
$D_{urban2000}$		7.62e-05***	5.17e-05***	5.25e-05***
		(5.72e-06)	(7.31e-06)	(7.35e-06)
D_{roads}		0.0682**	0.376***	0.387***
		(0.0313)	(0.0448)	(0.0454)
$Area_{property}$				0.000268*
				(0.000138)
Constant	1.950***	-2.539***	3.308***	3.332***
	(0.281)	(0.0896)	(0.293)	(0.293)
Observations	37,076	37,076	37,076	37,076
Log-likelihood	-12701	-13257	-12598	-12596
AIC	25419.07	26519.65	25217.94	25216.21
BIC	25495.75	26545.21	25311.66	25318.46

Standard errors in parentheses[13]
*** p<0.01, ** p<0.05, * p<0.1

[13] For the variables, D_{Hydro} is the $\log_{10}$ distance to the nearest watercourse, $D_{Forest2000}$ is the $\log_{10}$ distance to the nearest native vegetation at the start of the time period, Soils are dummy variables of the soil types from Woltzenlgel (1990), with the coefficient for Type 1 constrained to 0, $D_{Urban2000}$ and D_{Roads} indicate distances to urban areas at the start of the time period and $\log_{10}$-transformed distance to highways, respectively. Property area is calculated in hectares.

As an example, the positive coefficients for distance to roads and urban areas to probabilities of forest regeneration reflect broader conclusions from past research on spatial determinants of deforestation, that land closer to towns and roads is likely where deforestation is ongoing. However, incomplete spatial datasets inhibit observation of patterns of development affecting regeneration. The dataset for highways, which is maintained by the Brazilian federal government, does not include smaller roads built and maintained by the state, municipalities, or private groups. Given the importance of roads to land cover change elsewhere (Laurance et al., 2002) it is logical that they play a greater role in land cover dynamics in the study area as well, and are correlated with pasture and urban land use. New datasets are being developed to address this gap. IPÊ (Insituto de Pesquisas Ecológicas – Ecological Research Institute, in English) has developed a map of smaller roads for the Cantareira, but it does not cover the full extent of the study municipalities and so was omitted from this analysis (Uezu, pers. comm.).

The timing of observations and local events that affect land cover change present an additional challenge to this type of research. LANDSAT data and other satellite imagery have achieved greater coverage and higher resolution in recent years, but longer time series are limited by the available technology in 1990. These snapshots also result in large gaps in which ordered events that have significant effects on land cover are unobservable. These events, and their relationships with other dynamic landscape features, are difficult to capture in regression models. Other approaches, such as regression trees, may provide better clarity on the relative importance of certain variables.

Potential value in property-level data

The inclusion of property data has been used elsewhere in Brazil (Michalski et al., 2010), but to our knowledge the property maps from the CAR system have not been utilized to evaluate land cover change in the Cantareira region, and have only infrequently been used in the Atlantic Forest. This new dataset is very useful for enforcement of land use regulations, and in some cases it may be useful for testing models of landscape dynamics. In this study the CAR data provide some useful extensions to past work, but the temporal discrepancies limit the depth of an analysis. Despite the possession of granular household and production data from the 2015 survey, the only application of these data for this research is to restrict the sample of CAR properties to those that have been owned by the same family for 15 years, to link property delineations to older time-series data on land cover. Other production factors that likely affect regeneration, such as pasture management approaches and the dependence on on-farm income sources, are not captured here for the full study period.

Despite the restrictions on some data sources, the observations from the study are relevant to ongoing conservation activity within the region. The Cantareira System has been a priority for forest restoration in the Atlantic Forest since at least 2005, when the first payments for ecosystem services (PES) program, *Conservador das Águas* (Water Conservator), was conceptualized in Extrema, a municipality in Minas Gerais state (Richards et al., 2015). In the ensuing years, several other PES programs and initiatives targeting restoration on agricultural properties have been conducted in the region. The water crisis of 2013-2014 (Taffarello et al., 2016) and the completion of the CAR registration, with its penalties for non-compliance, will likely rekindle interest in forest restoration. Information on natural regeneration can aid development of cost-effective strategies to maximize future investments in restoration.

Conclusion

Natural regeneration in the São Paulo portion of the Cantareira System is influenced by a range of factors, and their relative importance has changed over time. While the shifts toward eucalyptus and abandonment of pasture may not be ubiquitous throughout Brazil, the general conclusions of this project support other research that emphasize the importance of watercourses and existing forests as enabling factors for forest expansion.

The patterns of regeneration across the subset of CAR-registered properties are valuable for future conservation strategies in the region. Payments for ecosystem services programs and other incentives to promote preservation and recovery of native vegetation on private land have received a great deal of attention in the region, but incentive design and recruitment remain an issue (Richards et al., 2017). Understanding where regeneration is likely to occur, and where forests persist on private land, is beneficial to tailor incentives and target programs to specific areas and groups where reforestation offers the greatest return.

CONCLUDING THOUGHTS

The ecological and ecosystem service value of the Canatareira region places it high on the list of priority areas within Brazil for forest restoration, and makes it a likely target for future PWS efforts. Any future effort should account for the social, economic, and ecological issues presented in this study in order to increase its impact.

The first chapter noted that incentives for enrolling in existing PWS programs do not address the needs of landowners who would not otherwise participate in forest restoration on their land. In addition, the legal penalties (e.g., credit restrictions) that are intended to encourage compliance with land use laws may operate as intended for large-scale producers elsewhere in the country, but is unlikely to have an effect on smaller landowners in the Cantareira, due to issues of scale and trust. As a result, enrollment will require substantial investments at project initiation, possibly limiting the gains of PWS as a concept.

The second chapter identifies incentive designs that may encourage greater uptake of PWS contracts. In-kind contributions, specifically fencing to intensify cattle production, have a strong appeal, especially among family farmers who would ideally be targeted by PWS. However, interest in PWS contracts is influenced by property characteristics. Because of the structure of Brazilian land use laws, which require forest restoration in riparian areas, the impact of PWS is heterogeneous at the property-level. In light of this complexity, strategic targeting is necessary.

Targeting should also account for trends in land cover change. The land cover dynamics of the region have shifted significantly over the last 30 years, as pasture, eucalyptus, and migration from São Paulo have fluctuated over time. More recently trends have shifted toward higher levels of forest cover and abandonment of pasture for eucalyptus or native forest. Insights into drivers of these trends will improve in the future as publicly-available property registries provide additional land use data at finer scales. Property-level data in this study suggest that forest ages are lower on smaller properties, and that regeneration may be temporary when landowner face spatial constraints.

The patterns of forest regeneration suggest that PWS programs in the Cantareira should target small landowners. Results from the policy analysis and choice experiment indicate that targeting these landowners will require thoughtful revisions to contract design. Greater positive incentives will be necessary, and the high levels of selection for the status option in the choice experiment suggest that, as in pilot PWS in the region, significant administrative costs will be necessary for landowner recruitment. As a result, future research efforts should seek to prioritize the regions in the Cantareira System where natural regeneration is less likely and ecosystem service values (e.g., avoided erosion) are higher in order to maximize the impact of PWS investments.

APPENDICES

Appendix 1 – References used in PWS policy review

Peer-reviewed Publications

Porto, M., Kelman, J., 2000.Water Resources Policy in Brazil. *Rivers* 7 (3), 250-257.

Richards, R.C., Rerolle, J., Aronson, J., Pereira, P.H., Gonçalves, H., Brancalion, P.H.S. 2015. Governing a pioneer program on payment for watershed services: Stakeholder involvement, legal frameworks and early lesson from the Atlantic Forest of Brazil. *Ecosystem Services* 16, 23-32.

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., Alencar, A., 2014. Cracking Brazil's Forest Code. *Science* 344, 363-364.

Veiga, L.B.E., Magrini, A., 2013. The Brazilian Water Resources Management Policy: Fifteen Years of Success and Challenges. *Water Resources Management* 27 (7), 2287-2302.

Young, C.E.F. 2005. Financial Mechanisms for Conservation in Brazil. *Conservation Biology* 19 (3), 756-761.

Zanella, M.A., Schleyer, C., Speelman, S. 2014. Why do farmers join Payments for Ecosystem Services (PES) schemes? An Assessment of PES water scheme participation in Brazil. *Ecological Economics* 105:166-176.

"Gray" literature

Agência de Água PCJ. Relatório Final: Plano das Bacias Hidrográficas dos Rios Piracicaba, Capivari e Jundiaí 2010-2020, com propostas de atualização do enquadramento dos corpos d'água e de program para efetivaçnao do enquadramento dos corpos d'água até o ano de 2035. Cobrape, 815p.

