Empirical and spatial analysis of tradable permits in private forest conservation

Marta Lisli Ribeiro de Morais Giannichi

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The candidate confirms that the work submitted is his/her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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MLG (the candidate), TRB and GZ conceived the study. MLG, GZ and MD designed the study. MLG collected and analysed the empirical data. MLG wrote the chapter and all co-authors provided critical feedback on the manuscript.

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Abstract

Approximately 40% of the world's ice-free land has lost its original natural habitat cover to other land uses, such as croplands and pastures, which poses major challenges to conservation. Many conservation strategies have been developed to halt or compensate for past or future natural habitat loss, but the effectiveness of such strategies remains poorly understood. This thesis explores how an emerging conservation scheme can result in effective conservation gains. I use The Environmental Reserve Quota (or CRA; Portuguese acronym) within The Brazilian Forest Code as a case study – the largest forest offset scheme in the world. Under this scheme, landowners must offset past deforestation (buyers) by trading hectares of deforested land with landowners who have standing forest available in their properties (sellers). Alternatively, buyers can offset by allowing forest regrowth. By examining the viewpoints of potential buyers and sellers about CRA (Chapter 2), I find sharp divergences related to programme-specific factors that could potentially affect trade, mostly around price expectations and contract length. Next, I combine policy scenarios with potential spatial scales of scheme implementation, to test how scale affects scheme's conservation outcomes (e.g. area directed to avoided deforestation and/or regrowth; Chapter 3), as the scale in which conservation strategies are implemented often affect conservation trade-offs. Allowing offsets to occur within large spatial scales results in greater area of avoided deforestation and only a small area allocated to regrowth, whilst at small spatial scales results in the opposite pattern. However, the greatest total area was directed to conservation when the scheme was implemented at small scales. Finally, I compare the potential environmental co-benefits (e.g. aboveground biomass storage and accumulation and beta-diversity) associated with avoided deforestation and regrowth at large and small spatial scales (Chapter 4) and find that trade-offs between biomass and biodiversity co-benefits are dependent on spatial scale. Whilst large scale might protect biomass-rich forests, small scale protects highly threatened beta-diversity. These results are important for understanding important aspects associated to conservation schemes and their conservation outcomes. It is key that conservation polices account for landowners preferences in the design of schemes as well as the landscape scale in which conservation gains are expected to be delivered, in order to improve conservation effectiveness.

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Abbreviations

AGB – Aboveground Biomass

Bmax – Maximum Biomass Potential

CAR – Cadastro Ambiental Rural (Rural Registry System)

CBD – Convention on Biological Diversity

CRA – Cota de Reserva Ambiental (Environmental Reserve Quota, free translation in English)

FC – Forest Code

GFC – Global Forest Cover

GHG – Greenhouse Gas

Ha – Hectares

LR – Legal Reserve

MBIs – Market-based Instruments

Mha – Million Hectares

MODIS – Moderate Resolution Imaging Spectroradiometer

NDC – Nationally Determined Contribution

MT – Mato Grosso

PA – Protected Area

PCA – Principal Component Analysis

PES – Payment for Ecosystem Services

PR – Protection Ratio

PRODES – Programme for Deforestation Monitoring in the Brazilian Legal Amazon

PS – Policy Scenario

REDD+ - Reduce Emissions from Deforestation and Forest Degradation

SCV – Species Composition Value

TCI – Trade Compatibility Index

TDR – Tradable Development Rights

TR – Threat Ratio

WTA – Willingness to accept

WTP – Willingness to pay

Chapter 1: Introduction

Human land-use activities have been responsible for extensively altering Earth’s surface, converting natural landscapes into human-dominated lands (Foley et al., 2005). Agriculture, for example, covers nearly 40% of the terrestrial ice-free surface (Ramankutty et al., 2008). Globally, such conversion of land for agriculture accounts for approximately 80% of global deforestation, 35% of global greenhouse gas emissions, and threatens 53% of terrestrial species (Tanentzap et al., 2015). In past decades, much of the conversion of natural habitats into agriculture occurred in the tropics (Gibbs et al., 2010). This trend is expected to persist, as global population continues to grow (Tilman et al., 2011), particularly in tropical regions (Laurance et al., 2014). Thus, safeguarding existing natural habitats and avoiding future biodiversity losses is a global priority in the conservation agenda (Godet and Devictor, 2018).

The current debate in conservation science has acknowledged that the most traditional forms of conservation (e.g. protected areas) alone are unlikely to be sufficient to effectively achieve conservation goals. This means that other forms of conservation, such as the protection of private and unprotected land, in particular those subject to agriculture and grazing, must also be part of the conservation agenda (Kareiva, 2014; Soule, 2014; Green et al., 2015). Such debate has supported the emergence of conservation policies and mechanisms that seek to align biodiversity conservation and economic development, often working within the context of a market (Pirard, 2012). Worldwide, these markets have gained popularity and have been implemented under diverse frameworks. For example, there are over 550 Payments for Ecosystem Services (PES) programmes around the world, targeting watershed, biodiversity and forest protection (Salzman et al., 2018). Biodiversity offsetting programmes sums nearly 70 and are most commonly used to mitigate or compensate for development impacts on biodiversity (Sonter et al., 2018). Voluntary carbon markets (Duchelle et al., 2018), tradable development rights (TDR; McConnell and Walls, 2009) and habitat banking (Santos et al., 2014) are other examples of popular Market-based Instruments (MBIs). In general terms, such schemes aim to promote conservation by either rewarding landowners for good environmental practices or compensating past or future environmental impacts. Although widely adopted, there is still limited understanding about the potential of such schemes to achieve conservation goals (Pirard, 2012; Börner et al., 2017) particular of compensatory schemes (Maron et al., 2010; Bull et al., 2013; Gonçalves et al., 2015). Hence, it is of extreme importance to gain a better understanding of how such schemes operate to foster better solutions for conservation.

The aim of this thesis is therefore to assess the effectiveness of offset schemes to deliver conservation goals from independent but interconnected angles, such as the viewpoints and engagement of potential participants, the implementation scale of the scheme and its environmental co-benefits. For instance, are buyers and sellers of offset schemes similarly engaged in participation? What factors associated to the scheme's design are perceived as most important? Will the spatial scale (local, regional, large, small) in which offset schemes are implemented influence conservation gains? What implementation scale will result in the greatest benefits for carbon and biodiversity? To achieve my goal I use the Brazilian Forest Code as a case study, which includes the largest emerging forest offset scheme in the world that requires landowners' to compensate for past deforestation (Soares-Filho et al., 2016). Given the vast amounts of native vegetation inside private land in Brazil, a thorough understanding of this legislation and its potential implications are essential to draw more effective environmental policies that avoid deforestation and biodiversity loss (Soares-Filho et al., 2014; Azevedo et al., 2017). I particularly focus on the Amazon biome, the world's largest intact tropical forest (Watson et al., 2018). The Brazilian Amazon originally covered nearly 400 Mha, but almost one fifth has been deforested (Assunção et al., 2017). In spite of reductions in the deforestation rate since the early 2000s, deforestation has been rising since 2014, making the application of the FC even more urgent (Rochedo et al., 2018).

In this first chapter, I review the literature associated with the current debate on conservation policies and schemes that have a clear market-based component in their rationale and clearly target private land conservation (so-called market-based instruments; MBIs). These schemes are the most similar to the Brazilian forest offset scheme I focus on. I particularly emphasise strategies applied as tradable permits (e.g. biodiversity offsets and TDR) and PES. Such categories of MBIs show more synergies with the chosen case study and their associated empirical evidence guided the main objectives of this study. The aim of this literature review is to develop an overview of how such schemes are implemented in different contexts, in relation to key points for their effectiveness as conservation strategies, such as the participation of landowners (Sorice et al., 2013) and the provisioning of conservation gains (Gibbons and Lindenmayer, 2007; Maron et al., 2013). From the literature, I derive knowledge gaps that each data chapter aims to answer. Section 1.5 provides the aim and specific objectives of this thesis, followed by the proposed thesis outline. In Section 1.7, I provide details of this thesis case study, the Brazilian Forest Code. In Section 1.8, I briefly describe the methodological approach used and in Section 1.9 I summarise the main data sources used in this research.

Chapters 2, 3 and 4 are presented as three independent but interconnected analytical chapters, that each addresses a unique aspect of the overarching study. Chapter 2 is already published as a jointly authored publication and empirically explores landowners' perceptions of a forest offset scheme, and particularly perceptions around factors associated to the rules of the scheme. In Chapter 3, I test how potential scheme implementation scales can alter conservation outcomes, in terms of the total area directed to avoided deforestation and potential forest regrowth. In Chapter 4, I draw from the results obtained in Chapter 3 to explore carbon-related and biodiversity co-benefits associated with each different implementation scale. Lastly, Chapter 5 provides the research conclusions and discusses the implications of the study.

1.1 Overview of private land conservation schemes

The world has been facing a major environmental crisis, with natural habitat and biodiversity disappearing at unprecedented rates (Hoekstra et al., 2004; Kindsvater et al., 2018). Land conversion to agriculture is behind this environmental crisis, causing climate change, biodiversity and habitat loss, and land degradation (Foley et al., 2011). Although protected areas are a major component of mainstream conservation strategies to halt habitat loss and preserve threatened ecosystems (Joppa et al., 2008), only 13% of the planet's land surface is protected (Geldmann et al., 2013). These protected areas, as a single conservation strategy, are highly important but therefore unlikely to achieve large-scale habitat protection alone (Sorice et al., 2013). Alternatively, private land conservation (i.e. land under the ownership of individuals or non-public entities) has gained much attention in the conservation debate, given its potential to safeguard significant portions of natural habitat (Kamal et al., 2015; Drescher and Brenner, 2018). However, private land has also been subject to intense conversion, mostly to agricultural expansion and intensification (Tanentzap et al. 2015; Song et al., 2018), given the costs of conservation are often higher than a more profitable land-use option (Börner et al., 2010; Banks-Leite et al., 2014).

Private land conservation comes accompanied by a myriad of polices and schemes aimed at avoiding future habitat losses and achieving meaningful conservation benefits (Cooke and Corbo-Perkins, 2018). Most commonly, these policies involve some sort of financial incentive (i.e. a fiscal policy, a subsidy, a reward) or even the creation of a market *per se*, in which environmental goods are traded (Pirard, 2012). Commonly known as MBIs, these environmental markets emerged in 1970s under the assumption that environmental losses and damages are consequences of economic development that are accelerated by agricultural intensification and overexploitation of natural resources. Thus, to avoid a potential failure in the provision of environmental goods, environmental damages had to be compensated (Stavins, 2003). MBIs rapidly gained popularity in the conservation arena, due to the failures of traditional environmental policy (such as protected areas) to reduce the high rate of decline of natural ecosystems (Gómez-Baggethun and Muradian, 2015) and became a highly employed environmental policy tool to promote solutions around biodiversity and habitat loss, climate change, deforestation and water supply (Lapeyre et al., 2015).

Although MBIs vary widely in terms of rationale, institutional arrangements and actors involved, they all share the same key feature, which is to attribute a price to nature and promote change in landowners' behaviour (Pirard, 2012; Lapeyre et al., 2015). Some MBIs for example, such as PES, are leading global policy tools to protect biodiversity and reduce land cover change (Alix-Garcia et al., 2018). In general, PES schemes aim to change landowner behaviour by offering financial rewards for conservation activities that result in the provision, regulation or support of ecosystem services, such as water supply, carbon storage and sequestration, and biodiversity protection (Cimon-Morin et al., 2013). In other MBIs, a regulatory entity sets a limit on a certain activity (habitat development or carbon emissions) and allocates permits amongst landowners or firms who can engage in trade as buyers and sellers (Ring et al., 2010). Such model follows “the polluter pays” principle, in which those causing environmental damage, to be in compliance with regulations, should compensate those who provide environmental goods (Vatn, 2015). Named tradable permits, such conservation policies have been applied in a variety of contexts and are becoming a widespread policy given its ability to provide flexible instruments that can potentially promote conservation whilst allow economic development (Drechsler and Hartig, 2011). Some examples of tradeable permits are voluntary carbon markets (Lockie, 2013); habitat banking (Wissel and Wätzold, 2010; Santos et al., 2014); biodiversity offsets (Alvarado-Quesada et al., 2014); and TDR in urban and rural land use preservation (Pruetz and Standridge, 2009). Schemes such as biodiversity offsets and TDR are typically associated with a regulatory component (e.g. cap-and-trade) controlling compliance that imposes sanctions or penalties if private actors are not liable to environmental regulations (Ring et al., 2010; Vatn, 2015).

In spite of the popularity, the widespread adoption of MBIs has also faced criticism. Firstly, due its strong financial component, some say that it promotes a commodification of nature and a potential erosion of individual’s intrinsic motivation to preserve (McAfee, 2012; Rode et al., 2015). Secondly, many of these schemes have been criticized for achieving poor conservation outcomes despite their substantial funding (Ferraro and Pattanayak, 2006; McDonald et al., 2018). The next sections in this Chapter explore the issues that can potentially undermine their conservation potential. I particularly focus on PES, biodiversity offsets and TDR schemes, which have been employed in different contexts and show clear synergies with the Brazilian forest offset scheme (Chomitz, 2004; McKenney and Kiesecker, 2010; Wissel and Wätzold, 2010; Bull et al., 2013; May et al., 2015).

1.1.1 Payment for Ecosystem Services (PES)

Since its inception two decades ago, PES has become the most popular and widespread conservation tool, with more than 550 programmes around the world (Salzman et al., 2018). By definition, PES is a voluntary transaction between service users (buyers) and service providers (sellers), achieved through land management practises (Wunder, 2015). The services transacted between sellers and buyers encompass several different ecosystems functions and processes that are essential to nature and society, such as pollination, climate and water regulation, nutrient cycling, food production, and aesthetic and educational values (Costanza et al., 2017). Although PES can take different institutional arrangements, which are normally programme-dependent, buyers are often individuals, companies, NGOs, public bodies, and sellers are those who supply ecosystem services – in general, private landowners (Engel et al., 2008).

The growing empirical literature about PES has documented several cases in which schemes were effective both environmentally and socially (Börner et al., 2017). For example, in Mexico, the national PES strategy has contributed to significant improvements in private land cover management activities (Alix-Garcia et al., 2018). In Uganda, the villages enrolled in the national programme showed an increase in tree cover when compared to other non-enrolled villages (Jayachandran et al., 2017). In Mozambique and Mexico, PES programmes have contributed to poverty alleviation and promoted an increase in participants' income (Hegde and Bull, 2011; Sims and Alix-Garcia, 2017). There are some cases, however, that such effectiveness is unclear or absent, as payments did not significantly reduce deforestation (Sanchez-Azofeifa et al., 2007) or had no impact on social welfare (Arriagada et al., 2009). Such heterogeneity, which is observed both at country and local level, might be explained by the participation – or lack of – of motivated buyers and sellers (Salzman et al., 2018).

Given that landowner participation in PES is essentially voluntary, it is crucial to understand what drives and motivates landowners to enrol in such programmes (Sorice et al., 2013). While empirical research on PES participation is limited, there are several studies that investigate factors that influence landowners' decisions to enrol (Bremer et al., 2014). The assessment of factors influencing landowners' participation can be done following two approaches: the assessment of socio-demographic factors and the assessment of programme-specific factors (Kosoy et al., 2008). The first is related to independent and intrinsic landowners' characteristics such as gender, education, and age, which might be important to target specific groups of landowners and promote social equity and fairness (Zabala et al., 2017; Alpízar et al., 2017). The second is related to technicalities and policy specificities of the programme, in which participation is a result of upon the rules the programme imposes (Kosoy et al., 2008). Income, education and farm size appear as highly influential sociodemographic factors, whereas programme-specific factors such as access to information, contract duration and payment value are also important drivers of landowners' decisions to participate (Zbinden and Lee, 2005; Kosoy et al., 2008; Ma et al., 2012; Bremer et al., 2014; Kwayu et al., 2014; Page and Bellotti, 2015).

In spite of its extensive adoption, PES schemes have been criticised for delivering poor conservation outcomes, such as little additionality (i.e. the provision of additional benefits to conservation that would not occur in the absence of the scheme), often targeting areas with low deforestation pressure and low opportunity costs (Muradian et al., 2013). Nevertheless, the overall additionality in PES schemes has been poorly evaluated given the lack of empirical evidence (Pattanayak et al., 2010) and the effectiveness of PES schemes remains inconclusive, as current literature has provided mixed results (Salzman et al., 2018).

1.1.2 Biodiversity offsets

Biodiversity offsets are another MBI that has become increasingly popular in the last decade, due to their potential to align conservation and economic development (Kiesecker et al., 2009). The offsetting approach consists in the compensation for damage or impacts with equivalent biodiversity gains elsewhere (Gordon et al., 2015). The main goal of biodiversity offsets is to ensure that offsets from the impacted site achieve no net loss and preferably a net gain in terms of species composition, habitat structure and ecosystem function (Bull et al., 2013). To achieve such gains, offset policies adopt two main strategies: averted loss, which is the protection of existing habitat, or restoration of degraded habitat (Maron et al., 2012). Although included in the environmental legislation of several countries (i.e. United States, Australia, Brazil and Colombia), biodiversity offsets remain highly controversial (Gordon et al., 2015).