Brancalion, P.H.S., Garcia, L.C., Loyola, R., Rodrigues, R.R., Pillar, V.D., Lewinsohn, T.M. 2016. A critical analysis of the Native Vegetation Protection Law (2012): updates and ongoing initiatives. *Natureza & Conservação* 14S, 1-15. http://dx.doi.org/10.1016/j.ncon.2016.03.003

Campanha de Oliveira, A.C., Vilar, M.B., Jacovine, L.A.G., Santos, M.O., Jacon, A.D. 2013. Histórico e implementação de sistemas de Pagamentos por Serviços Ambientais no Estado de Minas Gerais. *Sustainability in Debate* 4(1), 139-160.

Dean, W. (1997). *With Broadax and Firebrand: the Destruction of the Brazilian Atlantic Forest*. Univ of California Press.

Guedes, F.B., Seehusen, S.E. (eds.) 2011. *O PSA na Mata Atlântica – Situação Atual, Desafios e Recomendações*. Ministério do Meio Ambiente, Brasília.

Guedes, F.B., Seehusen, S.E. (eds.) 2011. *Pagamentos por Serviços Ambientais na Mata Atlântica – Lições aprendidas e desafios*. Ministério do Meio Ambiente, Brasília, 280p.

Guedes, F.B., Belchior, C., Tafuri, A., Seehusen, S.E. (eds.) 2013. Lições aprendidas na conservação e recuperação da mata Atlântica: Sistematização de desafios e melhores práticas dos projetos-pilotos de Pagamentos por Serviços Ambientais. Ministério do meio Ambiente, Brasília, 88p.

Hercowitz, M., Figueiredo, G.R. 2011. *Teste de viabilidade do uso de reverse auction como mecanismo para pagamentos por serviços ambientais*. Technical Report. Secretária do Meio Ambiente – SP, 80p.

Hirakuri, S. 2003. *Can Law Save the Forest? Lessons from Finland and Brazil*. CIFOR, Indonesia, 131 p.

Instituto Estadual de Florestas. 2012. *Bolsa Verde: Relatório Anual de Atividades – 2010-2011*. Belo Horizonte, 119p.

Instituto Estadual de Florestas. 2010. *Bolsa Verde: Manual de Prinicipios, critérios e procedimentos para a implantação da Lei n.17.727 de agosto de 2008*. Belo Horizonte, 47 p.

Kfouri, A., Favero, F. 2011. Projeto Conservador das Águas Passo a Passo: Uma Descrição Didática sobre o Desenvolvimento da Primeira Experiência de Pagamento por uma Prefeitura Municipal no Brasil. Série Água, Clima e Floresta. Vol. 4. The Nature Conservancy, Brasília, 60 pp.

Packer, L.A. 2015. *Novo Código Florestal & Pagamentos por Serviços Ambientais: Regime Proprietário sobre os Bens Comuns*. Juruá: Curitiba. 268 pp.

Padovezi, A., Viani, R.A.G., Kubota, U., Taffarello, D., Faria, M., Bracale, H., Ferrari, V., de Carvalho, F.H. 2012. *O Projeto Produtor de Água na bacia hidrográfica PCJ em São Paulo, Brasil*. World Bank, Washington.

Pagiola, S., von Glehn, H.C., Taffarello, D. 2013a. *Brazil's Experience with Payments for Environmental Services*. World Bank PES Learning Paper: Washington, DC.

Pagiola, S., von Glehn, H.C., Taffarello, D. 2013b. *Experiências de pagamentos por serviços ambientais no Brazil*. Secretaria do Meio Ambiente – Coordenadoria de Biodiversidade e Recursos Naturais, São Paulo.

Pereira, P.H., Cortez, B., Trindade, T., Mazochi, M.N., 2010. Conservador das Águas: 5 Anos. Extrema: Departamento de Meio Ambiente de Extrema. Extrema-MG.

Pinto, A.C. 2012. A política de pagamentos por serviços ecossistêmicos (PSE): O caso do programa *Bolsa Verde* em Minas Gerais (2010-2011). Master's thesis, UFU. 80p.

Santos, P., Brito, B., Maschietto, F., Osório, G., Monzoni, M. (eds.) 2012. *Marco regulatório sobre pagamento por serviços ambientais no Brasil*. Imazon, Belém.

Santos, R.F., Vivian, J.L. 2012. Pagamento por Serviços Ecossistêmicos em perspectiva comparada: recomendações para tomada de decisão. Brasília: Projeto Apoio aos Diálogos Setoriais UE-Brasil. 180p.

Veiga Neto, F.C. 2008. A construção dos mercados de serviços ambientais e suas implicações para o desenvolvimento sustentável no Brasil. Doctoral dissertation. UFRJ, 286 p.

von Glehn, H.C., Taffarello, D., Kamiyama, A., Dalla Vecchia, A.C., Cogueto, C.V. 2012. *O Projeto Mina d'Água em São Paulo*, *PES Learning Paper 2012-SP*. World Bank, Washington.

Whately, M., Cunha, P. 2007. Cantareira 2006: um olhar sobre o maior manancial de água da Região Metropolitana de São Paulo. Instituto Socioambiental, São Paulo.

Appendix 2 – Reference list from WoS search: 'brazil AND agricultur* AND cattle'

Alves-Pinto, H.N., Newton, P., Guedes Pinto, L.F. 2015. Reducing deforestation and enhancing sustainability in commodity supply chains: interactions between governance interventions and cattle certification in Brazil. *Tropical Conservation Science* 8(4), 1053-1079.

Alvez, J.P., Schmitt, A.L., Farley, J.C., Erickson, J.D., Méndez, V.E. 2014. Transition from Semi-Confinement to Pasture-Based Dairy in Brazil: Farmers' View of Economic and Environmental Performances. *Agroecology and Sustainable Food Systems*. 38, 995-1014.

Barbosa, W.F., de Sousa, E.P., Amorim, A.L., Coronel, D.A. 2013. Eficiência técnica da agropecuária nas microrregiões brasileiras e seus determinantes. *Ciência Rural, Santa Maria* 43(11), 2115-2121.

Bell, A.R. 2011. Environmental Licensing and Land Aggregation: An Agent-Based Approach to Understanding Ranching and Land Use in Rural Rondônia. *Ecology and Society* 16(1), 31.

Bell, A.R. 2011. Highly Optimized Tolerant (HOT) Farms in Rondônia: Productivity and Farm Size, and Implications for Environmental Licensing. *Ecology and Society* 16(2), 7.

Bernard, J., Le Gal, P.Y., Triomphe, B., Hostiou, N., Moulin, C.H. 2010. Involvement of small-scale dairy farms in an industrial supply chain: when production standards meet farm diversity. *Animal* 5(6), 961-971.

Bernardes, T.F., do Rêgo, A.C. 2014. Study on the practices of silage production and utilization on Brazilian dairy farms. *Journal of Dairy Science* 97, 1852-1861.

Borges, J.A.R., Lansink, A.G.J.M.O. 2015. Comparing groups of Brazilian cattle farmers with different levels of intention to use improved natural grassland. *Livestock Science* 178, 296-305.

Bowman, M.S. 2016. Impact of foot-and-mouth disease status on deforestation in Brazilian Amazon and *cerrado* municipalities between 2000 and 2010. *Journal of Environmental Economics and Management* 75, 25-40.

Bowman, M.S., Soares-Filho, B.S., Merry, F.D., Nepstad, D.C., Rodrigues, H., Almeida, O.T. 2012. Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production. *Land Use Policy* 29, 558-568.

Cardoso, V.L., Nogueira, J.R., Vercesi Filho, A.E., El Faro, L., Lima, N.C. 2004. Breeding Foals and Economic Values for Pasture Based Milk Production Systems in the Southeast Region of Brazil. *Revista Brasileira de Zootecnia* 33(2), 320-327.

Cardoso, V.L., Pereira Lima, M.L., Nogueira, J.R., de Carneiro, R.L.R., Sesana, R.C., Oliveira, E.J., El Faro, L. 2014. Economic values for milk production and quality traits in south and southeast regions of Brazil. *Revista Brasileira de Zootecnia* 43(12), 636-642.

Carrer, M.J., de Souza Filho, H.M., Brandão Vinholis, M.M. 2013. Determinants of feedlot adoption by beef cattle farmers in the state of São Paulo. *Revista Brasileira de Zootecnia* 42(11), 824-830.

Carrer, M.J., da Silveira, R.L.F., de Souza Filho, H.M., Brandão Vinholis, M.M. 2013. Factors influencing beef cattle farmers' use of risk management instruments in the State of São Paulo, Brazil. *Ciência Rural, Santa Maria* 43(2), 370-376.

Caviglia-Harris, J.L., Sills, E.O. 2005. Land use and income diversification: comparing traditional and colonist populations in the Brazilian Amazon. *Agricultural Economics* 32, 221-237.

Cerri, C.C., Moreira, C.S., Alves, P.A., Raucci, G.S., Castigioni, B.A., Mello, F.F.C., Cerri, D.G.P., Cerri, C.E.P. 2016. Assessing the carbon footprint of beef cattle in Brazil: a case study with 22 farms in the State of Mato Grosso. *Journal of Cleaner Production* 112, 2593-2600.

Cohn, A.S., Mosnier, A., Havlik, P., Valin, H., Herrerro, M., Schmid, E., O'Hare, Obersteiner, M. 2014. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proceedings of the National Academy of Sciences of the USA* 111(20), 7236-7241.

Costa, F.P., Rehman, T. 2005. Unravelling the rationale of 'overgrazing' and stocking rates in the beef production systems of Central Brazil using a bi-criteria compromise programming model. *Agricultural Systems* 83, 277-295.

Costa, J.H.C., Hötzel, M.J., Longo, C., Balcão, L.F. A survey of management practices that influence production and welfare of dairy cattle on family farms in southern Brazil. *Journal of Dairy Science* 96, 307-317.

da Silva, R.G., Ribeiro, C.G. 2004. Análise da Degradação Ambiental na Amazônia Ocidental: um Estudo de Caso dos Municípios do Acre. *RER, Rio de Janeiro* 42(1), 91-110.

da Silva, H.A., Koehler, H.S., de Moraes, A., Guimarães, V.D., Hack, E., de Faccio Carvalho, P.C. 2008. Análise da viabilidade econômica da produção de leite a pasto e com suplementos na região dos Campos Gerais – Paraná. *Ciência Rural, Santa Maria* 38(2), 445-450.

de Brito, M.M., Bánkuti, F.I., Bánkuti, S.M.S., Ferreira, M.C.M., Damasceno, J.C., dos Santos, G.T., Zambom, M.A. 2015. Horizontal arrangements: strategy for reducing the asymmetry information for dairy farmers in Paraná, Brazil. *Ciência Rural, Santa Maria* 45(11), 2069-2075.

de Léis, C.M., Cherubini, E., Ruviaro, C.F., da Silva, V.P., Lampert, V.N.L., Spies, A., Soares, S.R. Carbon footprint of milk production in Brazil: a comparative case study. *International Journal of Life Cycle Assessment* 20, 46-60.

de Moura, J.F.P., Filho, E.C.P., Neto, S.G., de Menezes, M.P.C., leite, S.V.F., Guilhermino, M.M. 2010. Caracterização dos sistemas de produção de leite bovino no Cariri paraibano. *Acta Scientiarum: Animal Sciences* 32(3), 293-298.

de Souza, R.S., Viana, J.G.A., Bortoli, A. 2006. Tendência histórica de preços pagos ao produtor na pecuária do Rio Grande do Sul, Brasil. *Ciência Rural, Santa Maria* 36(5), 1511-1517.

Dill, M.D., Emvalomatis, G., Saatkamp, H., Rossi, J.A., Pereira, G.R., Barcellos, J.O.J. Factors affecting adoption of economic management practices in beef cattle production in Rio Grande do Sul state, Brazil. *Journal of Rural Studies* 42, 21-28.

Diniz, F.H., Hoogstra-Klein, M.A., Kok, K., Arts, B. 2013. Livelihood Strategies in settlement projects in the Brazilian Amazon: Determining drivers and factors within the Agrarian Reform Program. *Journal of Rural Studies* 32, 196-207.

dos Santos, G.M., Assad, M.L.R.C.L., Hott, M.C., Otenio, M.H. 2014. Agricultural exploitation impact on the quality of natural waters in the trout-breeding region of the Mantiqueira ecological corridor. *Acta Scientiarum* 36(2), 175-180.

dos Santos, G., Bittar, C.M.M. 2015. A survey of dairy calf management practices in some producing regions in Brazil. *Revista Brasileira de Zootecnia* 44(10), 361-370.

Eaton, D.P., Santos, S.A., Santos, M.C.A., Vergílio, J., Lima, B., Keroghlian, A. 2011. Rotational Grazing of Native Pasturelands in the Pantanal: an effective conservation tool. *Tropical Conservation Science* 4(1), 39-52.

Faria, W.R., Almeida, A.N. 2016. Relationship between openness to trade and deforestation: Empirical evidence from the Brazilian Amazon. *Ecological Economics* 121, 85-97.

Ferraz, J.B.S., de Felício, P.E. 2010. Production systems – An example from Brazil. *Meat Science* 84, 238-243.

Filho, K.E. 2004. Supply chain approach to sustainable beef production from a Brazilian perspective. *Livestock Production Science* 90, 53-61.

Geist H.J., Lambin, E.F. 2002. Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 52(2),143–150.

Gerssen-Gondelach, S., Wicke, B., Faaij, A. 2015. Assessment of driving factors for yield and productivity developments in crop and cattle production as key to increasing sustainable biomass potentials. *Food and Energy Security* 4(1), 36-75.

Gibbs, H.K., Munger, J., L'Roe, J., Barreto, P., Pereira, R., Christie, M., Amaral, T., Walker, N.F. 2016. Did Ranchers and Slaughterhouses Respond to Zero-Deforestation Agreements in the Brazilian Amazon? *Conservation Letters* 9(1), 32-42.

Gil, J., Siebold, M., Berger, T. 2015. Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso, Brazil. *Agriculture, Ecosystems and Environment* 199, 394-406.

Gollnow, F., Lakes, T. 2014. Policy change, land use, and agriculture: The case of soy production and cattle ranching in Brazil, 2001-2012. *Applied Geography* 55, 203-211.

Gordo, J.M.L., da Silva, M.C., Solano, G.A., Lopes, F.B., Oliveira e Costa, M.F., de Castro Rocha, F.E., Fioravanti, M.C.S., Sereno, J.R.B. 2013. Cattle farmers: profile and speech content analysis while undergoing training to adopt artificial insemination in Goaiás State, Brazil. *Revista Brasileira de Zootecnia* 42(3), 162-167.

Haddade, I.R., Souze, P.M., Barros, E.E.L., Alves, G.R., Scolforo, L., Cordeiro, M.D., Peres, A.A.C., Henriques, L.T. 2005. Avaliação econômica sob condições de risco em sistema produtivo de gado de leite na região Norte do estado do Rio de Janeiro. *Arq. Bras. Med. Vet. Zootec.* 57(3), 361-366.

Henriksson, M., Cederberg, C., Swensson, C. 2014. Carbon footprint and land requirement for dairy herd rations: impacts of feed production practices and regional climate variations. *Animal* 8(8), 1329-1338.

Hoelle, J. 2014. Cattle Culture in the Brazilian Amazon. *Human Organization* 73(4), 363-375.

Honorato, L.A., Machado Filho, L.C.P., Barbosa Silveira, I.D., Hötzel, M.J. 2014. Strategies used by dairy family farmers in the south of Brazil to comply with organic regulations. *Journal of Dairy Science* 97, 1319-1327.

Hostiou, N., Cialdella, N., Vazquez, V., Müller, A.G., Le Gal, P-Y. 2015. Work organization on smallholder dairy farms: a process unique to each farm. *Tropical Animal Health Production* 47, 1271-1278.

Hötzel, M.J., Longo, C., Balcão, L.F., Cardoso, C.S., Costa, J.H.C. 2014. A Survey of Management Practices That Influence Performance and Welfare of Dairy Calves Reared I Southern Brazil. *PLoS ONE* 9(12), e114995.

Júnior, J.J., Cardoso, V.L., de Albuquerque, L.G. 2006. Modelo bioeconômico para cálculo de custos e receitas em sistemas de produção de gado de corte visando à obtenção de valores econômicos de características produtivas e reprodutivas. *Revista Brasileira de Zootecnia* 35(5), 2187-2196.

Krauß, M., Kraatz, S., Drastig, K., Prochnow, A. 2015. The influence of dairy management strategies on water productivity of milk production. *Agricultural Water Management* 147, 175-186.

Kuhnen, S., Stibulski, R.B., Honorato, L.A., Machando Filho, L.C.P. 2015. Farm Management in Organic and Conventional Dairy Production Systems Based on Pasture in Southern Brazil and Its Consquences on Production and Milk Quality. *Animals* 3, 479-494.