Much of the controversy in biodiversity offsetting policies is associated with implementation issues such as their currency, the spatial location of offsets as well as ecological equivalence and additionality (McKenney and Kiesecker, 2010; Gonçalves et al., 2015). Currency relates to establishing a common metric that could be more easily traded among different locations (e.g. habitat area). Although several metrics have been developed (i.e. involving habitat condition or ecological function), most offset policies that operate at a local level take a case-by-case approach (Bull et al., 2013; Gonçalves et al., 2015). This adds more complexity to the trade, impedes a comparable evaluation of scheme's performance and limits geographical outreach of trade (Bull et al., 2014). The issues around the spatial location of the offsets have been mostly associated with the choice of neighbouring or more distant offsets (McKenney and Kiesecker, 2010). While offsets near the impacted site contribute to the conservation of the same (or very similar) ecosystem, more distant offsets can benefit sites of great biodiversity importance and can be aligned with regional or national conservation goals (Kiesecker et al., 2009; Gordon et al., 2011). In terms of ecological equivalence, it is difficult to ensure that offsets can result in equivalent ecological gains, as unique characteristics of the impacted site cannot be replicated (Quétier and Lavorel, 2011). Since real equivalence may be very unlikely, it is argued that offsets placed near the impacted site might the best solution to reach such ecological equivalence. This shows that both near or distant offsets are likely to have trade-offs that need to be considered in the scheme's design (Bull et al., 2013). Lastly, offsets must ensure additionality, which is the provision of additional benefits to conservation that would not occur in the absence of the scheme (Maron et al., 2013). Unless offsets are placed in areas under imminent threat of biodiversity loss or are achieved via habitat restoration, non-additional offsets can undermine the conservation potential of the scheme (Gonçalves et al., 2015).

Another debated topic in the biodiversity offsets literature is the trade-off between restoration and averted loss offsets (Maron et al., 2012; Curran et al., 2014). Although restoration appears as a highly additional offset strategy (Gonçalves et al., 2015), its potential to deliver conservation gains has been questioned (Curran et al., 2014). The most common criticisms are that restoration strategies often result in uncertain conservation outcomes, have low success rates (Maron et al., 2012) and long time lags (Drechsler and Hartig, 2011). At the same time, averted loss offsets may contribute to preservation of important habitat but undermine ecological equivalence and additionality, if placed in areas where there is no threat (Bull et al., 2013). Both averted loss and restoration offsets need to produce relevant and measurable conservation gains to qualify as effective conservation tools (Gardner et al., 2013).

Overall, most of the literature on biodiversity offsets focuses on conceptual and implementation challenges (McKenney and Kiesecker, 2010; Wissel and Wätzold, 2010; Bull et al., 2013; Alvarado-Quesada et al., 2014; Gonçalves et al., 2015) and the effectiveness of restoration offsets (Maron et al., 2012). There is a general lack of evidence and no large-scale assessments of the actual effectiveness of programmes implemented around the world (Gardner et al., 2013), as all programmes are context-dependent and often operate at local levels. In general, biodiversity offset programmes are classified as relatively "thin-markets", a market characterized by small number of buyers and sellers (Alvarado-Quesada et al., 2014) and therefore engaging few landowners in participation.

1.1.3 Transfer of development rights (TDR)

Private land conservation comes with a set of rights and responsibilities that are levied by land-use regulations. As development and land-use change progressively expand, these regulations tend to face challenges in terms of preserving important and relevant sites that can be subject to depletion or fragmentation (McConnell and Walls, 2009). Based on this premise, transfer of development rights (TDR) is a market-based alternative instrument that trades the rights of an area to develop above the limits established by the regulator with the rights of undeveloped areas. The means to achieve this objective is to create a free-market in which development rights are traded amongst willing sellers and buyers (Johnston and Madison, 1997; Kaplowitz et al., 2008; Menghini et al., 2015). In simple terms, "sending" areas (supply side) are the ones to be preserved and "receiving" areas (demand site) are the ones appropriate for growth. Landholders in sending areas can choose to set aside a share within their property and sell rights to landholders in receiving areas. Typically, sending areas are nature reserves, upper watersheds, environmentally sensitive areas, farms and other types of open space land. Regulatory policies often allow the development of receiving areas without TDR obligations, but offer additional development potential when TDR buyers purchase rights. This trade happens on a simple 'hectare per hectare' basis. Having transferred the development rights, landowners from sending areas are restricted from developing their land. The areas to where the rights are transferred are then allowed to develop the area more intensively than allowed by its baseline regulations (McConnell and Walls, 2009).

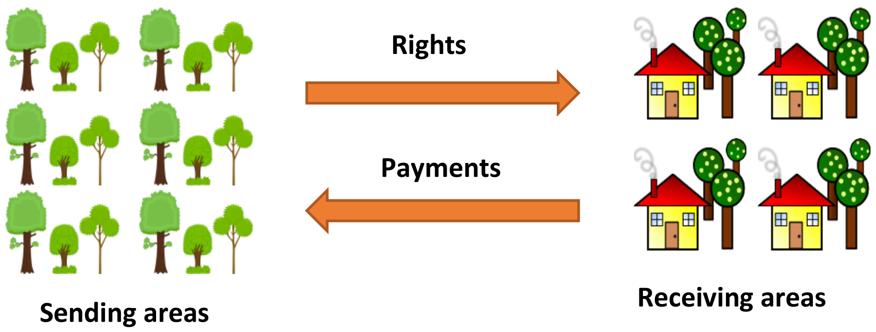

Figure 1.1 Schematic representation of how TDR schemes operate.

The concept of TDR was firstly applied in New York City for the protection of historic buildings and has been much used in urban development control, especially in areas with limited infrastructure or public services (Pruetz and Standridge, 2009). To date, it has also been expanded to environmental conservation, with programmes targeting protection of environmental values on agricultural lands, wetlands, and water quality preservation (Kaplowitz et al., 2008). TDR has become popular in some countries, such as Switzerland (Menghini et al., 2015), Netherlands (Janssen-Jansen, 2008) and Australia (Boronyak-Vasco and Perry, 2015) where schemes are complementary to command-and-control regulations.

TDR programmes have been widely adopted in the USA to preserve natural resources at low public cost (Kaplowitz et al., 2008; McConnell and Walls, 2009; Pruetz and Standridge, 2009). There are about 140 TDR programmes focusing on a variety of land use goals, including farmland preservation, prevention of development on environmentally sensitive areas, and restraining urban sprawl. Implemented programmes have different designs, goals, and enrolment specifications and tend to be very site-specific as each state has its own land use regulations and context (McConnell and Walls, 2009). Although TDR has preserved around 150,000 hectares in rural areas across USA (that includes farm and forest land), 47% of the programmes have resulted in no protection or have been revoked (Pruetz and Standridge, 2009). Possible explanations are a limited number of buyers and sellers – and consequently a small number of transactions, and lack of landowner participation, as participation is voluntary. As their implementation scale are often small (county or municipality), demand is often scarce, which undermines trade (McConnell and Walls, 2009).

1.2 Participation of landowners in conservation programmes

As highlighted above, the engagement and participation of private landowners is an essential component to ensure MBIs are effective and private land conservation achieved. Given that participation is typically voluntary, the decision of whether or not to participate is mostly dependent on factors that influence landowners' individual choice, such as costs, benefits, time and sociodemographic aspects (Greiner and Gregg, 2011). Understanding the influence of such factors can better inform policy-makers how to target specific groups of landowners and improve policy design (Sorice et al., 2013; Zabala et al., 2017).

Landowner participation has been widely debated in PES literature, particularly in developing countries (Zbinden and Lee, 2005; Kosoy et al., 2008; Ma et al., 2012; Bremer et al., 2014; Kwayu et al., 2014; Page and Bellotti, 2015). In TDR schemes, uniquely focused in the USA, studies are limited to and date from nearly 15 years ago (Conrad et al., 1979; Lynch and Lovell, 2003; Duke, 2004; Duke and Ilvento, 2004). In the biodiversity offset literature, landowner participation does not seem to be a debated issue. To have more global understanding, landowner participation in agri-environmental schemes (AES) were also included in this review. AES are widespread in developed countries and consist in the monetary compensation of farmers who voluntarily adopt practises that secure environmental goals. In general, landowners with a better education, wealthier status who own large farms are more likely to participate in conservation programmes (Table 1.1). In PES programmes, for instance, landholders who do not rely completely on farm income are more likely to be participants (Zbinden and Lee, 2005; Ma et al., 2012; Bremer et al., 2014). The same is observed in AES programmes – the higher the off-farm income, the more likely a landholder is to join an AES (Dobbs and Pretty, 2008; Defrancesco et al., 2008; Lastra-Bravo et al., 2015). In TDR, on the other hand, large and remotely located properties are more likely to enrol compared to properties more susceptible to development (Lynch and Lovell, 2003). Although less emphasis is given to programme-specific factors (Yeboah et al., 2015), conservation programmes that provide good access to information, have a clear conservation potential, have short contract durations and with attractive compensation tend to entice more participants (Bremer et al., 2014; Kwayu et al., 2014; Page and Bellotti, 2015).

Table 1.1 Summary of studies assessing sociodemographic and programme-specific factors influencing landowner participation in PES, AES and TDR schemes.

			Sociodemographic factors									Programme-specific factors								
References	Scheme	Region	Age	Gender	Education	Income	Farm size	Farm location	Land use	Arable land	Environmental attitude	Access information	Contracts	Value of payments	Transaction costs	Participation in design	Management change	Technical support	Eligibility	Eco-effectivenes
Zbinden & Lee 2005	PES	Developing	•	•	√	√	√	•	√	√	•	√	√	•	•	•	•	•	√	•
Kosoy et el. 2008	PES	Developing	•	•	•	√	•	•	√	•	•	√	√	√	√	√	√	•	√	•
Ma et al. 2012	PES	Developed	•	•	√	√	√	•	√	√	√	•	•	√	•	•	•	•	√	•
Bremer et al. 2014	PES	Developing	•	•	√	√	√	•	•	•	√	√	√	√	•	•	√	•	√	•
Kwayu et al. 2014	PES	Developing	•	•	•	√	√	•	•	•	•	√	•	•	•	√	√	•	√	√
Page & Bellotti 2015	PES	Developed	•	•	•	•	•	•	•	•	√	√	√	√	•	•	•	•	•	√
Wilson 1997	AES	Developed	√	•	√	√	√	•	-	√	√	√	•	√	•	•	•	•	•	•
Defrancesco et al. 2008	AES	Developed	√	•	√	√	•	•	√	•	√	√	•	•	•	•	•	•	•	•
Dobbs & Pretty 2008	AES	Developed	•	•	•	•	√	√	-	√	•	•	•	√	•	•	•	•	•	•
Lastra-Bravo et al. 2015	AES	Developed	•	•	√	√	√	•	√	•	•	•	•	•	•	•	•	•	•	•
Santos et al. 2015	AES	Developed	•	•	•	•	•	•	√	√	•	•	√	√	•	•	•	•	•	•
Conrad & LeBlanc 1979	TDR	Developed	√	•	•	√	•	•	√	•	•	•	•	√	•	•	•	•	•	•
Lynch & Lovell 2003	TDR	Developed	•	•	•	√	•	√	√	√	√	√	•	√	•	•	•	•	•	•
Duke 2004	TDR	Developed	•	•	•	•	√	√	•	•	•	•	√	•	•	•	•	•	•	•
Duke & Ilvento 2004	TDR	Developed	•	•	√	√	√	•	√	•	√	√	•	√	•	•	•	•	•	•

PES Payments for Ecosystem Services | AES Agri-Environmental Schemes | TDR Transfer of Development Rights

√ reported as influencial in participation | • reported as non-influencial in participation

Such studies provide evidence about sociodemographic and programme-specific factors that influence landowner participation. However, they only consider the perspectives of the sellers and do not assess whether buyers have similar or different perceptions of programme-specific factors. I address this gap in Chapter 2, by exploring the perceptions of potential buyers and sellers of the Brazilian forest offset scheme. The understanding of buyers' perceptions in MBIs in general is as important as that of sellers to stimulate trade and effectively meet conservation goals (Bastian et al., 2017). In addition, differently from sociodemographic factors, programme-specific factors can be amended by policy changes, which makes their assessment particularly important for policy design (Yeboah et al., 2015).

1.3 Spatial scale of programmes, trade-offs and additionality

The question of where to allocate conservation efforts in MBIs is an ongoing debate in the conservation realm (Ferraro and Pattanayak, 2006; Hartig and Drechsler, 2009; Wissel and Wätzold, 2010; Gonçalves et al., 2015). Such concern lies on the fact that environmental elements and ecological processes (e.g. biodiversity, threatened species, soil quality and protection of old-growth forests) are highly dependent on their spatial location (Walker et al., 2009; Hartig and Drechsler, 2009; Drechsler and Wätzold, 2009). In biodiversity offsets, for example, the spatial location of the offset is a key element to achieve meaningful conservation outcomes, whether near or distant from the impacted site (Wissel and Wätzold, 2010; Gonçalves et al., 2015). In TDR programmes, the spatial scale in which the scheme operates, whether large or small, may determine the number of buyers and sellers, and consequently, the volume of trade between them (McConnell and Walls, 2009).

Given that the primary logic of biodiversity offsets is to compensate biodiversity losses for ecologically-equivalent gains, the spatial allocation of such offsets are determined by a suite of strategies (Quétier and Lavorel, 2011; Maron et al., 2012; Gardner et al., 2013). The most commonly used, is the "like-for-like" strategy. Here, factors such as area and vegetation type, for example, are used to determine the location of offsets (e.g. a hectare of a certain vegetation type must be offset by a hectare of the same vegetation type; (Quétier and Lavorel, 2011)). Whilst a "like-for-like" strategy might be a more straightforward currency to offset biodiversity loss and minimally ensure ecological equivalence, it might be an oversimplification of complex ecological systems and lead to perverse conservation outcomes (Walker et al., 2009; Kujala et al., 2015). Alternatively, systematic conservation planning approaches are also used to strategically determine the location of offsets. In this case, habitat integrity, vegetation condition, species occurrence, complementarity and irreplaceability are commonly used metrics (Kiesecker et al., 2009; Kujala et al., 2015). Both strategies are commonly employed and their choice is typically programme-dependent and based on local or regional conservation goals (Kiesecker et al., 2009; Quétier and Lavorel, 2011).

The evaluation of where biodiversity offsets are placed, often generates trade-offs in regards to the type of offset, whether through averted loss or restoration (Kujala et al., 2015), and such trade-offs are far from being a settled debated in biodiversity offsets (Maron et al., 2012). Averted loss offsets tend to favour the protection of important existing habitat and tends to yield more certain conservation outcomes than restoration offsets but are likely to fail ecological equivalence (Kujala et al., 2015). Conversely, restoration offsets are a more certain strategy to promote ecological equivalence, especially if it happens near the impacted site and are likely to promote conservation gain if it occurs in highly degraded or scarce habitats (Wissel and Wätzold, 2010). Equally, averted loss and restoration offsets are only effective conservation strategies if they ensure additionality (Maron et al., 2012).

PES and TDR schemes do not have an explicit biodiversity component that allows for clear spatial targeting approaches as observed with biodiversity offsets. Instead, they are more grounded on the trade of hectares as their currency, hence, much of the discussion regarding the spatial location is associated with implementation scale – if strategies are implemented at local, regional or national levels (McConnell and Walls, 2009; Grima et al., 2016). Although several PES programmes are implemented at national levels (Börner et al., 2017), the most successful ones operate at local levels, particularly watershed PES (Grima et al., 2016). TDR programmes typically operate at small scales; however, different from PES programmes, the small spatial scale has been seen as problematic, due to low trade volume between buyers and sellers that undermines the programme's effectiveness (McConnell and Walls, 2009).

Additionality has also been reported as a critical issue in PES literature. Although poorly evaluated, it is still seen as a barrier to achieve effectiveness as, in most of the cases, PES programmes did not manage to reduce the pressures on the ecosystem because enrolment is often limited to low threat areas, where landholders have never had the intention to convert (Pattanayak et al., 2010; Arriagada et al., 2015; Grima et al., 2016). The same is observed in TDR where remotely located properties and unlikely to be under development pressure outcompete properties with high development pressure given their low opportunity costs (Santos et al., 2014). In addition, since TDR works on a hectare-basis trade, the conservation potential of the traded hectare is often disregarded, as rules of the programme do not explicitly account for its conservation value (Santos et al., 2014).

Overall, the poor evaluation of the spatial scale and the associated trade-offs, such as additionality, might undermine the conservation potential of the programme and result in poor or ineffective conservation outcomes. However, a quantification of potential conservation outcomes that may arise from different spatial scales wherein the programme is implemented has not yet been made. In Chapter 3, I test how different spatial scales of implementation (e.g. large and small) alter the conservation outcomes and affect the potential additionality of the Brazilian forest offset scheme.

1.4 Environmental co-benefits in conservation schemes

Conservation is a globally underfunded activity (Waldron et al., 2013). For this reason, conservation efforts typically attempt to deliver multiple benefits through a single strategy, under the logic that optimisation of conservation goals are possible and necessary given the limited resources (Iacona et al., 2018). There has been a growing interest in assessing the possibility of conservation initiatives to foster win-win solutions, especially solutions that align biodiversity conservation and the provision and regulation of ecosystem services (Cimon-Morin et al., 2013). However, to be effectively optimised, such conservation benefits are dependent on co-occurring in the same area and while there is much interested in developing win-win solutions, there is little understanding of what is required for them to be achieved (Howe et al., 2014).