Lampert, V.N., Barcellos, J.O.J., Kliemann Meto, F.J., Canellas, L.C., Dill, M.D., Canozzi, M.E.A. 2012. Development and application of a bioeconomic efficiency index for beef cattle production in Rio Grande do Sul, Brazil. *Revista Brasileira de Zootecnia* 41(3), 775-782.

Laske, C.H., Teixeira, B.B.M., Dionello, N.J.L., Cardoso, F.F. 2012. Breeding objectives and economic values for traits of low input family-based beef cattle production system in the State of Rio Grande do Sul. *Revista Brasileira de Zootecnia* 41(2), 298-305.

Latawiec, A.E., Strassburg, B.B.N., Valentim, J.F., Ramos, F., Alves-Pinto, H.N. 2014. Intensification of cattle ranching production systems: socioeconomic and environmental synergies and risks in Brazil. *Animal* 8(8), 1255-1263.

Mann, M.L., Kaufmann, R.K., Bauer, D.M., Gopal, S., Nomack, M., Womack, J.Y., Sullivan, K., Soares-Filho, B.S. 2014. Pasture conversion and competitive cattle rents in the Amazon. *Ecological Economics* 97, 182-190.

Marques, P.R., Barcellos, J.O.J., McManus, C., Oaigen, R.P., Collares, F.C., Canozzi, M.E.A., Lampert, V.N. 2011. Competitiveness of beef farming in Rio Grande do Sul State, Brazil. *Agricultural Systems* 104, 689-693.

Marques, P.R., Barcellos, J.O.J., Dill, M.D., Dias, E.A., Azevedo, E.V.T., Lampert, V.N., McManus, C.M. 2015. Competitiveness levels in cattle herd farms. *Ciência Rural, Santa Maria* 45(3), 480-484.

Martha, Jr., G.B., Alves, E., Contini, E. 2012. Land-saving approaches and beef production growth in Brazil. *Agricultural Systems* 110, 173-177.

Martins, H.C., de Muylder, C.F., Lopes, C.A., La Falce, J. 2014. The impacts of technology dissemination in dairy dattle: a study of milk agribusiness chain in a Minas Gerais county, Brazil. *Ciência Rural, Santa Maria* 44(6), 1141-1146.

McManus, C., Barcellos, J.O.J., Formenton, B.K., Hermuche, P.M., de Carvalho, Jr., O.A., Guimarães, R.F., Gianezini, M., Dias, E.A., Lampert, V.N., Zago, D., Neto, J.B. 2016. Dynamics of Cattle Production in Brazil. *PLoS ONE* 11(1), e0147138.

Mendes, R.E. 2006. Financial impact of tracking systems in the bovine production in the State of Santa Catarina, Brazil. *Ciência Rural, Santa Maria* 36(5), 1524-1528.

Mendonça, M.J., Loureiro, P.R.A., Sachsida, A. 2012. The dynamics of land-use in Brazilian Amazon. *Ecological Economics* 84, 23-36.

Merry, F.D., Sheikh, P.A., McGrath, D.G. 2004. The role of informal contracts in the growth of small cattle herds on the floodplains of the Lower Amazon. *Agriculture and Human Values* 21, 377-386.

Mertens, B., Poccard-Chapuis, R., Piketty, M-G., Lacques, A-E., Veturieri, A. 2002. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of São Félix do Xingú in South Pará. *Agricultural Economics* 27, 269-294.

Meyer, P.M., Rodrigues, P.H.M. 2014. Progress in the Brazilian cattle industry: an analysis of the Agricultural Censuses database. *Animal Production Science* 54, 1338-1344.

Minervino, A.H.H., Cardoso, E.C., Ortolani, E.L. 2008. Caraterísticas do sistema produtivo da pecuária no minicípio de Santarém, Pará. *Acta Amazonica* 38(1), 11-16.

Nascimento, A.C.C., de Lima, J.E., Braga, M.J., Nascimento, M., Gomes, A.P. 2012. Eficiência técnica da atividade leiteira em Minas Gerais: uma aplicação de regress quantílica. *Revista Brasileira de Zootecnia* 41(3), 783-789.

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., CiGiano, M., Shimada, J., Seroa da Motta, R., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O., Hess, L. 2014. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science* 344(6188), 1118-1123.

Newton, P., Alves-Pinto, H.N., Guedes Pinto, L.F. 2014. Crtification, Forest Conservation, and Cattle: Theories and Evidence of Change in Brazil. *Conservation Letters* 8(3), 206-213.

Nicoloso, R.S., Lanzanova, M.E., Lovato, T. 2006. Winter pastures management and productive potential of mixed systems in Rio Grande do Sul State, Brazil. *Ciiencia Rural, Santa Maria* 36(6), 1799-1805.

Oaigen, R.P., Barcellos, J.O.J., Canozzi, M.E.A., Soares, J.C.R., Canellas, L.C., Alves, C.O., Tavares, H.R., da Costa, F.M. 2013. Interregional competitiveness of the bee cattle production system. *Ciência Rural, Santa Maria* 43(8), 1489-1495.

Oviedo-Pastrana, M.E., Moura, A.C.M., Socarrás, T.J.O., Haddad, J.P.A. 2014. Mapa do desenvolvimento da pecuária leiteira no estado de Minas Gerais, Brasil: nova abordagem na pecuária para integração especial de variáveis produtivas. *Arq. Bras. Med. Vet. Zootec.* 66(4), 1147-1154.

Pacheco, P. 2012. Actor and frontier types in the Brazilian Amazon: Assessing interactions and outcomes associated with frontier expansion. *Geoforum* 43, 864-874.

Palermo, G.C., d'Avignon, A.L.A., Vasconcelos Freitas, M.A. 2014. Reduction of emissions from Brazilian cattle raising and the generation of energy: Intensification and confinement potentials. *Energy Policy* 68, 28-38.

Polaquini, L.E.M., de Souza, J.G., Gebara, J.J. 2006. Transformações técnico-produtivas e comerciais na pecuária de corte brasileira a partir da década de 90. *Revista Brasileira de Zootecnia* 35(1), 321-327.

Portela, J.N., Viégas, J., Neumann, P.S., Silva Neto, B., Laurentino, L.D. 2002. Economic analysis of production system of dairy cattle farms in central Rio Grande do Sul, Brazil. *Ciência Rural, Santa Maria* 32(5), 855-861.

Porto, R.G., Bezerra, A.J.A., Porto, V.H.F., Caldas, N.V. 2010. Pecuária Familiar: a emergiencia de uma categoria social no Sul do Brasil. *RESR, Piracicaba* 48(2), 473-494.

Rodrigues, D.M.T., Miziara, F. 2008. Expansão da fronteira agrícola: a intensificação da pecuária bovina no estado de Goiás. *Pesquisa Agropecuária Tropical* 38(10), 14-20.

Ruviaro, C.F., da Costa, J.S., Florindo, T.J., Rodrigues, W., Bom de Medeiros, G.I., Vasconcelos, P.S. 2016. Economic and environmental feasibility of beef production in different feed management systems in the Pampa biome, southern Brazil. *Ecological Indicators* 60, 930-939.

Salton, J.C., Mercante, F.M., Tomazi, M., Zanatta, J.A., Concenço, G., Silva, W.M., Retore, M. 2014. Integrated crop-livestock system in tropical Brazil: Toward a sustainable production system. *Agriculture, Ecosystems and Environment* 190, 70-79.

Sarmento, C.M.B., Veiga, J.B., Rischkowsky, B., Kato, O.R., Siegmund-Schultze, M. 2010. Characterization and evaluation of pastures and cattle at smallholder agriculturalists in northeast Pará State, Brazil. *Acta Amazonica* 40(3), 415-424.

Siegmund-Schultze, M., Rischkowsky, B., da Veiga, J.B., King, J.M. 2007. Cattle are cash generating assets for mixed smallholder farms in the Eastern Amazon. *Agricultural Systems* 94, 738-749.

Silva, R.O., Barioni, L.G., Albertini, T.Z., Eory, V., Topp, C.F.E., Fernandes, F.A., Moran, D. 2015. Developing a nationally appropriate mitigation measure from the greenhouse gas GHG abatement potential from livestock production in the Brazilian Cerrado. *Agricultural Systems* 140, 48-55.

Sistema Integrado de Gestão Ambiental – São Paulo (SIGAM-SP). 2016. http://www.sigam.ambiente.sp.gov.br/sigam3/ (accessed October 2016).