In PES programmes, much of the debate around how to foster win-win solutions has been focused on bundling carbon storage or sequestration and biodiversity conservation services (reviewed in Grima et al., 2016; Börner et al., 2017). In particular, with the increasing interest in carbon-focused strategies (e.g. REDD+) strategies, the potential inclusion of biodiversity co-benefits under carbon payments became attractive given the possibility of aligning both per money unit spent (Wendland et al., 2010; Phelps et al., 2012a). However, the extent to which such environmental co-benefits are spatially congruent varies greatly in relation to scale (e.g. local or global) and to data used. For instance, at global scales, such congruence is observed between species-rich and biomass-rich areas, although this link is not uniform across the globe (Strassburg et al., 2010). At local scales, species-rich areas indicate a positive and significant association with disturbed areas that are not necessarily biomass-rich (e.g. primary and secondary disturbed forests, fragmented forests and regenerating pastures), showing that carbon-focused strategies alone might fail to effectively protect biodiversity (Gilroy et al., 2014; Magnago et al., 2015; Ferreira et al., 2018). In addition, the combination of high-resolution biomass data with species richness show that carbon-focused strategies might be positive for certain threatened taxa (Deere et al., 2018). The spatial incongruences observed in these local-level studies suggest that conservation efforts will not necessarily result in simultaneous environmental gains, potentially resulting in trade-offs.

A recent review of biodiversity offset programmes around the world shows that 41% already consider ES in their design, especially when development projects explicitly report potential impacts on the provision or regulation of ES (Sonter et al., 2018). On the other hand, the same spatial incongruence between biodiversity and ES is also found in biodiversity offsets programmes for provisioning services (e.g. water supply, food and timber) but not for regulating services (e.g. carbon storage, sequestration and pollination) (reviewed in Cimon-Morin et al., 2013). Biodiversity offset schemes typically employ systematic conservation planning approaches at landscape level to spatially allocate offsets (Kujala et al., 2015). For example, spatial conservation prioritisation approaches typically use the “principle of complementarity”, which recognises the diversity shared between sites (Bush et al., 2016). This principle is required to achieve efficient conservation solutions because the biodiversity represented by a set of conserved sites is not simply an accumulation of their individual richness values (alpha-diversity, Bush et al., 2016). Instead, how species composition varies across space (beta-diversity) are implicitly accounted (Bush et al., 2016). Other key metrics in conservation planning that implicitly incorporates beta-diversity is the principle of irreplaceability, which accounts for species status (e.g. vulnerable, endangered), identity, and endemism, that combined inform how to select areas that, if lost, could compromise local conservation targets (Margules and Pressey, 2000).

Although these metrics are widely adopted in conservation planning in reserve selection at landscape levels, many conservation strategies are implemented at larger scales – often across large environmental gradients (Sullivan et al., 2017; Boyd et al., 2018). In these cases, an explicit consideration of beta-diversity, rather than implicit approaches is important to better assess how to conserve biodiversity across large spatial scales and understand regional biodiversity loss patterns (Socolar et al., 2016). However, the explicit use of beta-diversity as a tool to inform conservation decision across large environmental gradients remains poorly explored (Bergamin et al., 2017). I address this gap in Chapter 4 by using beta-diversity to assess potential synergies between biomass and biodiversity as potential environmental co-benefits the Brazilian forest offset scheme.

1.5 Aim and specific objectives

The introduction and literature review above have shown that global conservation efforts still have unresolved issues that need to be overcome, if real effective conservation gains are to be delivered. The overall aim of this thesis is to assess the potential of offset schemes to result in effective conservation gains, by evaluating three key issues to programmes' effectiveness: the participation of landowners, the scale of implementation and potential environmental co-benefits.

Objective 1: Explore the diversity of viewpoints between scheme potential participants as buyers and sellers associated with programme-specific factors (e.g. contract length, price, intermediaries, trust, information) and identify potential factors that result in sharp divergences between buyers and sellers that could potentially affect trade and undermine programme objectives.

1.1 Identify the most important programme-specific factors influencing buyers and sellers' participation;

1.2 Quantify agreements or divergences on programme-specific factors between buyers and sellers, using an index;

1.3 Identify buyers' offset preferences.

Objective 2: Test whether different policy scenarios and potential implementation spatial scales (large to small) generate distinct conservation outcomes (averted loss and restoration) and affect overall additionality of the scheme.

2.1 Simulate forest trade between buyers and sellers under different policy scenarios and spatial scales;

2.2 Quantify overall avoided deforestation, potential regrowth and total additionality resulted from each policy scenario and spatial scale;

2.3 Examine the trade-offs associated with each different policy scenario and spatial scale;

2.4 Compare the effect of different policy scenarios and spatial scales on conservation outcomes;

Objective 3: Quantify environmental co-benefits (e.g. biomass and biodiversity) resulting from large and small potential scheme implementation spatial scales (i.e. biome and municipality)

3.1 Estimate biomass stocks and potential biomass accumulation for buyers and sellers' from publicly available biomass datasets;

3.2 Estimate beta-diversity biodiversity co-benefits for buyers and sellers;

3.3 Calculate differences between buyers and sellers in biomass stock and species composition values at large and small spatial scales;

3.4 Compare trade-offs associated to biomass and biodiversity co-benefits at large and small spatial scales.

1.6 Thesis outline

This thesis uses a multidisciplinary and multi-methodological approach to address some of the key gaps associated with offset schemes. I use a combination of empirical and spatial analyses to understand the conservation implications of the largest offset scheme in world, regulated in the Brazilian Forest Code. In this thesis, the key findings of each data chapter feed the subsequent one.

The sections in **Chapter 1** introduce the literature about relevant conservation MBIs employed globally; factors that influence participation of landowners as buyers and sellers in MBIs; the spatial scale in which MBIs are implemented and their implications to conservation outcomes; and potential environmental co-benefits associated with MBIs. In section 1.8, I also provide a brief description of the methodological approach used and in section 1.9 the main data sources.

In **Chapter 2**, I identify viewpoints related to programme-specific factors (i.e. contract length, price, transaction costs) of buyers and sellers of the Brazilian forest offset scheme. I use Q-methodology, a semi-quantitative approach, to empirically identify such viewpoints. After, I create a "trade compatibility index" to quantify potential divergences between buyers and sellers' viewpoints that could become barriers to trade and affect their willingness to participate in certain offset strategies (Figure 1.2 – red dashed lines).

In **Chapter 3**, I test how different spatial scales of scheme implementation alter conservation outcomes, more specifically the overall additionality of the scheme through avoided deforestation and regrowth. I use the viewpoints identified in Chapter 2 to develop three policy scenarios that include a set of different offset options. Trade is simulated between buyers and sellers considering the different policy scenarios, in five nested spatial scales that gradually go from large (biome) to small (municipality). Additionally, I compare the overall additionality to assess which scale is able to provide more area directed to conservation (Figure 1.2 – blue dashed lines).

Chapter 4 uses the key spatial scales identified in Chapter 3 to assess potential trade-offs associated with environmental co-benefits. I estimate biomass stocks and potential biomass accumulation for all buyers and sellers involved in the offset scheme at both large and small spatial scales. I also use species composition (beta-diversity) as the biodiversity metric to estimate potential biodiversity co-benefits at both spatial scales. Lastly, I assess and compare and biodiversity co-benefits at both spatial scales to draw potential policy implications (Figure 1.2 – green dashed lines).

The main findings from chapters 2–4 are drawn together and discussed in **Chapter 5**. This section contains a general overview of the main findings and places them in the context of the literature. The key aims of the thesis are re-examined to see to whether they have been achieved, and the research limitations are discussed. I also discuss the potential implications of this research for conservation actions and suggest future research directions. Finally, the overall conclusions from the thesis are summarised.

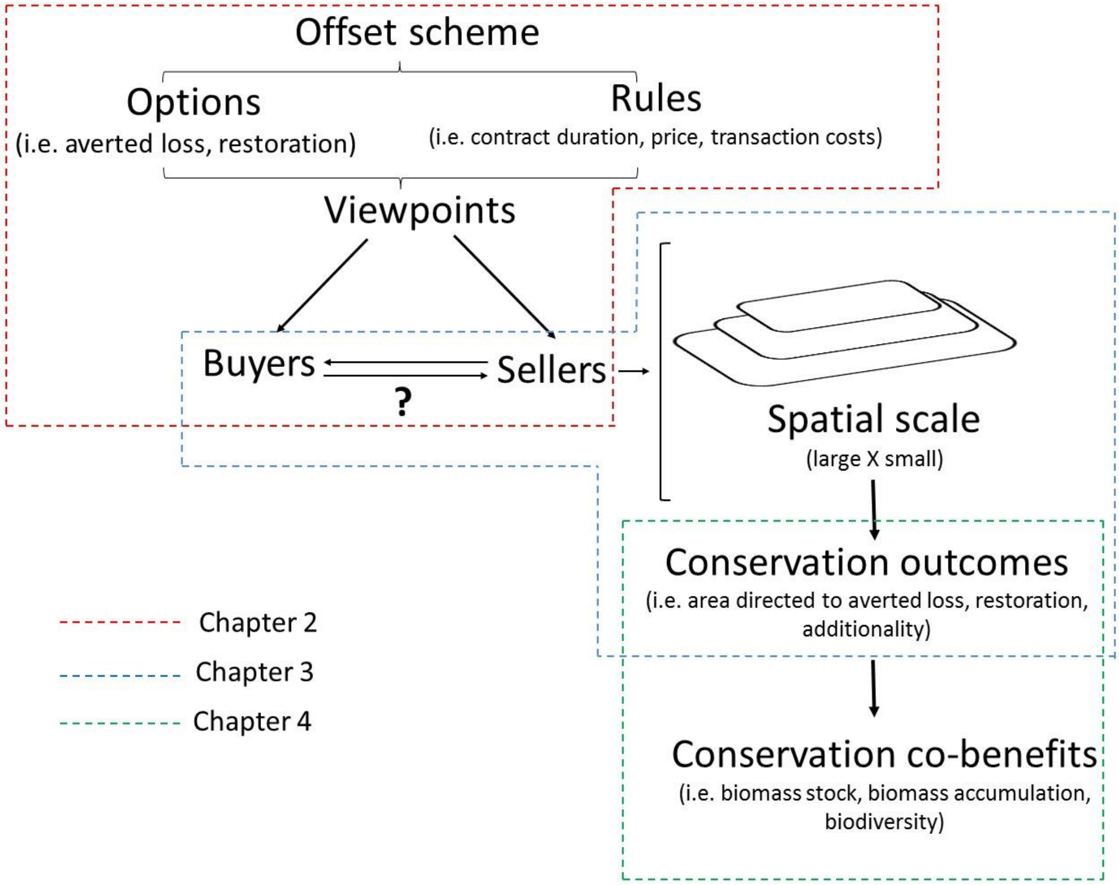

Figure 1.2 Conceptual diagram that summarises the thesis objectives. Different coloured dashed boxes represent each analytical chapter. The overlaps between two dashed boxes represent how each chapter's key findings feed the subsequent chapter. The red dashed box (Chapter 2) represent how scheme-specific factors and the offset options available generates distinct viewpoints amongst buyers and sellers and how such viewpoint potentially affects trade; the blue dashed box represents how trade between buyers and sellers limited to distinct potential spatial scales of scheme implementation affects the area directed to the key conservation outcomes of the scheme (Chapter 3); and the green dashed box represent the assessment of the environmental co-benefits associated with the conservation outcomes resulted from the different spatial scales of implementation (Chapter 4).

1.7 The Brazilian Forest Code as a case study

Brazil has achieved important milestones in the implementation of regulatory initiatives to combat land use change, mainly in the Amazon biome (Godar et al., 2014; Nepstad et al., 2014). Amongst many conservation strategies, perhaps the most important one was the approval of the new Brazilian Forest Code (FC), in 2012, which is the main legislation that regulates land use on private land (Soares-Filho et al., 2014). This legal framework contains important restrictions on forest clearing on private land and at the same time sets the scene to the implementation of an MBI.

Private lands in Brazil account for 605Mha. Additionally, of all its existing native vegetation (537Mha), 53% occur in private lands (Soares-Filho et al., 2014), which makes private land conservation particularly important. The main objective of the FC is to protect the vegetation within private properties by requiring landowners to set aside native vegetation areas in their properties. These areas are distinguished into Permanent Protected Areas (PPA) and Legal Reserve (LR). The former corresponds to areas situated alongside and around water bodies, steep slopes and hilltops that should be maintained intact. The LR, on the other hand, are set-aside areas designated to secure both economic and conservation uses, as long as managed sustainably and guaranteeing the provision of the natural resources and biodiversity conservation. All properties must maintain this vegetation, which can be primary or secondary forest, in every stage of regeneration. The proportion depends on which biome the property is located (Figure 1.3). In the Legal Amazon (the nine states covered totally or partially by the Amazon biome), this percentage in 80% in the Amazon forest, 35% in Cerrado and 20% in grasslands. All other biomes outside the Legal Amazon must maintain 20% of LR (Brasil, 2012). However, due to lack of enforcement and a long history of non-compliance (Sparovek et al., 2012) Brazil presents a LR debt of 16.4Mha to be offset (Soares-Filho et al., 2014).

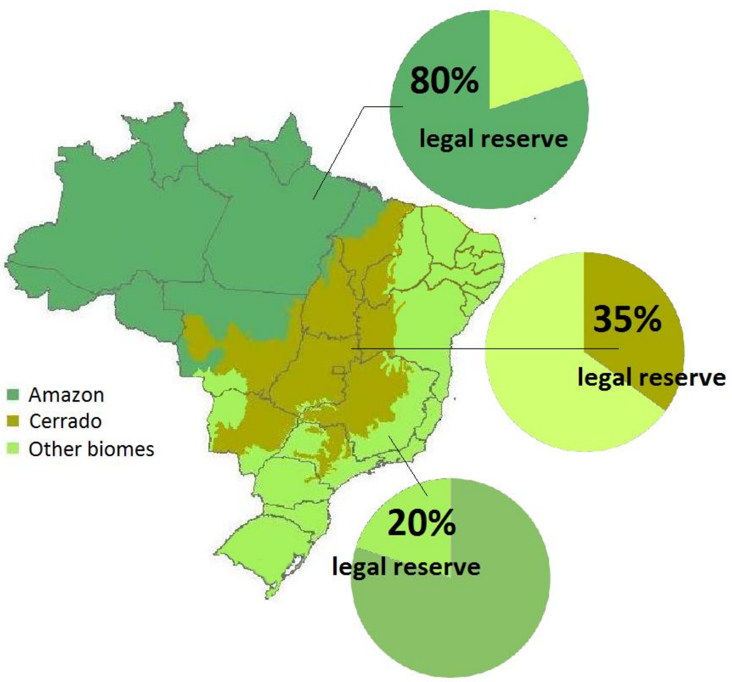

Figure 1.3 Minimum required percentages of legal reserve specific to each of the Brazilian biomes, according to the FC.

To encourage compliance and the conservation of LR, the FC allows landowners with a LR deficit (named “buyers”) to offset LR deficit with several options, if LR deforestation took place prior to 2008:

A) Acquisition of private land inside protected areas (PAs, Figure 1.4). In this case, buyers must purchase areas at least equivalent to their LR deficit and then donate the purchased area to the Environmental Agency in charge;
B) Adherence to an offset scheme named Environmental Reserve Quota, or CRA as the Portuguese acronym, in which buyers lease hectares from landowners who have kept their LR above the minimum required by law (named “sellers”). In CRA, sellers issue quotas that correspond to 1 hectare and buyers acquire quotas under a lease-based system. Trade between buyers and sellers must happen in the same biome and state. If outside the state, sellers must be located in areas designated as “conservation priority” (Figure 1.4);
C) Offset LR deficit with on-site natural regrowth or active reforestation.

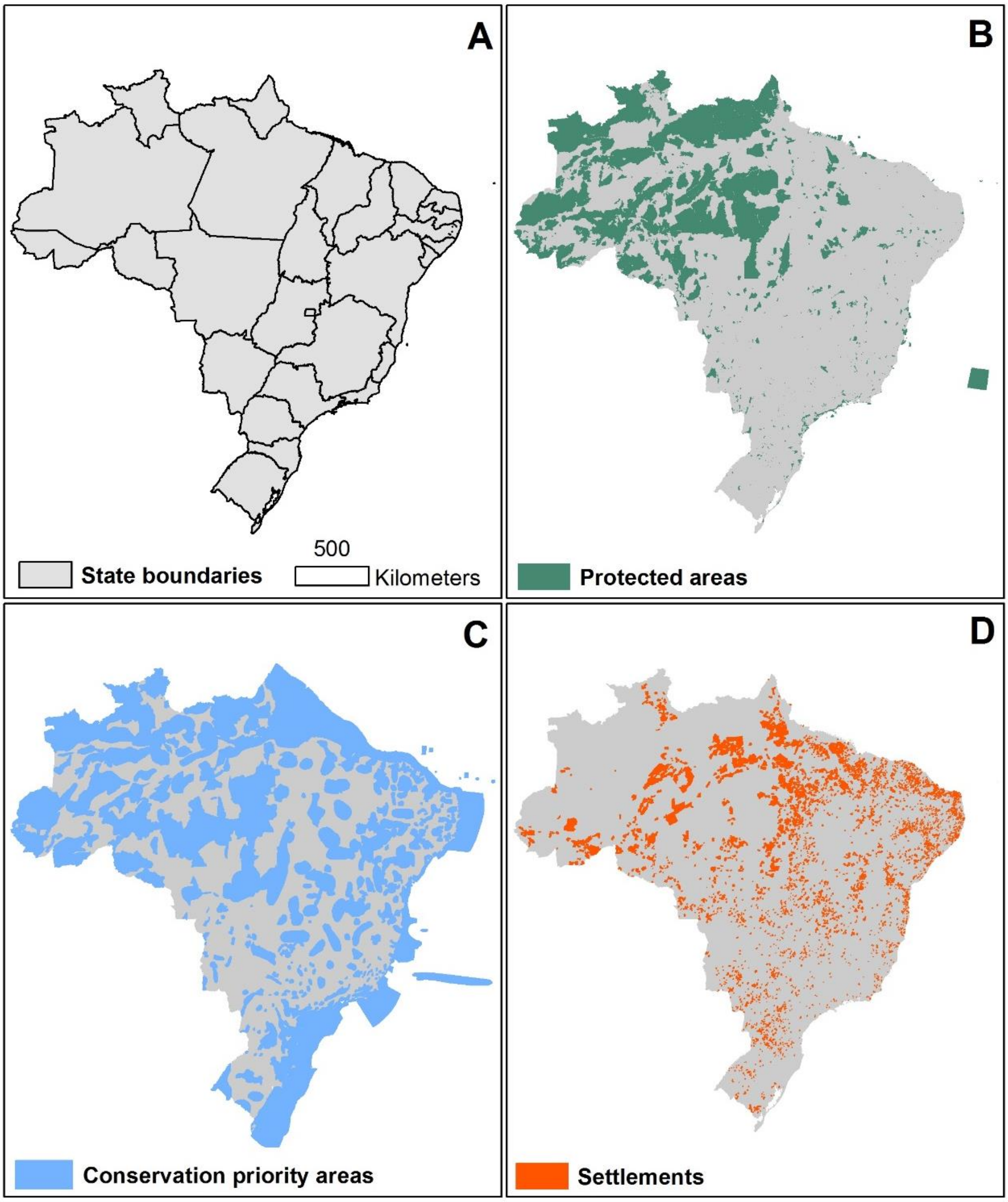

Figure 1.4 Overview of the relevant land use tenure categories for the FC. A) State boundaries (black); B) Federal, state and municipal protected areas (dark green); C) Conservation priority areas (blue); D) Settlements (orange). Conservation priority do not have established boundaries as they are just considered some sort of conservation hotspot. Settlements are defined as former mega-properties that were under-used and allotted and distributed to families as part of agrarian reform since the 1970's.

The FC legislates over the entire existing native vegetation in private lands (Azevedo et al., 2017). Given the magnitude of such legislation and its implications for both national and international environmental scenarios, several studies have examined the FC from different standpoints. For example, some studies examine the extent of LR in private lands and the associated policy implications for available offset strategies, such as CRA and forest regrowth (Sparovek et al., 2012; Soares-Filho et al., 2014; Nunes et al., 2016). Others investigate the contribution of mandatory rural registry system stated in the FC (named CAR) to avoid deforestation (Richards and VanWey, 2015; L'Roe et al., 2016; Azevedo et al., 2017). A few ecological assessments examine the importance of the LR set-asides to biodiversity and ecological processes to urge their permanent conservation (Banks-Leite et al., 2014; Barlow et al., 2016). In addition, considerable attention has been given to the offset options, particularly CRA. State-level studies show that allowing offsets to occur only in spatially restricted areas, such as areas designated as conservation priority, improves the conservation potential of the scheme although it increases compliances costs for landowners when compared to offsets with no spatial restrictions (Bernasconi et al., 2016). At the same time, a spatially unrestricted offsets results in more market activity between buyers and sellers, although undermines the ecological equivalence of offsets (Chomitz, 2004).

Other national-level studies highlight the policy implications of a general oversupply of LR surpluses, particularly from private land located in PAs and from small landowners and settlements (Soares-Filho et al., 2016; Freitas et al., 2017). This has been seen as a controversial issue for several reasons. Firstly, private land inside PAs (Figure 1.3B) are likely to absorb much of the offset demand given its low cost. On the other hand, as these areas are already protected and cannot be deforested, the additionality of the scheme is likely to be undermined (Soares-Filho et al., 2016). Secondly, small landowners and settlements (Figure 1.3D) have been granted compliance amnesty according to the FC – they are not required to offset their LR deficit (Brasil, 2012). Additionally, if they have any amount of native vegetation in their properties, they are eligible to offer in the offset market (Brasil, 2012). This may also undermine scheme's additionality, as their remaining their native vegetation cannot be deforested hence protecting nature that is already protected by law (Freitas et al., 2017).

At the moment, the FC offset scheme has not been fully implemented yet and awaits state-level legislators to allow for potential geographical restrictions (e.g. limiting offsets to the same municipality) to improve the programme's effectiveness (Freitas et al., 2017). Therefore, the analyses and findings presented in this thesis represent a great opportunity to provide meaningful contributions that can influence the implementation of the offset scheme and eventually result in effective conservation gains.

I particularly focus on the Amazon, a biome which has a global and local importance in the conservation scenario. Considered the most biodiverse rainforest in the world (ter Steege et al., 2016), Amazon forests account for 40% of global tropical forest area (Aragão et al., 2014) and contain nearly half of tropical forests carbon stocks (Saatchi et al., 2011). Additionally, the Amazon is crucial to local and global biogeochemical cycles (Spracklen and Garcia-Carreras, 2015). Although more than half of the Brazilian Amazon is protected (Soares-Filho et al., 2010), it has lost nearly 20% of its original territory (Assunção et al., 2017). Currently, as classified by the FC, 9.3 Mha of standing forest located in private lands can be legally deforested (Freitas et al., 2017). Thus actions towards the protection of native vegetation in private land are important to avoid future losses.

1.8 Methodological approach

To meet the objectives of this thesis I took two distinct methodological approaches. The first was an exploratory and empirical analysis in which landowners were interviewed following Q-methodology (details in Chapter 2 and Appendix 2). Briefly, Q-methodology is a semi-quantitative method designed to capture the underlying subjectivity within individual's viewpoints, allowing the construction of interpretative narratives about groups of people and their perspectives (Zabala et al., 2018). Through interviews, participants are presented a set of statements representing a wide range of possible opinions on a topic. Then they are asked to sort onto a grid which represents their level of agreement or disagreement.

Secondly, I employed spatial analyses to assess the overall environmental effectiveness of the CRA scheme across a large scale, the Amazon biome. I combine both numerical and spatial explicit analysis using publicly available databases.

1.9 Data sources

1.9.1 Landowners empirical data

The analysis presented in Chapter 2 involved empirical data. Between June and August 2016, I collected empirical data from landowners in the state of Mato Grosso, Brazil. I considered four criteria when sampling municipalities: (1) location (e.g. Amazon or Cerrado); (2) accessibility via major roads (BR-163, BR-158 and BR-070); (3)

predominant land use (crop or pasture) and (4) different farm size classes (e.g. small, large). To validate this decision, I interviewed two key policy actors of the state (Federation of Agriculture and Livestock – FAMATO and Institute of Agro-economics – IMEA). This sampling procedure resulted in six municipalities: Querência, Paranatinga, Sorriso, Sinop, Alta Floresta and Lucas do Rio Verde. These municipalities were selected as bases for the interviews. However, many interviewed landowners have parcels in other surrounding municipalities.

In each municipality, I contacted local organisations such as local associations and NGOs. After a brief explanation of my research, they were asked to provide contacts of affiliated landowners. Landowners were then contacted via phone and invited to participate in the study by taking part in face-to-face interviews. In total, 113 landowners were invited but only 59 agreed to participate. The participants were classified into buyers and sellers, according to their declared LR percentages. Although this sampling procedure is in accordance with the methodology used (see Chapter 2 and Appendix 2 for details), landowners who were not affiliated to any local organisation were not approached. Hence, the opinions of such group were not accounted in this study, limiting the conclusions of this chapter.

During interviews, I collected both sociodemographic data (e.g. age, education, farm size and land use) and their viewpoints about the Brazilian offset scheme. As this the analysis in Chapter 2 involved human participants, ethical approval was granted by University of Leeds Ethics Review Committee (ref: AREA 15-099, Appendix 1) prior to data collection. Key concerns raised were regarding discussing sensitive topics (as one of them was illegal deforestations), maintaining of full anonymity of respondents, obtaining free, prior informed consent and ensuring that personal data would remain undisclosed.

In order to avoid raising expectations, I maintained transparency with all participants about the purpose of my research and reminded them at the beginning of each interview, that I was an independent researcher, with no connection with any governmental body.

1.9.2 Brazilian land tenure database

To understand the environmental implications of the Brazilian offset across an entire biome (Chapter 3), I used a comprehensive land tenure database published by

Freitas et al. (2017) that integrates georeferenced land use categories including both private and public land. This land tenure map adopts a spatial resolution of 50 meters and contains the different categories of land use for all types of rural properties in Brazil. As the focus of this thesis is the Brazilian Amazon, I selected properties within the biome's boundaries, resulting in a database with nearly 370,000 rural properties, encompassing private land that overlaps with PAs and private land outside PAs (details in Appendix 3).

Private properties in Brazil must be registered in a national official data bank (e.g. Rural Environmental Registry – CAR as the Portuguese acronym). In this dataset, there were some voids in some portions of the area mapped, which indicated the absence of registered private properties as there were no property boundaries. Despite of this limitation, the analysis done in Chapter 3 was not affected, as only registered properties are eligible to participate in this scheme. However, these unregistered properties will likely be registered in the future, thus the ~370,000 properties used in the analysis of Chapter 2 might be underestimated.

1.9.3 Land cover data

Global Forest Cover (GFC) data

I used the GFC dataset (Hansen et al., 2013) to estimate potential cleared areas inside PAs to explore potential regrowth in Chapter 3. The most recent year available at the time of this analysis was 2016. This data was used exclusively for PAs as I was interested in forest and non-forest areas only.

GFC dataset accounts for tree loss or vegetation loss, and not specifically forest loss. Therefore, GFC incorporates secondary forest and/or forest plantations within the tree loss category. As a result, this dataset does not attempt to define what type of vegetation loss has occurred, e.g. secondary forest, old-growth forest, forest plantation. However, this particular limitation did not likely affect the analysis presented in Chapter 2, as it is solely focused on the Amazon biome.

TerraClass

The FC is specific about the cut-off date (2008) which buyers are eligible to offset their LR deficit. For this reason, I used TerraClass 2008 to estimate native vegetation and land use at the time to map potential buyers. TerraClass is a project of the Brazilian Space

Research Agency (INPE) together with The Brazilian Agricultural Research Corporation (EMBRAPA) that maps land use and land cover changes across the Brazilian Amazon and maps 15 different land cover classes (see Almeida et al., 2016). TerraClass explicitly accounts for classes, such as secondary forest and regenerating pasture (which can both be accounted as native vegetation remnants as part of the LR) hence the preference for this dataset. I also used TerraClass 2014 to map potential sellers with the latest TerraClass year available. As a result, all rural properties used in Chapter 3 had their native vegetation and land use mapped (details in Appendix 3).

To map deforestation across the Brazilian Amazon, TerraClass uses data from PRODES (Programme for Deforestation Monitoring in the Brazilian Legal Amazon) which records annual deforestation that is above 6.25ha (Almeida et al., 2016). Such limitation might miss small-scale deforestation especially in small properties. In addition, although TerraClass provides 30m resolution images, it uses MODIS (Moderate Resolution Imaging Spectroradiometer) to classify the land cover categories, which is 250m resolution. Such resolution might misclassify different categories of pasture, as all pasture categories exhibit similar ground structure (grasses, weeds and shrubs, Almeida et al., 2016). Nevertheless, the spatial analysis in Chapter 3 did not attempt to work with pasture categories directly as the main focus was the extent of native vegetation in each private property.

1.9.4 Aboveground biomass data

To estimate biomass stock and potential biomass accumulation in Chapter 4, I used a pan-tropical aboveground fused biomass map published by Avitabile et al. (2016). This dataset combines two existing aboveground biomass maps and a variety of field observations (e.g. tree-based field data and high-resolution local biomass maps) to derive a comprehensive 1km resolution pan-tropical fused map of aboveground biomass. To meet the objectives of Chapter 4, I used AGB values for each rural property in the Brazilian Amazon biome.

Although this is perhaps the most comprehensive AGB map for the tropics, there are some limitations. For example, areas which the existing biomass maps used to compose the fused map presented errors, these errors persisted in the fused map if field observations of such areas were inexistent and therefore unable to provide correction.

Particularly in heavily disturbed forests in South America, this was the case, where quality field observation data were lacking (Avitabile et al., 2016).

1.9.5 Species composition value

As the main interest of Chapter 4 was to use beta-diversity as the biodiversity component, I used a biodiversity dataset of the Amazon that uses a set of biodiversity metrics (e.g. phylogenetic composition, species richness and endemism) to map regions of unique species composition at 500m resolution (Strand et al., 2018). This dataset comprises terrestrial angiosperm, arthropods, and vertebrates (amphibians, birds and mammals).

To the best of my knowledge, this is the only dataset that attempts to map beta-diversity across the entire Amazon biome. The model employed by the authors considers species occurrence (presence/absence) to map species variation across the space. However, due to large sampling gaps in the Amazon, this dataset does not fully capture the species composition heterogeneity of the biome (Oliveira, 2015). In addition, the interpolation method the authors used to spatially model the species composition (see Strand et al., 2018) implies a linear relationship between species composition that might not be entirely realistic.

Chapter 2: Divergent landowners' expectations may hinder the uptake of forest certificate trading scheme

Abstract

A major challenge to reduce forest loss in the tropics is to incentivise conservation on private land in agricultural settings. Engaging private landowners in conservation schemes is particularly important along deforestation frontiers, such as in the southern Brazilian Amazon. While we know much about what motivates landowners to participate in schemes as providers, or sellers, of land for conservation, understanding what motivates landowners who act as buyers, i.e. those who require land to meet conservation obligations, remains lacking. Here we identify viewpoints of sellers and buyers of an emerging forest certificate trading scheme in Brazil and quantify the compatibility of their views to examine potential barriers to trade. Sellers and buyers could be divided into three groups, but only one group in each case was positive about participating. The differing viewpoints suggest that contracts should have minimum duration; and restricting spatial scope of trade could maximise uptake of unwilling landowners to effectively avoid future deforestation.

2.1 Introduction

The historical depletion of the natural environment (Gibbons et al., 2016) has led to the emergence of a wide variety of market-based conservation instruments. These schemes differ in rationale and implementation, but in essence attempt to create supply and demand for environmental goods (Lapeyre et al., 2015). Worldwide, forest conservation has often been the focus of such schemes, commonly based on Payment for Environmental Services (PES). Here, landowners receive payments from an institution (e.g. government, NGO, collective fund) to provide certain environmental goods or services, such as carbon storage/sequestration (Kosoy et al., 2008; Börner et al., 2017). Other recent schemes involve establishing markets for land, such as Tradable Development Rights, biodiversity offsets and habitat banking (Santos et al., 2014). These promote trade between private actors as “buyers” and “sellers” of environmental goods/services, potentially reconciling the trade-off between development and conservation (Ring et al., 2010). All such schemes rely on voluntary engagement of private landowners as an important factor to deliver long-lasting conservation gains (Kosoy et al., 2008; Yeboah et al., 2015).

In many conservation schemes, participation of rural landowners has been largely linked to socio-demographic factors: better-off, well-educated and owners of larger plots of land are more inclined to participate, whereas age and gender are not determinant factors (Pagiola et al., 2010; Ma et al., 2012; Lastra-Bravo et al., 2015). Less is known, however, about how programme-specific factors influence landowners’ participation (Greiner and Gregg, 2011; Yeboah et al., 2015). Additionally, the possibility that sellers and buyers might have different perceptions on programme-specific factors and be influenced by them in different ways is typically disregarded in the analysis of conservation schemes (Bastian *et al.* 2017; Zabala *et al.* 2017). For instance, long contracts and lack of information tend to be obstacles for sellers (Page and Bellotti, 2015; Yeboah et al., 2015). In contrast, a scheme that has clear conservation potential often encourages the participation of those landowners who have a positive environmental attitude (Greiner and Gregg, 2011; Bremer et al., 2014; Kwayu et al., 2014). High payment value can also encourage landowners to participate and forgo opportunity costs, but it is not always the main reason for their enrolment (Kosoy et al., 2008; Bremer et al., 2014; Page and Bellotti, 2015). Overall, understanding the influence of these programme-specific factors on the uptake of conservation schemes is important, as they can be modified by policy interventions.

Accounting for the perceptions of buyers and sellers within conservation schemes is particularly urgent in areas under high and increasing deforestation pressure and land-use change, such as at the deforestation frontier in tropical forest landscapes (Nordhagen et al., 2017; Zabala et al., 2017). Some tropical countries have incorporated conservation incentives into their environmental policies through protection of forest within private land (Börner et al., 2016). For example, Brazil, with the world's largest tropical forest, has invested in a variety of strategies to halt deforestation, which have resulted in a 70% decline in forest loss from 2005 to 2013 (Nepstad et al., 2014), although deforestation has risen more recently (Tollefson, 2016). In particular, the Brazilian Forest Code has introduced a promising strategy - the Environmental Reserve Quota (Portuguese acronym, CRA; see Appendix 2 for details) - that could potentially avoid the deforestation and degradation of native vegetation across a wide range of biomes (Soares-Filho et al., 2016). The CRA is a mechanism of tradable forest certificates in which private landowners can trade hectares of native standing forest (Bernasconi et al., 2016). This chapter aims to explore the diversity and agreement between potential sellers and buyers' perceptions of programme-specific factors within CRA (e.g. contract length, price, intermediaries, trust, information) and identify factors that result in sharp divergences between sellers and buyers that could potentially affect trade.