Soares, E.M., de Quadros, F.L.F., de Carvalho, R.M.R., de Oliveira, L.B., Jochims, F., Dutra, G.M., Fernandes, A.M., Trindade, J.P.P., Ilha, G.F. 2015. Beef heifers performance in natural grassland under continuous and rotational grazing in the autumn-winter. *Ciência Rural, Santa Maria* 45(10), 1859-1864.

Stickler, C.M., Nepstad, D.C., Azevedo, A.A., McGrath, D.G. 2013. Defending public interests in private lands: compliance, costs and potential environmental consequences of the Brazilian Forest Code in Mato Grosso. *Philosophical Transactions of the Royal Society B* 368, 20120160.

Tinini, R.C.R., Zambom, M.A., Pozza, M.S.S., Fernandes, T., Castagnara, D.D., Radis, A.C., dos Santos, G.T., Defante, L. 2015. Technical assistance and seasonality in the diet and production of dairy herds in household agriculture of Western Parana. *Revista Brasileira de Zootecnia* 44(2), 67-75.

Valente, L.C.M., de Souza, E.C., do Vale, S.M.L.R., Braga, M.J. 2012. Relação entre gastos preventivos e com tratamento: levantamento da situação em fazendas produtoras de leite de Minas Gerais, Brasil. *Revista Brasileira de Zootecnia* 41(1), 212-220.

Viana, J.G.A., Zen, B., Karlec, F., de Souza, R.S. 2009. Behavior of historical prices of milk in Rio Grande do Sul, Brazil. *Ciência Agrotecnica, Lavras* 34(2), 451-460.

Walker, R., Moran, E., Anselin, L. 2000. Deforestation and Cattle Ranching in the Brazilian Amazon: External Capital and Household Processes. *World Development* 28(4), 683-699.

Appendix 3 – Focus group questions for farmers and agronomists

Questions for agronomists

1. What is more important for productivity – capital investments or technical knowledge?
    a. How does technical knowledge affect productivity?

2. What are the most important land characteristics for cattle production?

3. What laws and regulations aid or slow land use change by landowners?

4. Development in the Cantareira region is affected by real estate speculation and proximity to São Paulo. Where does this impact occur? Close to urban areas, or on old properties with low productivity that are more likely to be sold?

5. How do agricultural activities change spatially in the region? Do neighbors typically practice the same types of agriculture as their neighbors? What affects these decisions (e.g., land characteristics, culture, something else)?

6. Why do people become cattle producers in this region?

7. What types of production occur on rural properties in the region – is it family agriculture or does it depend on hired labor?

8. What are the challenges to selling products in the market?

9. What investments are needed for milk production in the region? How is this different from beef production?

10. What agricultural activity has the greatest variation in revenue? How stable are market prices for beef/milk and other products?
    a. Sometimes producers shift from milk to beef and back. What is the reason for these shifts?

11. How do property owners pay for improvements or for emergencies? Are loans available? Or government support?

12. Are cattle sold during financial difficulties? How often does this occur?

Questions for farmers

1. What are the motivations for people to work with cattle in the region?

2. What factors affect productivity in the region?

3. What are the most important characteristics of land for cattle production?

4. What factors determine agricultural activities in the region (e.g., distance to market)?
    a. Do neighbors practice the same types of agriculture? What affects this? Is is culture, history, land characteristics, or something else?

5. What three factors have the greatest impact on income from agriculture?

6. How stable are market prices for beef and milk?

7. What financial investments are needed for milk production?

8. What are the challenges for selling your products in the market?

9. How do landowners pay for improvements or emergencies? Are loans available? Or government support?

10. How do government policies affect annual income on your property? What policies have the greatest impact? Are they federal, state, or municipal policy?

11. Are cattle sold during financial difficulties? How often does this occur?

Is robbery of cattle or products common? Have you or a neighbor experienced this?

Appendix 4 – Distribution of direct and inferred valuation responses

Group No.	Set	No.	Years	Payment	Restoration	Voisin	Direct Choice (%)	Inferred Choice (%)
1	11	11A	20	350	15	0	22.5	23.1
1	11	11B	10	250	20	1	26.5	25.6
1	11	11C	0	0	0	0	51.0	51.3
1	12	12A	5	250	5	1	63.3	43.6
1	12	12B	20	150	15	0	10.2	25.6
1	12	12C	0	0	0	0	26.5	30.8
1	13	13A	5	150	15	0	14.3	20.5
1	13	13B	10	250	20	1	30.6	25.6
1	13	13C	0	0	0	0	55.1	53.8
1	14	14A	10	250	15	0	16.3	30.8
1	14	14B	20	150	5	1	44.9	33.3
1	14	14C	0	0	0	0	38.8	35.9
1	15	15A	10	150	20	0	8.2	23.1
1	15	15B	5	350	15	1	40.8	20.5
1	15	15C	0	0	0	0	51.0	56.4
1	16	16A	20	150	5	0	24.5	30.8
1	16	16B	5	250	20	1	28.6	25.6
1	16	16C	0	0	0	0	46.9	43.6
2	21	21A	20	350	20	1	28.3	29.2
2	21	21B	5	250	5	0	32.6	51.2
2	21	21C	0	0	0	0	39.1	19.5
2	22	22A	20	150	20	0	15.2	21.9
2	22	22B	10	350	15	1	43.5	43.9
2	22	22C	0	0	0	0	41.3	34.1
2	23	23A	5	250	20	0	17.4	26.8
2	23	23B	10	350	5	1	56.5	61.0
2	23	23C	0	0	0	0	26.1	12.2
2	24	24A	10	350	20	1	28.3	29.3
2	24	24B	5	250	15	0	17.4	34.1
2	24	24C	0	0	0	0	54.3	36.6
2	25	25A	5	350	5	1	54.3	63.4
2	25	25B	10	150	15	0	15.2	21.9
2	25	25C	0	0	0	0	30.4	14.6

Group No.	Set	No.	Years	Payment	Restoration	Voisin	Direct Choice (%)	Inferred Choice (%)
2	26	26A	10	150	15	1	37.0	36.6
2	26	26B	5	350	20	0	17.4	26.8
2	26	26C	0	0	0	0	45.6	36.6
3	31	31A	10	250	5	0	31.3	31.6
3	31	31B	20	350	15	1	25.0	43.9
3	31	31C	0	0	0	0	43.7	24.5
3	32	32A	20	250	15	0	16.7	19.3
3	32	32B	5	150	5	1	35.4	50.9
3	32	32C	0	0	0	0	47.9	29.8
3	33	33A	20	250	5	0	31.2	33.3
3	33	33B	10	350	15	1	25.0	40.4
3	33	33C	0	0	0	0	43.8	26.3
3	34	34A	10	350	5	0	39.6	42.1
3	34	34B	5	150	20	1	12.5	24.6
3	34	34C	0	0	0	0	47.9	33.3
3	35	35A	5	150	5	1	29.2	52.6
3	35	35B	20	250	20	0	16.7	17.6
3	35	35C	0	0	0	0	54.1	29.8
3	36	36A	20	250	5	1	31.3	49.1
3	36	36B	5	350	15	0	18.7	22.8
3	36	36C	0	0	0	0	50.0	28.1
4	41	41A	20	350	20	1	30.4	26.9
4	41	41B	10	150	5	0	41.3	40.4
4	41	41C	0	0	0	0	28.3	32.7
4	42	42A	10	350	5	0	41.3	48.1
4	42	42B	5	150	20	1	23.9	25.0
4	42	42C	0	0	0	0	34.8	26.9
4	43	43A	20	350	5	0	45.7	40.4
4	43	43B	10	150	15	1	30.4	34.6
4	43	43C	0	0	0	0	23.9	25.0
4	44	44A	20	250	5	1	45.7	44.2
4	44	44B	5	350	20	0	28.3	25.0
4	44	44C	0	0	0	0	26.1	30.8
4	45	45A	20	250	15	1	30.4	30.8

Group No.	Set	No.	Years	Payment	Restoration	Voisin	Direct Choice (%)	Inferred Choice (%)
4	45	45B	5	150	20	0	21.7	21.2
4	45	45C	0	0	0	0	47.8	48.1
4	46	46A	5	250	15	1	32.6	34.6
4	46	46B	10	350	20	0	26.1	23.1
4	46	46C	0	0	0	0	41.3	42.3

Appendix 5 – Socioeconomic and property characteristics of farmers, split by selection of at least one contract in the direct valuation section.