2.2 Methods

The Brazilian Forest Code states that private landowners must set aside areas of native vegetation within their farmland. Those who have deforested these set-aside areas (hereafter "Legal Reserve"; LR) above the maximum permitted may compensate for their deficit by acquiring hectares from landowners who have LR surplus. Non-compliant landowners are also given other options, such as: (1) buy and/or register another property with LR surplus; (2) acquire private areas pending tenure regularization inside publicly owned protected areas and donate to the Environmental Agency; (3) allow natural recovery or reforestation of the area (Brasil 2012). Another key piece of the Forest Code that will help monitor CRA trades is the rural registry system, which is still to be finalized.

Under this system, landowners must register and georeference their land, to promote transparency and compliance (May et al., 2015).

2.2.1 Study location

Mato Grosso is the third largest state in Brazil and has extensive coverage by the Amazon, Cerrado and Pantanal biomes (Figure 2.1). Since the early 1990s, Mato Grosso has experienced high rates of deforestation, mainly driven by expansion in pasture and soybean plantations (Brando et al., 2013). Private properties in Mato Grosso occupy 73 (of 90) Mha and nearly 22% (16Mha) of native vegetation was cleared between 1990 and 2012 (Brando et al., 2013). Across the state as a whole, around 5.6 Mha of native vegetation within private land have been deforested above the maximum permitted (Soares-Filho et al., 2014). There should, therefore, be considerable demand from landowners to 'buy' forest credits in order to meet their legal obligations (Soares-Filho et al., 2014). Nevertheless, there are also landowners who retain set-aside areas which exceed the minimum required who could, therefore, act as sellers. This makes Mato Grosso a large potential market for CRA trades (Soares-Filho et al., 2016), once the Forest legislation is fully enforced and the CRA is regulated.

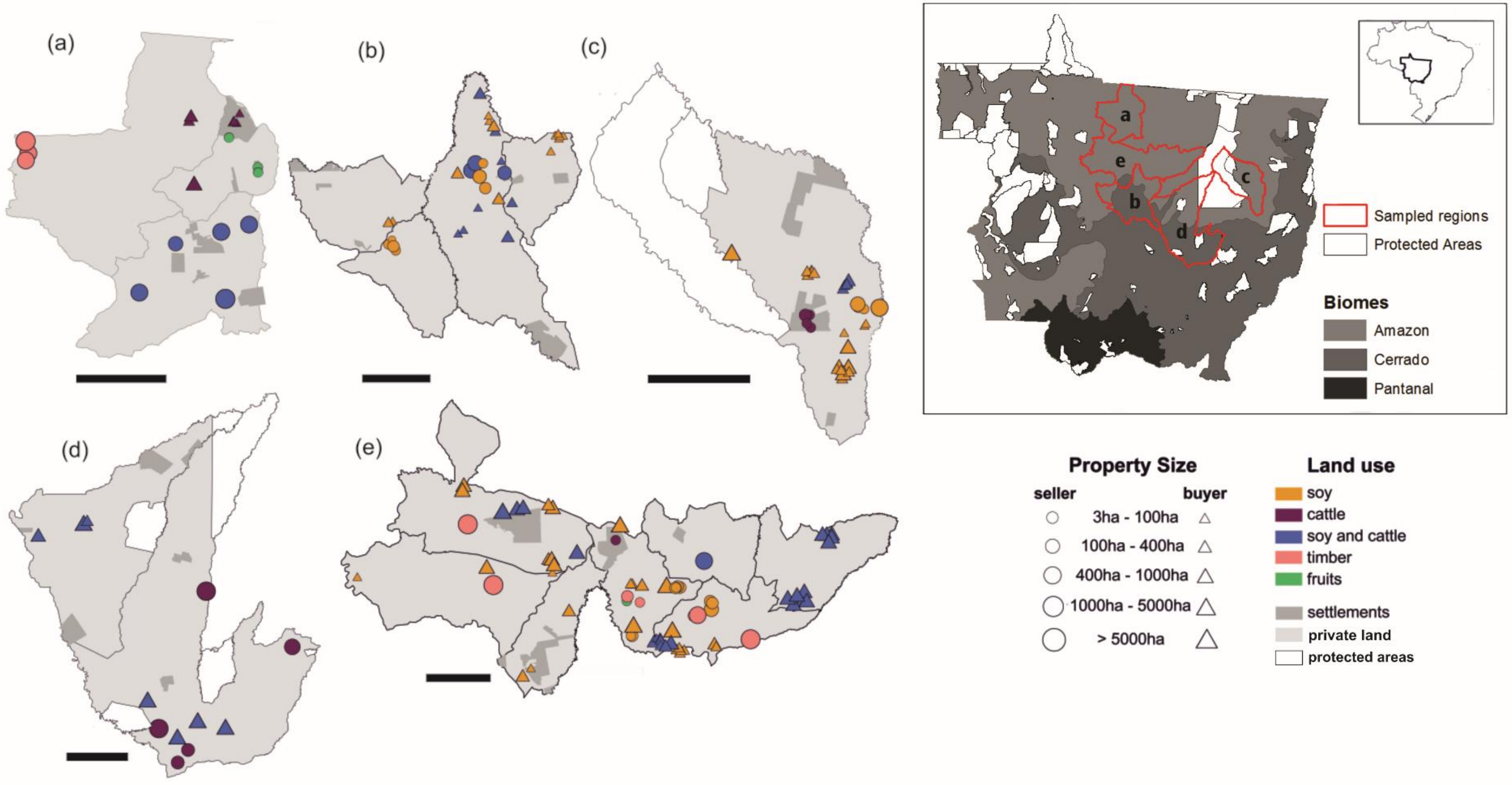
(a)
(b)
(c)
(d)
(e)
a
b
c
d
e
Sampled regions
Protected Areas
Biomes
Amazon
Cerrado
Pantanal
Property Size
seller
buyer
3ha - 100ha
100ha - 400ha
400ha - 1000ha
1000ha - 5000ha
> 5000ha
Land use
soy
cattle
soy and cattle
timber
fruits
settlements
private land
protected areas

Figure 2.1 Inset: location of municipalities sampled in Mato Grosso (MT). Dark grey shades indicate the biomes in MT and the white areas are conservation units or indigenous lands. **Main figure**: Panels (a)–(e) show the municipalities where buyers and sellers have plots (a single landowner can own several plots of land): (a) Alta Floresta, Carlinda and Nova Canaã do Norte; (b) Tapurah, Lucas do Rio Verde, Sorriso and Vera; (c) Querência; (d) Paranatinga and Nova Ubiratã; and (e) Tabaporã, Ipiranga do Norte, Sinop, Cláudia, União do Sul and Santa Carmem. White areas represent the same conservation units or indigenous lands in the inset; grey areas area settlements and lighter grey shading represents area covered by private land. Different symbols represent buyers or sellers, symbol size is proportional to property size and each colour represents a different land-use. Black solid bars represent 50 kilometres in each of the (a)–(e) panels to give an indication of scale.

2.2.2 Assessing willingness to participate in CRA

I used Q-methodology to explore the diversity of opinions of buyers and sellers regarding the CRA programme-specific factors (details in Appendix 2). Q-methodology identifies and clusters individuals according to distinct perceptions of a topic (Watts and Stenner, 2012). Our main objective was to assess different opinions on CRA, and Q-methodology enables an exploratory narrative of these opinions via a systematic and quantitative analysis (Zabala and Pascual, 2016).

Between June and August of 2016 I contacted farmers within the sampled municipalities (Figure 2.1) via local organisations that could facilitate communication by providing local landowners contacts (e.g. rural unions, cooperatives, local NGOs and Municipal Agricultural and Environmental Agencies). Of the 113 farmers invited to participate, 59 agreed to be interviewed (52.2% response rate), comprising 35 potential sellers (landowners who stated they have LR surplus) and 24 potential buyers (stated LR deficit). Participants were shown 39 statements representing possible opinions on CRA programme-specific factors and asked to sort these onto a grid which represents their level of disagreement or agreement, namely Q-sort (Appendix 2, Figure A2.2). Twenty-seven statements were identical to both groups, five were similar with opposing meanings (Table 2.2) and seven were specific to either sellers or buyers (Tables 2.3 and 2.4). I built statements and thematic categories (contract length, price, intermediaries, trust, transaction costs, payment vehicle, information, eco-effectiveness and demotivation) based on literature review and interviews with key actors (details in Appendix 2). All statements were pilot-tested with six landowners prior to application with participants.

In spite of the efforts to cover a variety of land-uses, farm sizes and demographic profiles (Table 2.1), landowners who are remotely-based and non-affiliated to any organisation are likely undersampled. However, our final sample reflects the main characteristics of Mato Grosso’s agriculture: large landholdings (> 1000 ha) dominated by pasture and soybean (DeFries et al., 2013; Godar et al., 2014).

Table 2.1 Summary information about sellers and buyers (covering landholder and farm characteristics) and respective explained variances for each grouping identified as part of the Q analysis: **A** represents independent conservationists; **B** environmental disbelievers; **C** willing deforesters; **D** CRA outsiders; **E** cautious buyers; and **F** compensation seekers.

		Sellers			Buyers		
		A	B	C	D	E	F
		n=14	*n*=10	*n*=7	*n*=8	*n*=10	*n*=5
	Explained variance (%)*	20	14	10	19	17	10
Landholder							
	Average age	46	53	55	49	51	46
	Education						
	Primary school (%)	28	20	40	25	20	0
	Secondary school (%)	29	20	0	37	10	40
	Technical (%)	7	0	20	0	0	20
	University (%)	36	60	40	38	70	40
Farm							
	Mean farm size† and SD	2224 (3779)	7119 (16169)	3768 (7029)	12931 (20369)	6186 (6548)	2740 (2675)
	Mean arable area and SD	797 (1429)	475 (450)	2070 (2718)	7730 (11351)	4967 (6552)	1748 (1125)
	Mean Legal Reserve and SD	1417 (2781)	5957 (16335)	2604 (4908)	5890 (11555)	911 (1395)	920 (1762)
	Land-Use						
	Pasture (%)	50	50	28	12	10	20
	Agriculture (%)	14	20	28	50	60	80
	Pasture + agriculture (%)	0	20	30	38	30	0
	Timber (%)	7	10	14	0	0	0
	Fruits (%)	29	0	0	0	0	0
	Biome						
	Cerrado (%)	36	50	43	25	30	20
	Amazon (%)	64	50	57	75	70	80

*Altogether, the three factors extracted explained 44% of the study variance. Factor analysis considers as a reasonable solution an explained variance above 35% (Howard et al., 2016).

† Most of the areas registered in CAR (rural database system) for MT are greater than 1,000 hectares (Godar et al., 2014).

2.2.3 Data analysis

Q-sorts from buyers and sellers were analysed separately using Principal Component Analysis (PCA) and varimax rotation in R package ‘qmethod’ (Zabala, 2014). The analysis provides representative groups of participants who share similar views about CRA. The final product of the analysis is an idealized sorting distribution of statement scores (hereafter ‘normalised factor scores’; ranging between -4 (strongly disagree) to +4 (strongly agree)) corresponding to the view of a hypothetical best representative participant of each group; and the statements that are statistically distinguishable to groups of sellers or buyers for p-value < 0.05 (Zabala, 2014). To ease subsequent calculations, I negated the buyers normalized factor scores for statements with opposing meaning between the two groups (Table 2.2, statements with asterisks).

2.2.4 Measuring trade compatibility between buyers and sellers

To assess whether buyers and sellers have similar views about programme-specific factors that could indicate a potential trade, I developed a Trade Compatibility Index (TCI) for each combination of buyer and seller category across all statements (details in Appendix 2), based on significant differences in normalised factor scores. TCI is calculated for a particular pair of sellers and buyers as derived from the PCA analysis. The lower the TCI, the more compatible a pair is in their perceptions (i.e. more similar Q-sort). More formally, we define TCI as:

$$TCI(\{s\}) = \frac{\sum_{i \in s} |S_i - B_i|\, p_i^S p_i^B}{C \times \sum_{i \in s} p_i^S p_i^B} \qquad \text{(Eq. 2.1)}$$

where S_i is the normalised factor score for statement i for sellers and B_i is the normalised factor score for statement i for buyers. p_i^X equals 1 if the respective statement was given a significantly different score ($p < 0.05$) by a group, when pairwise compared to scores given by all other groups. If not significant, p_i^X equals 0. This is to ensure that only statements that were distinct to define how a group “thinks” were included in the calculations. The constant C ensures TCI range from 0 to 1 (here $C = 8$; C is the sum of minimum and maximum absolute values of normalised factor scores). I calculated TCI for each pair of sellers and buyers, starting with statements set $\{s\}$ belonging to the contract thematic category, and step-wise added other thematic categories to the statements set in Eq. 2.1 (details in Appendix 2).

2.3 Results

PCA analyses revealed three groups of sellers and three of buyers (total explained variance 44% and 46%, respectively). Q-methodology is designed to capture the diverse viewpoints from a relatively small sample size (Zabala and Pascual, 2016). Thus the number of assigned sellers and buyers to each group (Table 2.1) cannot be used as an accurate measure of their relative proportion within the overall landowner population. Of the 35 potential sellers interviewed, four were not representative of any of the three groups, while of the 24 potential buyers, only one was not representative (all identified via automatic flagging; details in Appendix 2). Hence, they were not considered in subsequent analyses.

2.3.1 Sellers

A lack of awareness about their responsibilities (statement 12 for sellers, hereafter denoted S12) was a consensus statement among sellers. Sellers also collectively agreed that transaction costs should be included in CRA price per hectare (S37). Beyond these areas of consensus, three groups of sellers were identified:

Independent conservationists (group A)

Ideas of conservation provoked strong feelings for these landowners. They not only agreed that CRA can be a good conservation scheme to significantly protect forests at a large scale (S4, S5), but are also eager to conserve regardless of an economic incentive (S6). Predominantly composed of small landowners, 29% rely exclusively on growing fruits and vegetables as their main land-use (Table 2.1).

Their mean LR is the lowest of the sellers (Table 2.1), but this does not alter their perception that CRA could be a way to receive income for their LR (S34). Price (S28) was important, and for them it should vary according to forgone opportunity costs, even though they do not wish to deforest their land. ‘With or without CRA the forest must be preserved. Our consciousness does not let us do any type of deforestation', said one *independent conservationist* in this interview.

This group was strongly motivated to take part in CRA as they disagreed with statements on potential barriers (S24, S31). However, they require more information to facilitate their engagement (S8). They do not anticipate deforesting their LR surplus in the near future (S33) and a 10-year contract appears to be a good period (S2).

Environmental disbelievers (group B)

Although attributing importance to conservation (S4, S33), this group does not believe that CRA will help protect forests (S5). They distrust negotiation with other landholders (S22) and do not wish to create opportunities to build trust (S23), indicating reluctance to be involved at all. Even a higher price (S30) per hectare did not influence their distrust in CRA, or in other landowners. Additionally, they do not see any reason to participate (S24). They recognise the importance of intermediaries in facilitating trade (S16) and are aware that this can have an impact on pricing (S14) but were unconcerned about the other roles intermediaries might have (S13, S17, S35). Long-term and perpetual contracts are unthinkable (S3, S36) and the potential CRA returns were not important (S20, S28, S32).

Table 2.2 Sellers and buyers' statements and respective programme-specific factors, including the normalised factor scores for each group (group definitions given in Table 1 caption). The scores range from -4 (strong disagreement) to + 4 (strong agreement). Asterisks represent significant differences (**p < 0.05) of the scores given by the groups thus scores with asterisks are significantly different from the other scores given by the other groups. Sentences in bold are consensus statement amongst either sellers or buyers.

Thematic categories	Statement number	Statement	Sellers			Buyers		
			A	B	C	D	E	F
Contract	S1/B1	Five years is the maximum period I'd contract CRA.	-1**	1**	-2*	0**	-3	-3
Contract	S2/B2	I think a 10-year contract is good length to guarantee stability and a fair price for contracting CRA.	3**	-1	-3	0**	-2	-1
Contract	S3/B3	I'd rather sign long-term contracts, from 15 years onwards.	-1	-3**	0	-2*	0**	2**
Eco-effectiveness	S4/B4	The CRA scheme will significantly help animal and plant conservation.	4**	3**	-1**	2**	4	3
Eco-effectiveness	S5/B5	The CRA scheme will help protect forested areas.	4**	1**	-2**	1	-1	3**
Eco-effectiveness	S6/B6	I'd deforest all native vegetation on my property if the Forest Code allowed.	-4	-4	-1**	-2	-4**	-2
Information	S7/**B7**	**Before this interview, I already had a good knowledge of the regulations and requirements in the new Forest Code.**	0	2**	0	**2**	**1**	**2**
Information	S8/B8	Before this interview, I was well-informed of the possibility to trade forest credits (CRA).	-4	-1*	-2	-1	-1	0*
Information	S9/B9	I think the CRA rules are too complicated.	0	-1	3**	-1	1**	-1
Information	S10/B10	I think CRA will not work.	-2**	0*	1**	-3**	1**	-3*
Information	S11/B11	I know intermediary institutions of CRA such as BVRio and Biofilica.	-2	-2	-4**	0**	-2**	-4**
Information	**S12/B12**	**I don't know what my responsibilities are as a seller/buyer.**	**2**	**3**	**1**	**0**	**-1**	**0**

Intermediary	S13/B13	I would be willing to pay an annual fee for an intermediary institution that monitors the contract yearly.	1**	0**	-2**	-3	-2	1**
Intermediary	S14/B14	Having an intermediary makes the whole process more expensive.	0**	2	3	1**	2**	-1**
Intermediary	S15/B15	To me it would be impossible to go through all the CRA process without an intermediary.	1**	-1**	2**	1	-2**	0
Intermediary	S16/B16	I do not know where to find buyers and I need somebody to do that for me.	2	2	0**	0	0	1**
Intermediary	S17/B17	I prefer to negotiate CRA contract with a buyer/seller myself, without intermediaries.	-1*	0*	2**	1	1	-2**
Payment vehicle	S18/B18	I prefer to receive/pay annual payments for the duration of the contract.	0	2**	-1	-1	0	-2*
Payment vehicle	S19/B19	I only feel safe to receive/ pay the payment via an intermediary.	1	-3**	1	-2	-2	0**
Price	S20/B20	The price will depend on my land-use.	1**	-1**	4**	1*	0	1
Transaction costs	S21/B21	The associated expenses (negotiation, fencing (as seller) etc.) are a significant barrier for me to participate in CRA	0	-1	2**	0	0	-1
Trust	S22/B22	I would trust an unknown landholder to proceed with a CRA contract.	-2**	-3	-2	0	-4**	0
Trust	S23/B23	I would visit the property of the seller/buyer, no matter how far it is, before selling credits	1**	-2	-1	-4**	3**	1**
Demotivation	S24/B24	I do not see any real incentive for me to sell/compensate my exceeding Legal Reserve	-2**	4**	-1*	1*	2**	-1**
Demotivation	S25/B25	I think the Forest Code will change again, so will wait and do nothing in the next few years	0**	1	1	-1	2**	0
Contract	S26/B26	I would only sell/buy CRA for perpetuity.	-3	-4	-1**	-2**	2**	4**
Transaction costs	**S27**/B27	**CRA must have a fiscal incentive for aiming at conservation.**	**2**	**3**	**4**	3**	3	2

Price	S28	The per-hectare price of CRA should be at least how much I would get renting my land	3	1**	3	NA	NA	NA
Price	B28*	The per-hectare price of CRA should be at most how much I make per hectare	NA	NA	NA	(+)-3**	(+)-1**	(-)2**
Price	S29	The per-hectare price of CRA should be at least how much I would get selling my land	-2*	-2**	1**	NA	NA	NA
Price	**B29**	**The per-hectare price of CRA should be at most how much I would pay purchasing vegetated land in my region.**	NA	NA	NA	**3**	**3**	**2**
Price	S30	For a higher price, I would sell to any landowner regardless of his location in my state	-3	-2	-4**	NA	NA	NA
Price	B30†	For a lower price, I would buy from any landowner regardless of his location in my state.	NA	NA	NA	(+)-1	(+)-1	(-)1*
Demotivation	S31	CRA will only be attractive for who has Legal Reserve well above the minimum.	-1**	0	1	NA	NA	NA
Demotivation	B31†	CRA will only be attractive for who has Legal Reserve well below the minimum.	NA	NA	NA	(+)-1**	(-)2**	(+)-3**
Price	S32	The longer the contract the higher the price should be.	-1*	0**	2**	NA	NA	NA
Price	B32*	The longer the contract the lower the price should be.	NA	NA	NA	(-)3	(-)1	(-)4*

† the normalised factor scores of these statements were negated to ease calculations using Eq. 2.1

Table 2.3 Sellers' only statements and respective programme-specific factors, including the normalized factor score for each group (group definitions given in Table 1 caption). Asterisks represent differences between groups significant at **p-value < 0.05. Sentences in bold are consensus statement amongst sellers.

Thematic categories	Statement number	Statement	Sellers			Buyers		
			A	B	C	D	E	F
Eco-effectiveness	S33	I wouldn't deforest my exceeding Legal Reserve.	3	4	-3**	NA	NA	NA
Information	S34	I see CRA as an investment so I will definitely be part of this market.	2**	-2	-3	NA	NA	NA

Intermediary	S35	An intermediary institution as a mediator reduces the risk of default.	2**	0	0	NA	NA	NA
Transaction costs	S36	The requirement of fencing makes CRA unattractive to me	-1**	1	0	NA	NA	NA
Transaction costs	**S37**	**The costs for travelling, documentation, certificates and other associated expenses must considered as part of the CRA price**	**1**	**2**	**0**	NA	NA	NA
Demotivation	S38	My exceeding LR is not significantly large so I wouldn't be willing to issue CRA	-3**	1	2	NA	NA	NA
Demotivation	S39	Only CRA credits are not enough to make up the effort I made to conserve my exceeding Legal Reserve.	0*	0	0	NA	NA	NA

Table 2.4 Buyers' only statements and respective programme-specific factors, including the normalized factor score for each group (group definitions given in Table 1 caption). Asterisks represent differences between groups significant at **p-value < 0.05. Sentences in bold are consensus statement amongst buyers.

Thematic categories	Statement number	Statement	Sellers			Buyers		
			A	B	C	D	E	F
Eco-effectiveness	B33	If buying from another private landholder I'd like it to be from a conservation priority area.	NA	NA	NA	2**	0	1
Price	B34	I am very afraid of getting fined for non-compliance with the Forest Code.	NA	NA	NA	2**	-1	0
Trust	B35	I am afraid to run the risk of the sellers not keeping their obligations to preserve the land appropriately.	NA	NA	NA	-2	1**	-1
Demotivation	B36	I would prefer to buy vegetated land from another private landholder to be in compliance as opposed to renting CRA.	NA	NA	NA	2**	4**	-4**
Demotivation	B37	I would prefer to buy a land within a protected area and donate to the government as opposed to renting CRA.	NA	NA	NA	4**	0	1

Demotivation	B38	I prefer natural regeneration than buying CRA.	NA	NA	NA	-4**	-3	-2
Demotivation	B39	To reforest my deficit is my least option.	NA	NA	NA	4**	-3**	3**

Willing Deforesters (group C)

Price is all that matters to this group. CRA should provide the same financial return as productive land (S20, S28), regardless of its potential to protect native standing forests (S4, S5). How this potential monetary return will reach them does not matter (S18, S19). They do not perceive that complete deforestation is necessarily a poor outcome (S6) and would be willing to deforest their LR surplus (S33), suggesting they have no intrinsic motivation to conserve. They see CRA rules as too complicated (S9) and limited to specific groups of landowners (S31, S38). Interestingly, they were neutral about long-term and perpetual contracts (S3, S26): CRA is simply not seen as a profitable investment (S34). This will act as a barrier to them entering the market as they will favour more profitable land-uses, such as cattle or agriculture.

2.3.2 Buyers

Lack of awareness about their responsibilities was also consensus among buyers (B12) and, in general, buyers did not attribute much importance to being uninformed about CRA.

CRA outsiders (group D)

This group wants to be exempted from their environmental liability for a competitive price, preferably without any responsibilities for land management (statement 37 for buyers, hereafter denoted B37). They are very production-driven and would not promote any sort of environmental conservation activity if it meant a loss of productive land (B38, B39). CRA seems to be an odd and unfair compensation strategy to them. It involves making regular payments for a forest certificate that will never be theirs and has an "expiry date". Interestingly, from our interviews with them we learned that half of this group had recently acquired private land in areas designated by the government for conservation - the so called public conservation units. For them, to have somebody (the seller) managing a forested land for them is not a rational decision. They prefer to delegate this responsibility to the government (B36, B37) and are not prepared to consider any of the contract lengths proposed for CRA (B1, B2, B3, B26). In their own words: 'The whole society should pay to maintain forest inside farms as the big urban centres also depend on clean air and water. To make this as an exclusive expense on the farmer is unfair.'

Cautious buyers (group E)

As opposed to the other buyers, this group understands the conservation value of their LR (B6). They believe CRA has conservation potential (B4) but not at a large scale (B5). To ensure reliable negotiations they like to take the lead and are unwilling to go through intermediaries (B15). This is illustrated by their preference to visit a seller's property to minimise risks (B23) and to engender trust in the negotiation (B22). Perpetual contracts are the only contract duration that would be agreeable (B26). They are concerned about the longevity of CRA and stability of the Forest Code (B25), leaving them disinclined to participate (B24). They did not think they would participate in the market as: (i) they would rather acquire another forested farm in order to meet their obligations, rather than use CRA (B36); and (ii) in contrast with other buyers, they feel that active reforestation on their own land remains a possible strategy to recover their forest deficit (B39).

Compensation seekers (group F)

This group was the most willing to enter in CRA market, but their participation would be conditional on long-term contracts (B1, B2, B3, B26). They declined other compliance options (B36, B38, B39) and are indifferent about acquiring land in conservation units (B37). They see the conservation potential in CRA (B4, B5) and are positive about the success of the scheme (B10). However, a competitive price is important to guarantee their long-term participation (B28, B32). As they are seeking a perpetual contractual commitment, they seek the lowest price per hectare and trusting an unknown landowner is not an issue (B22, B23, B35).

2.3.3 Trade Compatibility Index (TCI)

Pairs of buyers and sellers were not substantially incompatible regarding CRA programme-specific factors (Figure 2.2). The overall TCI (i.e. including all thematic categories) for the most compatible pair (*independent conservationists* and *compensation seekers*: AF) was 0.16 on the scale of 0 to 1 (low TCI values indicate strong agreement; high values indicate strong disagreement for all statements in common). The most incompatible pair, *willing deforesters* and *compensation seekers* (CF), had a TCI of 0.417. TCI overall results suggest that *willing deforesters*, as the most incompatible group of sellers, is unlikely to engage in a trade. Although *environmental disbelievers* are ranked as the second and third most compatible sellers, they clearly stated their disinterest in CRA. Apart from pairing up successfully (TCI = 0.167) with *independent conservationists*, *compensation seekers* were the most incompatible group of buyers (TCI range = 0.4 – 0.417). Ironically, they were the only group of buyers who considered participating in CRA.

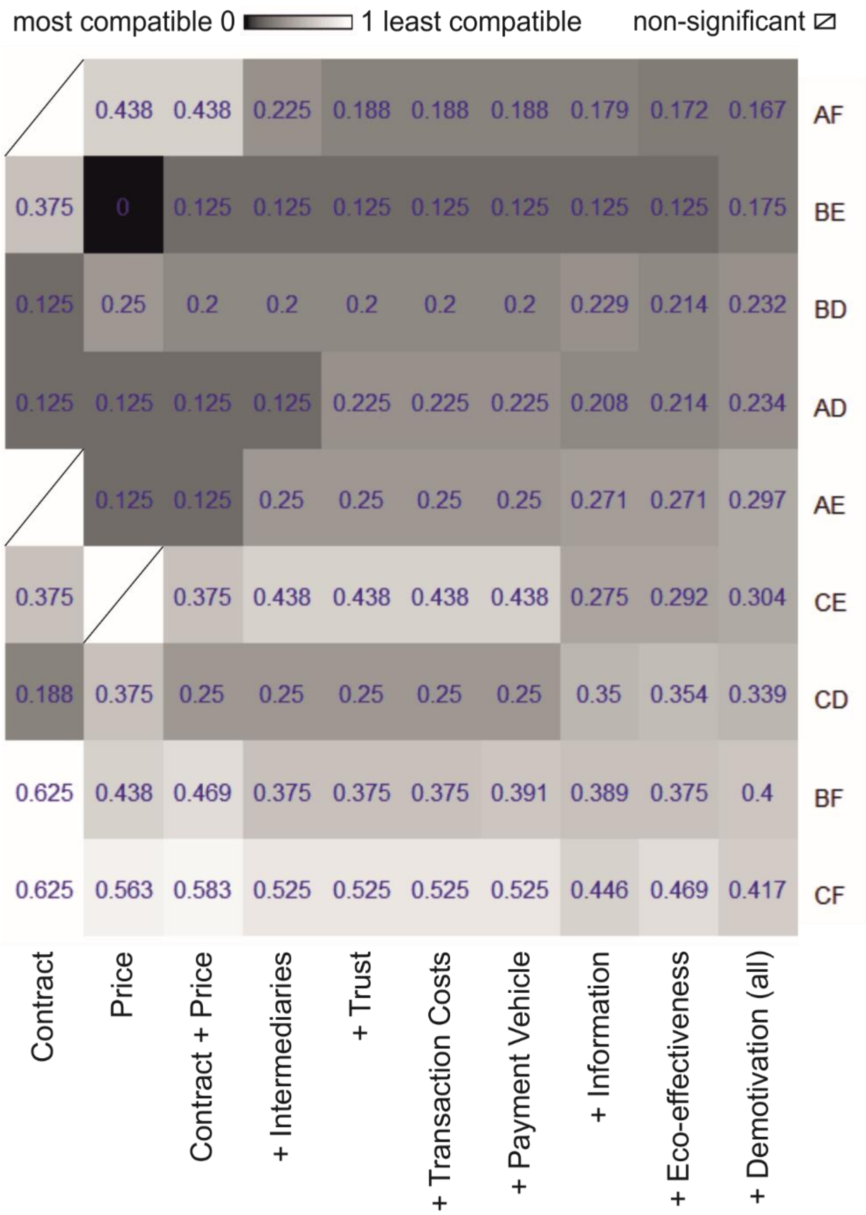

Figure 2.2 Trade Compatibility Indexes (Eq. 2.1) for each pair of sellers and buyers. The darker the cell, the more compatible the pair. The thematic categories were included in the model step-wise left to right. For **A** to **F** titles, see caption in Table 1. To assess overall compatibility, sorting was made according to right-most column, which the one including all thematic categories.

Analysing how TCI values vary among different categories of factors allows us to identify the causes of particularly high agreement or disagreement between groups. For example, TCI values for contract length only are particularly high (e.g. TCI = 0.625) between *environmental disbelievers* and *compensation seekers* (BF), and the latter and *willing deforesters* (CF), as *compensation seekers* have a strong preference for long or perpetual contracts. For *independent conservationists* and *compensation seekers* (AF), contract length was not significant, in spite of independent conservationists' disagreement with perpetual contracts (S26). However, when the TCI values were based only on price, AF had a relatively high TCI (0.438). When statements about other thematic categories were included, the incompatibility decreased suggesting price the main point of disagreement between them.

2.4 Discussion

Differences among landowners must be considered in the design of market-based conservation instruments as I show that perceptions of programme-specific factors vary widely among potential groups of sellers and buyers. Here, in the case of CRA, not all sellers were equally inclined to participate and not all buyers saw CRA as a good compensation strategy. Two programme-factors in particular played a major role in determining compatibility between buyers and sellers: contract length and price.

Sellers prefer short-term contracts, as they associate long-term agreements with land management restrictions and the potential to miss future advantageous opportunities. In analogous programmes, such as PES and conservation easements, long-term and perpetual contracts discouraged the participation and permanence of sellers (Sorice et al., 2013; Yeboah et al., 2015; Bastian et al., 2017). The results presented here corroborate these findings as potential CRA sellers are reluctant to accept long-term contracts. In contrast, it was found that buyers have a strong preference for long-term or perpetual agreements. Many buyers, therefore, might choose to acquire land inside publically owned protected areas. In Mato Grosso, these areas represent 800,000 ha in the Amazon and 50,000 ha in Cerrado (Andrade, J., May, P.H. & Bernasconi, 2013) which would cover a portion of the estimated LR deficit of 3.9Mha and 1.6Mha in Amazon and Cerrado, respectively (Soares-Filho et al., 2014).

Despite the fact that some buyers, such as *CRA outsiders,* are likely to meet their Forest Code obligations by purchasing land in conservation units, Amazon and Cerrado would still have 3.1Mha and 1.1Mha of demand left, respectively, which could result in successful CRA trades. Sellers willing to participate, such as *independent conservationists*, are well-placed to trade with *compensation seekers*, if issues around contract length can be resolved. To encourage this match, CRA regulation could set a minimum of 10-15 year contracts to ensure medium-term supply of forest certificates and to provide a middle-ground for sellers and buyers. This time-frame is widely adopted in analogous schemes (Lennox and Armsworth, 2011) and contributes to increased likelihood in future re-enrolment (Ando and Chen, 2011).

Another important issue policy-makers need to address is how to make CRA more attractive to unwilling sellers like *willing deforesters* - landowners who clearly stated an intention of legally deforesting their LR surplus. If this land could be brought into CRA, the potential gains for the area of land under protection could be huge. In Mato Grosso, nearly 1.6Mha and 4Mha, in the Amazon and Cerrado, respectively, could face legal deforestation. For *willing deforesters,* who are more profit-driven, price will likely play an important role. Because their properties are located in regions of high opportunity costs, buyers will prefer trading with low-cost areas under no imminent deforestation pressure. A potential strategy to address issues around price is to restrict the spatial scale of trade (May et al., 2015). If trade could be constrained sub-regionally within the state, potentially restricted to areas under similar deforestation pressure, surpluses owned by *willing deforesters* could be brought into the market. Spatially restricted trade appears as an effective measure to achieve conservation gains both in CRA (Bernasconi et al., 2016) and in PES schemes (Sattler et al., 2013; Grima et al., 2016).

These findings provide empirical evidence of how different perceptions on programme-specific factors can become substantial barriers to sellers and buyers engaging in trading land. To overcome these barriers, I suggest that (1) establishing minimum contract durations; and (2) restricting the spatial scale of trade to resolve issues around price and target specific landowner groups, are important policy recommendations that could minimise barriers to trade and improve chances of success. In addition, law enforcement and transparent monitoring should not be overlooked by regulators.

This study provides useful insights which can be applicable in contexts where peer-to-peer schemes are promoted to avoid further forest conversion. In settings that provide similar pre-conditions in terms of environmental policies and land tenure, it is likely that many buyers will also prefer perpetual solutions whereas sellers will prefer short-term contracts to avoid long-term commitments. In addition, landowners' heterogeneity about a given scheme should be considered, in order to target specific groups that are not likely to participate. The Trade Compatibility Index, as a novel and generally applicable methodological step, allows a systematic comparison between groups, emphasizing trade potentialities and key programme-specific factors that could be points of concern. Forest conservation objectives are likely to be attainable if policies are sensitive to the intended audience.