	Contract-selecting Farmers		Status Quo Farmers	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Gender (proportion male)	0.84	--	0.846	--
Age (years)	53.93	13.5	55	14.46
Education (years)	7.51	5.27	7.89	6.23
Household Size	4.3	3.93	3.62	3.22
No. children/retired	1.62	1.72	1.72	1.78
Monthly income[14]				
<1	0.04	--	0.102	--
1-3	0.493	--	0.513	--
4-10	0.367	--	0.231	--
>10	0.1	--	0.154	--
Off-farm income (%)	55.41	37.25	72.89	36.52
Hectares	45.48	66.57	28.57	31.72
Spring Density (no./ha)	0.127	0.21	0.09	0.116
River Density (meters/ha)	26.16	36.92	46.77	100.27
Pasture Cover (%)	65.67	26.8	63.26	24.9
Forest Cover (%)	15.51	14.51	18.10	18.61
Area with slope >30°				
<30%	69.33	--	69.23	--
30-60%	16	--	17.95	--
60-90%	10.67	--	10.26	--
>90%	4	--	2.56	--

[14] Categories relative to monthly minimum wage, R$788 (approx. US$230)

Appendix 6 – Log-likelihood, AIC, and BIC values for mixed logit models (Note: 50 Halton draws)

Model	Log-likelihood	AIC	BIC
ContractVars			
ContractVars*RestTotal*RestImpact*PayRest*LegalMax	-772.43	1578.86	1683.1
ContractVars*RestTotal*RestImpact*PayRest	-754.28	1538.55	1630.53
ContractVars*RestTotal*RestImpact	-750.55	1527.11	1606.83
ContractVars*RestTotal*PayRest	-753.36	1532.72	1612.43
ContractVars*RestImpact*PayRest	-746.29	1518.59	1598.31
ContractVars*RestTotal	-765.86	1553.72	1621.18
ContractVars*RestImpact	-749.28	1520.56	1588.01
ContractVars*PayRest	-751.77	1525.54	1592.99
ContractVars*RestTotal*RestImpact*LegalMax	-739.63	1509.26	1601.24
ContractVars*RestTotal*PayRest*LegalMax	-745.29	1520.59	1612.57
ContractVars*RestTotal*LegalMax	-748.77	1523.53	1603.25
ContractVars*RestImpact*LegalMax	-748.72	1523.44	1603.16
ContractVars*PayRest*LegalMax	-744.67	1515.34	1595.05
ContractVars*LegalMax	-745.15	1530.29	1597.75
ContractVars*RelFenceValue*AbsFenceValue*FencePotential	-754.25	1538.49	1630.47
ContractVars*AbsFenceValue*FencePotential	-751.37	1528.74	1608.46
ContractVars*RelFenceValue*FencePotential	-773. 38	1572.76	1652.48
ContractVars*RelFenceValue*AbsFenceValue	-741.01	1508.02	1587.74
ContractVars*RelFenceValue	-750.32	1522.64	1590.09
ContractVars*AbsFenceValue	-754.77	1531.54	1598.99
ContractVars*FencePotential	-752.59	1527.18	1594.63
ContractVars*RelFenceValue*AbsFenceValue*FencePotential *RestTotal*RestImpact*PayRest*LegalMax	-734.00	1514.00	1655.05

REFERENCES

Adamowicz, W., Louviere, J., Swait, J. 1998a. *Introduction to attribute-based stated choice methods*. Report to the NOAA/US Department of Commerce, 47pp.

Adamowicz, W., Boxall, P., Williams, M., Louviere, J. 1998b. Stated preference approaches for measuring passive use values: choice experiments and contingent valuation. *American Journal of Agricultural Economics* 80(1), 64-75.

Agência Nacional de Águas, 2011. *Cuidando das águas: soluções para melhorar a qualidade dos recursos hídricos.* Programa das Nações Unidas para o Meio Ambiente, Brasilia.

Aide, T. M., Clark, M. L., Grau, H. R., López-Carr, D., Levy, M. A., Redo, D., ... & Muñiz, M. (2013). Deforestation and reforestation of Latin America and the Caribbean (2001–2010). *Biotropica*, 45(2), 262-271.

Arrigiada, R.A., Ferraro, P.J., Pattanayak, S., Sills, R.E., Cordero, S., 2012. Do Payments for Environmental Services Reduce Deforestation? A farm-level evaluation from Costa Rica. *Land Economics* 88, 382-399.

Assunção, J., Gandour, C., Rocha, R., Rocha, R. 2013. *Does Credit Affect Deforestation? Evidence from a Rural Credit Policy in the Brazilian Amazon*. Technical Report, Climate Policy Initiative, Rio de Janeiro, 50 pp.

Balvanera, P., Uriarte, M., Almeida-Leñero, L., Altesor, A., DeClerck, F., Gardner, T., Hall, J., Lara, A., Laterra, P., Peña-Claros, M., Silva Matos, D.M., Vogl, A.L., Romero-Duque, L.P., Arreola, L.F., Caro-Borrero, A.P., Gallego, F., Jain, M., Little, C., de Oliveira Xavier, R., Paruelo, J.M., Peinado, J.E., Poorter, L., Ascarrunz, N., Correa, F., Cunha-Santino, M.B., Hernández-Sánchez, A.P., Vallejos, M. 2012. Ecosystem services research in Latin America: The state of the art. *Ecosystem Services* 2, 56-70.

Banks-Leite, C., Pardini, R., Tambosi, L.R., Pearse, W.D., Bueno, A.A., Bruscagin, R.T., Condez, T.H., Dixo, M., Igari, A.T., Martensen, A.C., Metzger, J.P., 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science* 345 (6200), 1041-1045.

Barbosa, W.F., de Sousa, E.P., Amorim,.L., Coronel, D.A. 2013. Eficiência técnica da agropecuária nas microrregiões brasileiras e seus determinantes. *Ciência Rural, Santa Maria* 43(11), 2115-2121.

Bennett, G., Ruef, F., 2016. *Alliances for Green Infrastructure: State of Watershed Investment 2016*. Forest Trends, Washington, DC, Available online at: http://www.forest-trends.org/documents/files/doc_5463.pdf.

Bennett, G., Carroll, N., Hamilton, K. 2013. *Charting New Waters: State of Watershed Payments 2012*. Washington, DC: Forest Trends. Available online at http://www.ecosystemmarketplace.com/reports/sowp2012

Borges, J.A.R., Lansink, A.G.J.M.O. 2015. Comparing groups of Brazilian cattle farmers with different levels of intention to use improved natural grassland. *Livestock Science* 178, 296-305.

Brancalion, P.H.S., Schweizer, D., Gaudare, U., Mangueira, J.R., Lamonato, F., Farah, F.T., Nave, A.G., Rodrigues, R.R. 2016. Balancing economic costs and ecological outcomes of passive and active restoration in agricultural landscapes: the case of Brazil. *Biotropica* 48(6), 856-867.

Brancalion, P.H.S., Garcia, L.C., Loyola, R., Rodrigues, R.R., Pillar, V.D., Lewinsohn, T.M. 2016. A critical analysis of the Native Vegetation Protection Law (2012): updates and ongoing initiatives. *Natureza & Conservação* 14S, 1-15. http://dx.doi.org/10.1016/j.ncon.2016.03.003

Brancalion, P.H.S., Viani, R.A.G., Strassburg, B.B.N., Rodrigues, R.R. 2012. Finding money for tropical forest restoration. *Unasylva* 63, 25-34.

Bremer, L.L., Auerbach, D.A., Goldstein, J.H., Vogl, A.L., Shemie, D., Kroeger, T., Nelson, J.L., Benítez, S.P., Calvache, A., Guimarães, J. Herron, C. 2016. One size does not fit all: Natural infrastructure investments within the Latin American Water Funds Partnership. *Ecosystem Services* 17, 217-236.

Carlsson, R., Frykblom, P., Lagerkvist, C.J. 2005. Using cheap talk as a test of validity in choice experiments. *Economics Letters* 89(2), 147-152.

Chazdon, R. 2008. Beyond deforestation: Restoring Forests and Ecosystem Services on Degraded Lands. *Science* 320, 1458.

Chen, X., Lupi, F., He, G., Liu, J. 2009. Linking social norms to conservation investment in payments for ecosystem services. *Proceedings of the National Academy of Sciences of the USA* 106, 11812-11817.