Chapter 3: The scale of a forest offset scheme alters the outcomes for conservation

Abstract

Offset schemes help to reduce or avoid habitat loss either via averting loss, through protection of existing habitat, or by the restoration of degraded areas. The spatial scale of an offset scheme may influence which of these two outcomes is favoured, and is an important aspect of the design of these schemes. However, how spatial scale influences the trade-off between the preservation of existing habitat and restoration of degraded areas is poorly understood. Here, I therefore used the largest emerging forest offset scheme in the world, which is part of the Brazilian Forest Code, to explore how implementation at different spatial scales may affect the outcome in terms of the area of avoided deforestation and/or natural regrowth. I employed an efficiency frontier approach to identify which spatial scale provided greater averted loss or restoration. Allowing offsets over large spatial scales led to a greater area of avoided deforestation and only a small area allocated to regrowth, whilst restricting offsets to small spatial scales led to the opposite pattern. Overall, the greatest total area, and the largest area in regions that are already highly deforested, was directed to conservation when the scheme was implemented at small scales. To maximize conservation gains from averted loss and restoration, it is important that offset schemes embrace a "think local" focus when implementing nationwide strategies. A "think local" strategy will help to ensure that conservation benefits stay localized, and promote the recovery of degraded areas in the most threatened forest landscapes.

3.1 Introduction

A variety of mechanisms have been developed to manage human-caused habitat change and promote outcomes that aid conservation (Betts et al., 2017). Some of these systems incentivise landowners to follow good environmental practices (e.g. subsidy payments and payments for ecosystem services), while others legislate to ensure that past or future environmental disturbances are compensated for (e.g. tradable permits or habitat and biodiversity offset schemes). The latter group operate as markets, in which environmental goods are traded between landowners who supply the market goods ("sellers") and those who need to compensate for environmental damage ("buyers", Ring et al. 2010).

Offset schemes have gained popularity around the globe due to the straightforward logic of trading environmental losses for equivalent conservation gains, although there has been concern whether such equivalency can, in fact, be achieved (Bull et al., 2013; Bull et al., 2015). To compensate for environmental loss, offset schemes typically employ averted loss or restoration as offset strategies. These different strategies target different kinds of habitat (Gardner et al., 2013): averted loss targets the protection of existing biodiversity and natural habitat, such as old growth forest, whilst restoration favours the recovery of degraded habitats and promotes secondary vegetation (Curran et al., 2014; Maron et al., 2016).

The trade-offs between the advantages and disadvantages of conservation schemes that favour either averted loss or restoration have been extensively debated (Maron et al., 2012; Gardner et al., 2013; Curran et al., 2014; Quétier et al., 2015). While the length of time that restoration requires increases the risk of failure (Drechsler and Hartig, 2011; Maron et al., 2012), this strategy might be attractive if occurring on-site or near impacted areas (Wissel and Wätzold, 2010). For example, where impacts are caused by land cover change to pasture or agriculture, such as in many tropical forest regions, restoration via natural regrowth has been promoted to recover degraded land and enhance secondary forest cover (Chazdon et al., 2016; Strassburg et al., 2016). Averted loss, on the other hand, can favour the protection old-growth vegetation, but to result in effective conservation gains, the protected habitat needs to be ecologically equivalent (i.e. the same habitat type) to the damaged site (Bull et al., 2013). The protection also needs to occur in sites where threats or development pressure are imminent, and therefore generate benefits that would not occur in the absence of the scheme – a concept defined as ‘additionality’ (Maron et al., 2010).

A key element that determines the effectiveness of averted loss and restoration is the spatial location of the offset (Gonçalves et al., 2015). Several studies have used conservation planning approaches to identify the spatial scale (e.g. local or regional) where potential offsets should be located; they typically consider specific biological targets or habitat characteristics (e.g. species distributions, or the presence of certain taxa) to determine where offsets should occur (Kiesecker et al., 2009; Gordon et al., 2011; Underwood, 2011; Kujala et al., 2015). These studies indicate that both local and regional spatial scales have the potential to achieve averted loss and restoration goals, as long as offsets are placed in strategically defined areas. Conservation planning approaches have been particularly useful in offset schemes that explicitly include biodiversity metrics in their offset strategies (Gordon et al., 2011). However, some offset schemes have simpler offset conditions (e.g. a hectare of loss for a hectare of gain) that do not include specific biodiversity metrics (McKenney and Kiesecker, 2010). In these cases, conservation planning approaches cannot be used so readily to determine the location of offsets. For these schemes, administrative boundaries, such as the limits to municipalities, states or counties, may be an appropriate way to influence the spatial scale and location of offsets in order to maximise the benefits for conservation.

The approach to use administrative boundaries to define the spatial scales of offset schemes is currently used in the United States (e.g. for conservation banking and transferable development rights, McConnell & Walls 2009; McKenney & Kiesecker 2010) and in Brazil (Brazilian Forest offsets, Soares-Filho et al. 2014) as they represent well-known jurisdictions in which many policy decisions already operate and therefore facilitate the implementation of offset markets. Some studies suggest that averted loss might not be achieved within offset schemes that use small administrative boundaries to limit trade, as this restriction will lead to a reduced number of sellers, and little area available for compensation (Chomitz, 2004; McConnell and Walls, 2009). Conversely, the use of larger administrative boundaries to expand trade, may lead to limited additionality. In these cases, areas that are under no current development pressure are likely to absorb the offsets that the scheme requires, as these areas will tend to have low opportunity costs, and outcompete areas under deforestation pressure that are typically associated with high opportunity costs. Hence, only areas that would likely remain untouched even in the absence of the scheme may ultimately be protected, and scheme additionality will be very low (McConnell and Walls, 2009; Freitas et al., 2017). However, explicit tests of how the spatial scale of offsets might alter the trade-off between averted loss and restoration, and overall scheme additionality, have not been performed.

Here, I quantify the effect of scale on the trade-offs between averted loss and restoration as conservation outcomes of an offset scheme, using the Brazilian Forest Code as a case study (Brasil 2012). This analysis focuses on the Amazon, the world's largest standing forest covering 400 million hectares (Assunção et al., 2017) and holding nearly 26% of total carbon stored in tropical forests (Baccini et al., 2012). Despite a historical decline, deforestation in the Brazilian Amazon has risen since 2014, endangering national commitments to reduce carbon emissions (Rochedo et al., 2018). I used avoided deforestation to represent averted loss and natural regrowth as a restoration strategy, as these are the principal conservation outcomes of the offset strategies within this example. I employed different administrative boundaries as approximations of different spatial scales (i.e. small to large) and compared the effect of scale on conservation outcomes across a range of policy scenarios. The administrative boundaries represent regions over which the scheme could be implemented and are well-established jurisdictions. I hypothesize that allowing offsets across large spatial scales will yield more avoided deforestation than regrowth, given the number of sellers available to offset, whilst the opposite happens at small spatial scales. I expect that intermediary spatial scales yield similar gains from avoided deforestation and regrowth. Regrowth and avoided deforestation were estimated using numerical simulation of offset trade between > 370,000 buyers and sellers and consider our results in light of the current implementation guidelines for offsetting policies.

3.2 Methods

3.2.1 Description of case study

The case study here is the Brazilian Forest Code (FC), which requires compliance from landowners who deforested property-level native vegetation above the limits established law (Soares-Filho et al., 2016), hereafter called “buyers”. In general terms, offset can be via:

1. Acquisition of private land inside protected areas (PAs). Private lands that overlap with PAs need to be expropriated. Offsets can be made via acquisition of such private lands followed by donation to the statutory environmental agency;
2. For private landowners located outside PAs who own hectares of native vegetation above the minimum established by law (“sellers”) – a scheme called *Cota de Reserva Ambiental* (hereafter CRA as the Portuguese acronym);
3. On-site offset restoration through natural regrowth or active reforestation.

Buyers who wish to offset inside PAs (option 1) must purchase private land equivalent to the area deforested. This option allows for a perpetual solution for non-compliant buyers, which appears to be buyers’ preferred option (Giannichi et al., 2018). CRA (option 2), conversely, is a hectare-by-hectare market. A buyer can, therefore, trade with several sellers and one seller can supply several buyers. Instead of a single perpetual transaction, CRA works as a lease, in which contracts with specific durations are made between buyers and sellers. Lastly, regrowth (option 3) requires buyers to abandon deforested hectares to allow secondary forest to recover or actively reforest the deforested hectares (Soares-Filho et al., 2016).

I used a land tenure database (Freitas et al., 2017) to acquire landowners’ property boundaries, and land cover datasets (TerraClass, Almeida et al. 2016, and Global Forest Change, Hansen et al. 2013) to calculate the extent of native vegetation per property - the Legal Reserve (LR). Based on the LR extent, I classified landowners into buyers or sellers. According to the FC, a landowner is a potential buyer if LR deforestation occurred prior to 2008. If the LR currently (I used TerraClass 2014 as proxy to estimate LR extent at the present) exceeds 80%, the property was classified as a seller. In private lands, LR that exceeds 80% can be legally deforested. Although native vegetation below this amount can never be deforested (so its protection in an offset scheme is non-additional), in some cases landowners who have LR below 80% are also eligible to supply the market. These cases include smallholders and settlements (i.e. former mega-properties that were under-used and allotted and distributed to families as part of agrarian reform since the 1970’s), who can offer any amount of LR within their property. Private properties inside

PAs were also classified as sellers and their native vegetation was considered non-additional for the same reasons as above. Section 1.7 in the introduction describes the specifics of the FC and Appendix 3 describes the datasets used (A3.2, A3.3) and the classification of buyers and sellers (A3.4).

3.2.2 Offset spatial scales and policy scenarios

I considered five different nested administrative boundaries as offset spatial scales (Table 3.1, Figure 3.1), from the large (biome) to small (municipality). The FC states that offset must occur within the same biome. If between states, offsets must occur in areas identified as priorities for conservation (Appendix 3, Figure A3.1). These areas represent regions of high biodiversity importance and are established by the Ministry of the Environment as regions of endemism or biodiversity hotspots. However, these areas are not protected. Instead, a number of private lands occur within these regions.

Besides the boundaries mentioned in the law (biome and state), I used other three nationally established administrative boundaries (meso-regions, micro-regions and municipalities) that could facilitate implementation. The FC offset scheme has not been fully regulated, and thus offset scales can still be amended once each state legislates their own offsetting rules. Apart from biome, all administrative boundaries include several individual units which vary in size (Table 3.1).

For each spatial scale, I considered three policy scenarios (Appendix 3, Figure A3.1):

- ***Policy Scenario 1: Offset in all PAs, CRA and regrowth.*** Offset was allowed in private land inside all PAs. The text in the FC is not specific about whether the PA must be a federal, state or municipal area thus this scenario included all PAs, followed by CRA and regrowth as offset options.
- ***Policy Scenario 2: Offset in federal PAs, CRA and regrowth*.** The Ministry of the Environment established a regulatory framework (Brasil, 2016) that considers only federal PAs for compensation. As states still need to legislate their offset rules, we included this framework as a scenario, excluding offsets in state and municipal PAs, followed by CRA and regrowth as offset options.

- ***Policy Scenario 3: Offset with CRA and regrowth.*** This scenario ruled out offset within private land inside any PAs and included only CRA and regrowth as offset options.

Table 3.1 Spatial scales and respective deciles of units' sizes in Mha, showing size variation within each scale. The biome scale is a single unit of 422 Mha, thus the absence of deciles.

	Units	1st decile (Mha)	5th decile (Mha)	9th decile (Mha)
Biome	1	-	-	-
State	9	9.8	22.4	131
Meso-region	26	1.6	9.2	38.6
Micro-region	81	0.5	3.1	12.1
Municipality	499	0.04	0.3	2.1

Scenario 1 included all offset options stated by law – the most permissive scenario. Scenarios 2 and 3 gradually imposed restrictions on the offsets. I imposed such restrictions to better assess if the outcomes of imposing different scales would be consistent regardless of the restrictions.

This analysis assumed that compliance is a buyer-led strategy, as incompliance incurs severe penalties, such as fines, land embargoes or no access to loans. Therefore, buyers actively 'looked' for sellers in our analysis. Offset in PAs appears to be preferred by buyers as, besides being perpetual (Giannichi et al., 2018), they tend to be low-cost (Freitas et al., 2017). Thus, in policy scenarios 1 and 2, I first attempted to exhaust demand inside the respective PAs. Then, CRA trade was simulated with the remaining demand.

To simulate offset (PAs and CRA), an algorithm was developed (Appendix 3, A3.5) whereby each buyer sought the best-matching seller. In the case of offset in PAs, I assumed that buyers would be willing to purchase areas that were equivalent or up to 20% larger than their LR deficit, given their low-cost. If the conditions of area equivalence were met, a buyer was considered compliant. If not, a buyer remained non-compliant and available for CRA trade. As CRA is a hectare-by-hectare offset market, each buyer looked for a seller that had the most similar area of native vegetation surplus to their deficit. A buyer was then considered compliant when they managed to offset all their deficit within the number of transactions allowed: we only allowed a limited number of transactions (one, for offset in PAs, and three for offset as CRA) as the general behaviour of buyers and sellers is to minimize transaction costs associated with each trade (Reid et al., 2015). If a buyer remained non-compliant after CRA trade, they were automatically allocated to offset through natural regrowth by default. Importantly, the assumptions above are simplifications of a complex and embryonic offset policy. There is still no data on offsets in PAs and CRA as they are still in early or pending regulatory stages. I submitted the simulations to a sensitivity analysis (Appendix 3, A3.7) (e.g. changes in the 20% limit of private land inside PAs and the number of transactions in CRA) to assess whether our results are robust.

The best-match algorithm was iterated for each policy scenario at each spatial scale. After each of the 15 simulations, I computed the sum of total offset (in Mha) for each of the three compliance options: offset in PAs, CRA, and regrowth. Offset in PAs was subset into two conservation outcomes: the area of potential regrowth and the area representing non-additional offset. Private land in PAs, after acquired by buyers, must be donated to the statutory environmental agency, making their non-forested portions likely to be allocated to regrowth. The area covered by natural vegetation was therefore considered non-additional, as it is already protected. Total offset with CRA was also subset in two conservation outcomes: the avoided deforestation and non-additional offset. Avoided deforestation corresponded to offsets occurring in unprotected native vegetation (e.g. vegetation that can be deforested). Lastly, offsets through regrowth outside PAs was computed as a single conservation outcome.

To calculate total additionality for each simulation, I summed avoided deforestation and regrowth (inside and outside PAs), assuming that these are both conservation benefits that would not occur in the absence of the offset scheme. Non-additional outcomes represented offsets in already protected vegetation that are mostly in the land of smallholders and settlements. Thus, the key conservation outcomes of this analysis were avoided deforestation, regrowth and total additionality. Finally, for each policy scenario and spatial scale, I calculated the percentages of each conservation outcome based on the total deficit, to assess the proportion of total forest deficit that was effectively converted to a conservation gain.

3.2.3 Optimal spatial scale with efficiency frontiers

I constructed efficiency frontiers to assess the trade-off between avoided deforestation and regrowth for the five spatial scales for each scenario. Efficiency frontiers illustrate a set of optimal situations where returns of one objective cannot be increased without diminishing returns of another (Gourevitch et al., 2016). In this case, the returns were avoided deforestation and regrowth at each scale.

This approach considers a hypothetical frontier representing a set of optimal values of avoided deforestation or regrowth. If any conservation outcome, at any spatial scale, lies on the hypothetical frontier, that given scale was interpreted as optimal to provide the maximum return of one outcome or the other. Frontiers were calculated as slopes (Appendix 3, A3.6), based on the differences between the maximum and minimum percentages of avoided deforestation and regrowth resulted from the largest to the smallest spatial scale (biome to municipality).

Percentages of avoided deforestation and regrowth were plotted as curves showing the five spatial scales as points connected by lines, in each policy scenario. Although the lines did not represent a series of values between the spatial scales, I assumed that if other scales existed in between, they would follow the same trend.

3.3 Results

The total native vegetation deficit across the Brazilian Amazon was 4.94 Mha whereas the total supply of native vegetation that could be used for compensation (50 Mha) was 10 times greater. Of this, 8.8 Mha could be legally deforested according to current legislation. Of the 41 Mha that could not be legally deforested, 17.8 Mha was in settlements and 13 Mha in already protected vegetation, such as private land inside protected areas. Small landholdings and non-additional sellers could offer 8.5 and 1.5 Mha, respectively. There were substantial differences in the spatial distribution of the deficit. Mato Grosso, Pará and Rondônia contributed 80% of the total deficit, with the northern Mato Grosso and south-eastern Pará containing around half of the deficit (2.3 Mha). These regions are inevitably likely to absorb much of the demand for surplus.

3.3.1 Effect of spatial scale

Simulations showed three main results. Firstly, as scales became smaller, the area of offsets via avoided deforestation decreased and the area of offsets via regrowth increased (Figure 3.1, Table 3.2). Across all scenarios, offsets via avoided deforestation remained higher than regrowth at all scales, except at the municipality level, when more offsets were allocated to regrowth. This pattern was observed because whilst some municipalities hold large amounts of forest deficit and little surplus, others have vast amounts of surplus and very little deficit. At the municipality level, this imbalance becomes more evident, as municipalities with large amounts of deficit had little surplus to offset. Consequently, as scale decreases, we observed an increased contribution of regrowth to total additionality and a decreased contribution of avoided deforestation (Figure 3.1).