Dean, W. 1997. *With Broadax and Firebrand: the Destruction of the Brazilian Atlantic Forest*. Univ of California Press.

de Brito, M.M., Bánkuti, F.I., Schiavi Bánkuti, S.M., Melo Ferreira, M.C., Damasceno, J.C., dos Santos, G.T., Zambom, M.A. 2015. Horizontal arrangements: strategy for reducing the asymmetry information for dairy farmers in Paraná, Brazil. *Ciência Rural* 45(11), 2069-2075.

de Oliveira, J.B. 1999. Mapa pedológico do Estado de São Paulo: Legenda expandida. IAC/Embrapa, Campinas/Rio de Janeiro.

Dill, M.D., Emvalomatis, G., Saatkamp, H., Rossi, J.A., Pereira, G.R., Jardim Barcellos, J.O. 2015. Factors affecting adoption of economic management practices in beef cattle production in Rio Grande do Sul state, Brazil. *Journal of Rural Studies* 42, 21-28.

Diniz, F.H., Hoogstra-Klein, M.A., Kok, K., Arts, B. 2013. Livelihood Strategies in settlement projects in the Brazilian Amazon: Determining drivers and factors within the Agrarian Reform Program. *Journal of Rural Studies* 32, 196-207.

Ditt, E.H., Knight, J.D., Mourato, S., Padua, C.V., Martins, R.R., Ghazoul, J. 2008. Defying legal protection of Atlantic Forest in the transforming landscape around the Atibainha reservoir, south-eastern Brazil. *Landscape and Urban Planning* 86, 276-283.

Engel, S., Pagiola, S., Wunder, S. 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics* 65(4), 663-674.

Ferraro, P.J. 2008. Asymmetric information and contract design for payments for environmental services. *Ecological Economics* 65, 810-821.

Ferraro, P. J., Kiss, A. 2002. Direct payments to conserve biodiversity. *Science* 298 (5599), 1718-1719.

Freitas S.R., Hawbaker, T.J., Metzger, J.P. 2010. Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. *Forest Ecology and Management* 259(3), 410–417.

Garcia, L.C., Silveira dos Santos, J., Matsumoto, M., Silva, T.S.F., Padovezi, A., Sparovek, G., Hobbs, R.J., 2013. Restoration Challenges and Opportunities for Increasing Landscape Connectivity under the New Brazilian Forest Act. *Natureza & Conservação* 11 (2), 1-5.

Government of Brazil. 2006. *Lei N^o 11.236 - Estabelece as diretrizes para a formulação da Política Nacional da Agricultura Familiar e Empreendimentos Familiares Rurais*.

Available at http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11326.htm (last accessed January 2017).

Guedes, F.B., Seehusen, S.E. (eds.) 2011. *O PSA na Mata Atlântica – Situação Atual, Desafios e Recomendações*. Ministério do Meio Ambiente, Brasília.

Guanziroli, C., Buainain, A., Sabbato, A. 2013. Family farming in Brazil: evolution between the 1996 and 2006 agricultural censuses. *The Journal of Peasant Studies* 40(5): 817-843.

Hercowitz, M., Figueiredo, G.R. 2011. Teste de viabilidade do uso de reverse auction como mecanismo para pagamentos por serviços ambientais. Produto Técnico No. 04, Projeto de Recuperação de Matas Ciliares. São Paulo: Secretaria do Meio Ambiente, 80p.

Hirakuri, S. 2003. *Can Law Save the Forest? Lessons from Finland and Brazil*. CIFOR, Indonesia, 131 p.

Hole, A.R. 2007. Fitting mixed logit models by using maximum simulated likelihood. *The Stata Journal* 7(3), 388-401.

Holl, K.D. 2017. Restoring tropical forests from the bottom up. *Science* 355(6324), 455-456.

Holl, K.D., Aide, T.M. 2011. When and where to actively restore ecosystems? *Forest Ecology and Management* 261, 1558-1563.

Hostiou, N., Cialdella, N., Vazquez, V., Müller, A.G., Le Gal, P-Y. 2015. Work organization on smallholder dairy farms: a process unique to each farm. *Tropical Animal Health Production* 47, 1271-1278.

Instituto Brasileiro de Geografia e Estatística (IBGE). 2016. http://www.ibge.gov.br/english/. Accessed April 2016.

Instituto Brasileiro de Geografia e Estatística (IBGE). 2010. *Censo 2010.* Available at: http://censo2010.ibge.gov.br/ Accessed 10 June 2016.

Instituto Nacional de Pequisas Espaciais (INPE) and Fundação SOS Mata Atlântica. 2015. *Atlas da Mata Atlântica*. https://www.sosma.org.br/projeto/atlas-da-mata-atlantica/dados-mais-recentes/. Accessed October 2016.

IUCN-Global Partnership on Forest Landscape Restoration (IUCN-GPFLR). 2014. *Bonn Challenge*. Available at http://www.bonnchallenge.org/content/challenge Accessed March 2017.

Jayachandran, S., de Laat, J., Lambin, E.F., Stanton, C.Y. 2016. Cash for Carbon: A Randomized Controlled Trial of Payments for Ecosystem Services to Reduce Deforestation. *NBER Working Paper No. 22378*, 64 pp.

Kaczan, D., Swallow, B.M., Adamowicz, W.L. 2013. Designing a payments for ecosystem services (PES) program to reduce deforestation in Tanzania: An assessment of payment approaches. *Ecological Economics* 95: 20-30.

Kfouri, A., Favero, F. 2011. *Projeto Conservador das Águas Passo a Passo: Uma Descrição Didática sobre o Desenvolvimento da Primeira Experiência de Pagamento por uma Prefeitura Municipal no Brasil*. Série Água, Clima e Floresta. Vol. 4. The Nature Conservancy, Brasília, 60pp.

Landell-Mills, N. and I. Porras. 2002. *Silver Bullet or Fool's Gold? A Global Review of Markets for Forest Environmental Services and Their Impact on the Poor*. London: International Institute for Environment and Development. 272pp.

Laurance, W.F., Albernaz, A.K.M., Schroth, G., Fearnside, P.M., Bergen, S., Venticique, E.M., da Costa, C. 2002. Predictors of deforestation in the Brazilian Amazon. *Journal of Biogeography* 29, 737-748.

McFadden, D. L. 1974. Conditional logit analysis of qualitative choice behavior. In *Frontiers in Econometrics*, P. Zarembka (ed.), 105-142. Academic Press: New York.

Meli, P., Holl, K.D., Benayas, J.M.R., Jones, H.P., Jones, P.C., Montoya, D., Mateos, D.M. 2017. A global review of past land use, climate, and active vs. passive restoration effects on forest recovery. *PLoS ONE* 12(2), e0171368.

Melo, F.P.L., Pinto, S.R.R., Brancalion, P.H.S., Castro, P.S., Rodrigues, R.R., Aronson, J., Tabarelli, M. 2013. Priority setting for scaling-up tropical forest restoration projects: Early lessons from the Atlantic Forest Restoration Pact. *Environmental Science & Policy* 33, 395-404.

Mendes, R.E. 2006. Financial impact of tracking systems in the bovine production in the State of Santa Catarina, Brazil. *Ciência Rural, Santa Maria* 36(5), 1524-1528.

Merry, F.D., Sheikh, P.A., McGrath, D.G. 2004. The role of informal contracts in the growth of small cattle herds on the floodplains of the Lower Amazon. *Agriculture and Human Values* 21, 377-386.

Michalski, F., Metzger, J.P., Peres, C.A. 2010. Rural property size drives patterns of upland and riparian forest retention in a tropical deforestation frontier. *Global Environmental Change* 20(4), 705-712.

Molin, P.G., Gergel, S.E., Soares-Filho, B.S., Ferraz, S.F.B. 2017. Spatial determinants of Atlantic Forest loss and recovery in Brazil. *Landscape Ecology* 32(4), 857-870.

Molin, P.G., de Souza e Miranda, F.T., Sampaio, J.V., Fransozi, A.A., Ferraz, S.F.B. 2015. *Mapeamento de uso de solo e cobertura do solo da bacia do rio Piracicaba, SP: Anos 1990, 2000, e 2010*. Circular tecnica/Instituto de Pesquisas e Estudos Florestais no. 207. Available at http://www.ipef.br/publicacoes/ctecnica/nr207.pdf

Moreno-Fernández, D., Cañellas, I., Bareito, I., Sánchez-González, M., Ledo, A. 2015. Alternative approaches to assessing the natural regeneration of Scots pine in a Mediterranean forest. *Annals of Forest Science* 72, 569-583.

Morrison, A., Aubrey, W. 2010. *Payments for Ecosystem Services Literature Review: A review of lessons learned and a framework for assessing PES feasibility* 28(1), 69-92.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853-858.

NASA, METI. 2011. ASTER GDEM. Sioux Falls, South Dakota. https://lpdaac.usgs.gov/data_access. Accessed 10 Dec 2014

Nobre, C.A., Marengo, J.A., Seluchi, M.E., Cuartas, L.A., Alves, L.M. 2016. Some characteristics and impacts of the drought and water crisis in Southeastern Brazil during 2014 and 2015. *Journal of Water Resource and Protection* 8, 252–262. doi:10.4236/jwarp.2016.82022

Packer, L.A. 2015. *Novo Código Florestal & Pagamentos por Serviços Ambientais: Regime Proprietário sobre os Bens Comuns*. Juruá: Curitiba. 268 pp.

Padovezi, A., Viani, R.A.G., Kubota, U., Taffarello, D., Faria, M., Bracale, H., Ferrari, V., de Carvalho, F.H. 2012. *O Projeto Produtor de Água na bacia hidrográfica PCJ em São Paulo, Brasil*. World Bank, Washington.

Pagiola, S., von Glehn, H.C., Taffarello, D. 2013. *Experiências de pagamentos por serviços ambientais no Brazil*. Secretaria do Meio Ambiente – Coordenadoria de Biodiversidade e Recursos Naturais, São Paulo.

Pagiola, Stefano. 2008. Payments for Environmental Services in Costa Rica. *Ecological Economics* 65(4), 712–724.

Pagiola, S., Arcenas, A., Platais, G. 2005. Can Payments for Environmental Services Help Reduce Poverty? An Exploration of the Issues and the Evidence to Date From Latin America. *World Development*, 33(2), 237-253.

Pattanayak, S.K., Wunder, S., Ferraro, P.J. 2010. Show me the money: Do payments supply environmental services in developing countries? Review of Environmental Economics and Policy, 4(2), 1–21.

Pereira, P.H., Cortez, B., Trindade, T., Mazochi, M.N., 2010. *Conservador das Águas: 5 Anos.* Extrema: Departamento de Meio Ambiente de Extrema. Extrema-MG.

Pinto, S.R., Melo, F., Tabarelli, M., Padovezi, A., Mesquita, C.A., Scaramuzza, C.A.M., Castro, P., Corrascosa, H., Calmon, M., Rodrigues, R., César, R.G., Brancalion, P.H.S. 2014. Governing and Delivering a Biome-Wide Restoration Initiative: The Case of Atlantic Forest Restoration Pact in Brazil. *Forests* 5, 2212-2229.

Porto, M., Kelman, J., 2000.Water Resources Policy in Brazil. *Rivers* 7 (3), 250-257.

Quezada, M.L., Arroyo-Rodríguez, V., Pérez-Silva, E., Aide, T.M. 2014. Land cover changes in the Lachuá region, Guatemala: patterns, proximate causes, and underlying driving forces over the last 50 years. *Regional Environmental Change* 14(3), 1139-1149.

Rabe-Hesketh, S., Skrondal, A., Pickles, A. 2005. Maximum likelihood estimation of limited and discrete dependent variable models with nested random effects. *Journal of Econometrics* 128, 301-323.

Rezende, C.L., Uezu, A., Scarano, F.R., Araujo, D.S.D. 2015. Atlantic Forest spontaneous regeneration at landscape scale. *Biodiversity Conservation* 24, 2255-2272.

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M. 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation* 142(6): 1141-1153.

Richards, R.C., Rerolle, J., Aronson, J., Pereira, P.H., Gonçalves, H., Brancalion, P.H.S. 2015. Governing a pioneer program on payment for watershed services: Stakeholder involvement, legal frameworks and early lesson from the Atlantic Forest of Brazil. *Ecosystem Services* 16, 23-32.

Robalino, J.A., Pfaff, A.S.P. 2013. Ecopayments and Deforestation in Costa Rica: a Nationwide Analysis of PSA's Initial Years. *Land Economics*, 89(3):432-448.

Rodrigues, R. R., Gandolfi, S., Nave, A.G., Aronson, J., Barreto, T.E., Vidal, C.Y., Brancalion, P.H.S. 2011. Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest Ecology and Management 261, 1605–1613.

Rodrigues, R.R., Gandolfi, S., 2007. Restoration actions. In: Rodrigues, R.R., Martins, S.V., Gandolfi, S. (Eds.), *High Diversity Forest Restoration in Degraded Areas*. Nova Science Publishers, New York, pp. 77–101.

Rose, J.M., Bleimer, M.C.J. 2009. Constructing Efficient Stated Choice Experimental Designs. *Transportation Systems* 29(5), 587-617.

Rudel, T.K., Coomes, O.T., Moran, E., Achard, F., Angelsen, A., Xu, J., Lambin, E. 2005. Forest transitions: towards a global understanding of land use change. *Global Environmental Change* 15, 23-31.

São Paulo Environment Secretariat. 2015. Projeto de Pagamento por Serviços Ambientais Mina D'Água. http://www.ambiente.sp.gov.br/municipioverdeazul/files/2016/07/Projeto-de-Pagamento-por-Servi%C3%A7os-Ambientais-Mina-D%C2%B4%C3%81gua-Piracaia.pdf (Accessed December 2007).

São Paulo State Agricultural Extension Service. 2008. *Levantamento Censitário das Unidades de Produção Agropecuária do Estado de São Paulo – LUPA*. http://www.cati.sp.gov.br/projetolupa/ (In Portuguese. Accessed November 2016).

Sills, E., Arriagada, R., Ferraro, P., Pattanayak, S., Carrasco, L., Ortiz, E., Cordero, S., Caldwell, K., Andam. K. 2008. *Impact of Costa Rica's Program of Payments for Environmental Services on Land Use*. PES Learning Paper 2008-3. Washington: World Bank.

Sloan, S., Sayer, J. A. 2015. Forest Resources Assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. *Forest Ecology and Management*, 352, 134-145.

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., Alencar, A., 2014. Cracking Brazil's Forest Code. *Science* 344, 363-364.

Sparovek, G., Berndes, G., Giaroli de Oliveira Pereira Barretto, A., Klug, I.L.F. 2012. The revision of the Brazilian Forest Act: increased deforestation or a historic step towards balancing agricultural development and nature conservation? *Environmental Science & Policy* 16, 65-72.

State Government of São Paulo. 2008. *Levantamento Censitário das Unidades de Produção Agropecuária do Estado de São Paulo*. Available at: http://www.cati.sp.gov.br/projetolupa/ (Accessed 10 August 2016).

Tafarello, D., Mohor, G.S., Calijuri, M.C., Mediondo, E.M. 2016. Field investigations of the 2013-2014 drought through quali-quantitative freshwater monitoring at the headwaters of the Cantareira System, Brazil. *Water Internation* 41(5), 776-800.

The Nature Conservancy-Brasil. 2015. *Produtor de Água no PCJ – Pagamentos por Serviços Ambientais. Lições Aprendidas e Próximos Passos*. São Paulo: The Nature

Conservancy. 80p. http://www.tnc.org.br/quem-somos/publicacoes/produtor-de-agua-pcj-licoes-aprendidas.pdf (Accessed November 2016).

Veiga, L.B.E., Magrini, A., 2013. The Brazilian Water Resources Management Policy: Fifteen Years of Success and Challenges. *Water Resources Management* 27 (7), 2287-2302.

von Glehn, H.C., Taffarello, D., Kamiyama, A., Dalla Vecchia, A.C., Cogueto, C.V. 2012. *O Projeto Mina d'Água em São Paulo*. Payments for Environmental Services (PES) Learning Paper; no. 2012-3. World Bank, Washington.

Whately, M., Cunha, P. 2007. *Cantareira 2006: um olhar sobre o maior manancial de água da Região Metropolitana de São Paulo*. Instituto Socioambiental, São Paulo.

Woltzenlogel, A.A. 1990. *Isoietas de precipitação média anual*. DAEE, Piracicaba.

Wunder, S. 2005. *Payments for environmental services: some nuts and bolts*. CIFOR Occasional Paper no. 42, 24p.

Zanella, M.A., Schleyer, C., Speelman, S. 2014. Why do farmers join Payments for Ecosystem Services (PES) schemes? An Assessment of PES water scheme participation in Brazil. *Ecological Economics* 105:166-176.

BIOGRAPHY

Ryan Clark Richards received his Bachelor of Science in wildlife biology from the University of California, Davis in 2006, and dual Master's degrees in conservation biology and public policy from the University of Maryland-College Park in 2010. He has worked at the Smithsonian Conservation Biology Institute since 2010, and was a Smithsonian-Mason Doctoral Fellow at George Mason University.