Secondly, the total area directed to conservation was larger in an offset scheme implemented at smaller scales, than in a scheme allowing offsets over large scales. Using scenario 1 as an example (Figure 3.1), 2.07 Mha (41.9%) of the total deficit resulted in avoided deforestation and regrowth at the municipality level, compared to 1.38 Mha (27.8%) at the biome level (Table 3.2).

Thirdly, spatial scales also altered the area of offsets inside PAs. As the scale of implementation was reduced, offsets inside PAs declined substantially (Table 3.2). The total supply of private land inside PAs would likely be enough to absorb the entire total deficit when using larger scales (e.g. biome) and result in very little additionality. However, our simulations showed that reducing the spatial scale also reduced offsets inside PAs, as high supply from PAs is less available at smaller scales.

The sensitivity analysis showed that increasing the best-match limit of offset in PAs from 20% to 150%, resulted in an increase of only 4% of the total offset, at all scales (Appendix 3, Table A3.2). This result indicates that, even if the best-match assumptions established were more flexible, the findings showed here would likely remain the same, and that smaller scales would still result in more additionality when compared to larger scales.

In all scenarios, across all spatial scales, most of the offset was non-additional. In scenarios 1 and 2, offsets in PAs generated little regrowth compared to the total offset. For CRA offsets, avoided deforestation was lower than the non-additional offsets. Overall, the total additionality was smaller than 50% in all scenarios, with scenario 3 resulting in the greatest total additionality across all scales (Table 3.2).

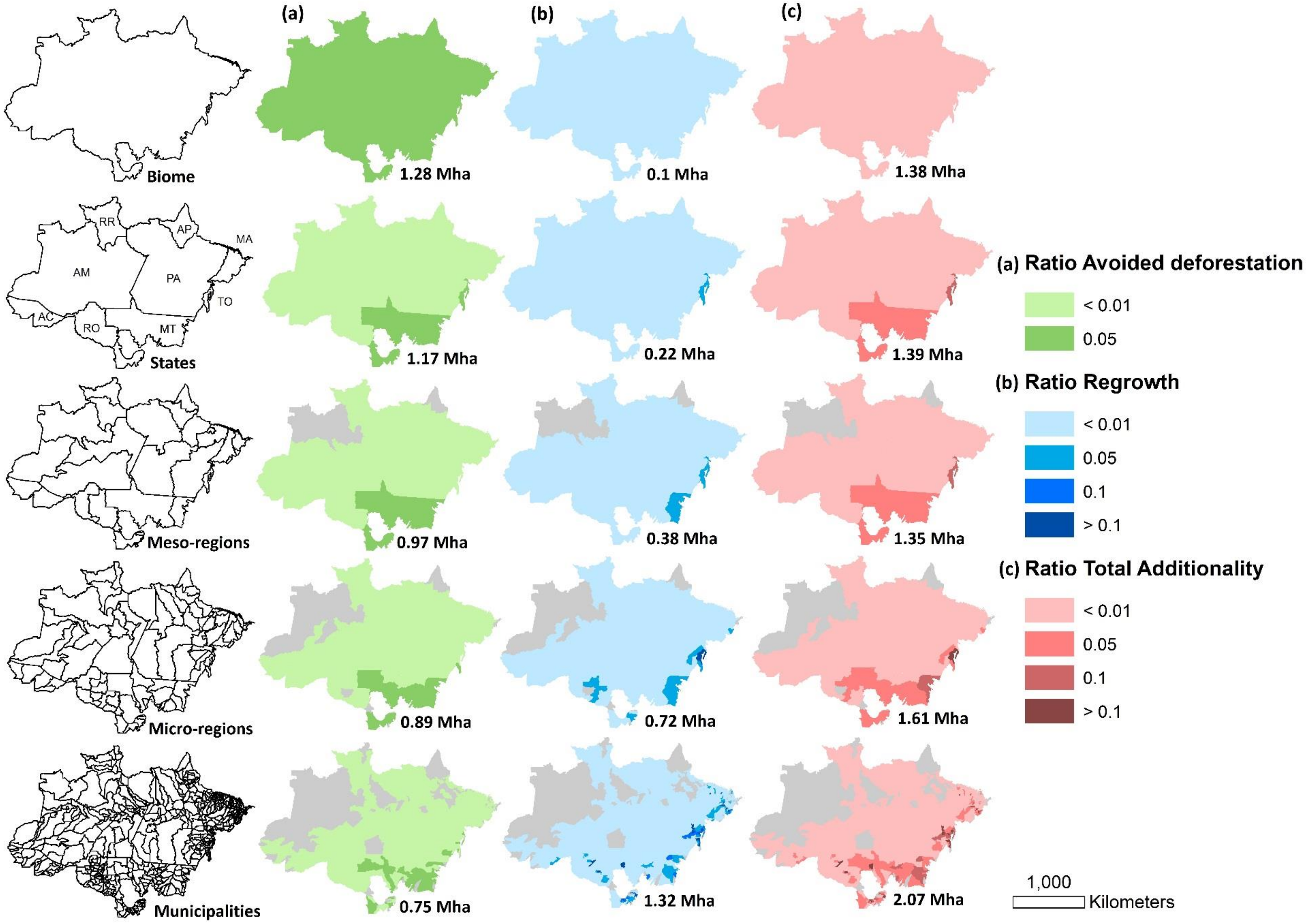
(a)
(b)
(c)
Biome
1.28 Mha
0.1 Mha
1.38 Mha
RR
AP
MA
AM
PA
TO
AC
RO
MT
States
1.17 Mha
0.22 Mha
1.39 Mha
Meso-regions
0.97 Mha
0.38 Mha
1.35 Mha
Micro-regions
0.89 Mha
0.72 Mha
1.61 Mha
Municipalities
0.75 Mha
1.32 Mha
2.07 Mha
(a) Ratio Avoided deforestation
< 0.01
0.05
(b) Ratio Regrowth
< 0.01
0.05
0.1
> 0.1
(c) Ratio Total Additionality
< 0.01
0.05
0.1
> 0.1
1,000
Kilometers

Figure 3.1 Expected spatial distribution and extent of conservation outcomes (avoided deforestation, regrowth and total additionality) in each spatial scale, for policy scenario 1. Maps in the far left column show boundaries of the scales, rows represent the five nested spatial scales. At state-level is given the acronym of each of the nine states: AC (Acre), AM (Amazonas), AP (Amapá), MA (Maranhão), MT (Mato Grosso), PA (Pará), RO (Rondônia), RR (Roraima) and TO (Tocantins). Maps show conservation outcomes as a proportion of the total area of the spatial scale units. Shades of (a) green, correspond to avoided deforestation; (b) blue, regrowth; and (c) red, total additionality. Darker shades represent more of a given conservation outcome. Light grey shades show areas where buyers were absent. Numbers under each coloured map show the sum of the given conservation outcome across all spatial scale units, in Mha.

Table 3.2 Total offsets and conservation outcomes in protected areas (option 1), CRA trade (option 2) and regrowth (option 3) in million hectares (Mha), for each spatial scale and policy scenario (PS). The sum of the total offset for each option corresponds to the total native vegetation deficit (4.94Mha). Total offset inside PAs resulted in regrowth inside PAs as a conservation outcome and total offset with CRA resulted in avoided deforestation (avoided). Regrowth outside PAs was a single conservation outcome by itself. Total additionality is the sum of both avoided deforestation and regrowth (from inside and outside PAs) and total non-additionality is the sum of offsets that occurred in already protected standing vegetation. Each conservation outcome has a percentage given in bold and in brackets, calculated based on the total deficit. The percentage of total additionality and non-additionality sums to 100%.

PS	Spatial Scale	Protected Areas (Mha)		CRA Trade (Mha)		Regrowth (Mha)	Total additionality	Total non-additionality
		Offset	Regrowth	Offset	Avoided	Offset		
1	Biome	1.36	0.1 **(2)**	3.58	1.28 **(25.8)**	0.0005 **(0.01)**	1.38 **(27.8)**	3.56 **(72.2)**
	State	1	0.09 **(1.9)**	3.82	1.17 **(23.6)**	0.13 **(2.6)**	1.39 **(28.1)**	3.55 **(71.9)**
	Meso	0.68	0.07 **(1.3)**	3.95	0.97 **(19.6)**	0.31 **(6.2)**	1.35 **(27.1)**	3.59 **(72.9)**
	Micro	0.47	0.06 **(1.2)**	3.81	0.89 **(18.1)**	0.66 **(13.3)**	1.61 **(32.6)**	3.33 **(67.4)**
	Municipality	0.24	0.03 **(0.6)**	3.41	0.75 **(15.1)**	1.29 **(26.2)**	2.07 **(41.9)**	2.87 **(58.1)**
2	Biome	0.36	0.005 **(0.1)**	4.58	1.48 **(30)**	0.0004 **(0.0008)**	1.48 **(30.1)**	3.46 **(69.9)**

	State	0.18	0.003 **(0.07)**	4.63	1.3 **(27.5)**	0.13 **(2.6)**	1.43 **(30.7)**	3.51 **(69.3)**
	Meso	0.17	0.003 **(0.07)**	4.45	1.1 **(22.6)**	0.32 **(6.5)**	1.42 **(29.2)**	3.52 **(70.8)**
	Micro	0.06	0.001 **(0.03)**	4.20	1 **(21.2)**	0.68 **(13.8)**	1.68 **(35)**	3.26 **(65)**
	Municipality	0.01	0.0003 **(0.007)**	3.72	0.84 **(17)**	1.21 **(24.4)**	2.05 **(41.4)**	2.89 **(58.6)**
3	Biome	-	-	4.94	1.64 **(33.2)**	0.0004 **(0.0008)**	1.64 **(33.2)**	3.3 **(66.8)**
	State	-	-	4.73	1.48 **(29.9)**	0.21 **(4.3)**	1.69 **(34.2)**	3.25 **(65.8)**
	Meso	-	-	4.62	1.20 **(24.2)**	0.32 **(6.5)**	1.52 **(30.7)**	3.42 **(69.3)**
	Micro	-	-	4.26	1.06 **(21.5)**	0.68 **(13.8)**	1.74 **(35.3)**	3.2 **(64.7)**
	Municipality	-	-	3.63	0.84 **(17)**	1.31 **(26.5)**	2.15 **(43.5)**	2.76 **(56.6)**

3.3.2 Different conservation outcomes at different scales

The efficiency frontiers showed that both biome and municipality levels are the best scales to implement the offset scheme if the objective of the offset strategy is to preserve standing forest or promote secondary forest growth, respectively. Avoided deforestation was maximized at the biome level whereas regrowth at the municipality level, across all scenarios (Figure 3.2). At intermediary scales (state, meso-region and micro-region), neither avoided deforestation nor regrowth were maximized, except in scenario 3, where at state-level both conservation outcomes were also maximized. However, maximizing avoided deforestation at the biome level resulted in almost no regrowth, whereas the municipality level fostered regrowth without substantially reducing avoided deforestation.

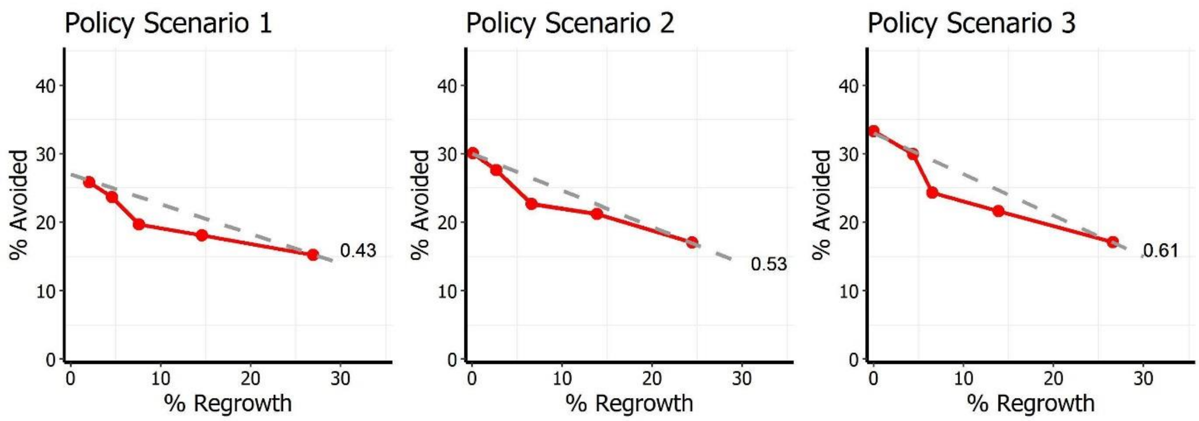

Figure 3.2 Avoided deforestation and regrowth (percentages from total deficit) under three policy scenarios. Red dots on the curves show percentages measured at five spatial scales: biome, state, meso-region, micro-region, municipality (left to right). Grey dashed lines show efficiency frontiers. Dots that lie on the efficiency frontiers are the most efficient spatial scale for either avoided deforestation or regrowth.

In all policy scenarios it is observed a decline in the efficiency of avoided deforestation offsets at the intermediary scales, mostly at meso and micro-regions (Figure 3.2). This could be explained by a significant spatial limitation in terms of area, when restricting the trade from state to meso-region. In Pará state, for example, at state level, offsets can occur within an area of nearly 1,200,000 km^2. When restricting offsets to meso-regions, the entire state is sub-divided into four smaller areas (Figure 3.1). At micro-regional level, the state is then sub-divided into eight smaller areas (Figure 3.1). Such spatial limitation reduces the number of potential areas available for avoided deforestation offsets, especially in regions of high deforestation rates, such as regions in Pará, Mato Grosso and Rondônia states. For this same reason, an increase in regrowth is observed, as buyers would be limited to this offset option only, with the lack of forest surpluses to offset via avoided deforestation.

3.4 Discussion

The offset simulation exercise showed that the larger spatial scales (e.g. biome level) achieved more avoided deforestation, compared to smaller spatial scales (e.g. municipality level) which were associated with more regrowth. However, importantly, avoided deforestation was not substantially reduced at smaller spatial scales, meaning the greatest total benefit to conservation in terms of area was achieved at the smallest scale of offset implementation. All policy scenarios showed similar areas of avoided deforestation and regrowth.

These results suggest that, in offset schemes, the choice of large or small spatial scales of implementation will influence the outcomes for conservation. For example, larger spatial scales could favour the protection of old-growth and remote habitats through averted loss. The protection of old-growth habitats would ensure that conservation values such as above and belowground carbon storage, hydrological services, and the diversity of flora and fauna are maintained (Watson et al., 2018). Although not necessarily under imminent threat, the protection of these areas is extremely relevant for conservation, for being considered a proactive conservation approach (Brooks et al., 2006). Such approach is important as it accounts for areas where many species are endemic, irreplaceable and sensitive to future human impact but are not yet threatened because such impact is currently low (Cardillo et al., 2006). On the other hand, smaller spatial scales could favour restoration and protect secondary-growth habitats, particularly in areas where habitat loss have already occurred. These areas are typically of high vulnerability, where a reactive conservation approach is needed – and often urgent – to prevent more habitat loss (Brooks et al., 2006). The restoration of highly vulnerable and degraded habitats can contribute to increase provision of biodiversity and ecosystem services and improve the environmental quality of the degraded site (Benayas et al. 2009). In places such as tropical forests, passive restoration also allows the growth of secondary forests, and consequently, increases carbon sequestration and above-ground biomass (Chazdon et al., 2016).

The findings presented here have a range of scheme-specific policy implications. Firstly, the FC currently states that CRA offsets must happen in the same biome and, preferably, in the same state (Soares-Filho et al., 2014). However, CRA offsets are still pending regulation, and each state is entitled to restrict the offset scale within their boundaries (Freitas et al., 2017). These findings indicate that restricting offsets to the municipality level would ensure that the scheme results in the greatest additionality. Secondly, to achieve even greater additionality, policy-makers could also primarily target unprotected native vegetation, as more than 50% of offsets occurred in already protected vegetation.

I showed that spatial scales were key to determine trade-offs between averted loss and restoration in offsets schemes. More importantly, these findings highlight that averted loss and restoration could be similarly incentivised by maintaining offsets at small scales. Although larger scales might have more market activity (Walker et al., 2009) and generate more averted loss in untouched habitats, the scheme might result in few conservation gains without strict requirements on the location of the offset (Gordon et al., 2011). Consequently, offsets might take place far from the impacted site, undermining ecological equivalence. In addition, areas that are not under development or land use pressure, tend to have lower conservation costs (McConnell and Walls, 2009). When the decision of where to offset is at the discretion of the buyer, cheaper areas are unavoidably likely to absorb the offsets. This might also lead to little additionality, weakening the conservation potential of the scheme.

Using small administrative boundaries as spatial scales might also be useful to maximise other conservation objectives, in offset schemes that do not explicitly include biodiversity or habitat characteristics in their requirements. For example, maintaining offsets near the impacted site may contribute to preserve similar ecological values when compared to distant sites (Wissel and Wätzold, 2010), avoid future habitat losses of areas under development pressure (Drechsler and Wätzold, 2009) and promote a more connected habitat with larger habitat patches (Helmstedt and Potts, 2018).

Although this chapter uses administrative boundaries as spatial scales, the use of other ecologically-focused criteria to limit constrain where offsets should occur (e.g.

areas of endemism, ecoregions[1], and biogeographical regions) could be argued as more ecologically fit. In fact, this used to be the case of the FC. Prior to its revision in 2012, offsets were determined based on the limits of micro-watersheds (Sparovek et al., 2012). Such determination was amended to administrative boundaries in the revised version under the assumption that would facilitate environmental governance, potentially leading to better conservation outcomes. However, several meso-regions, micro-regions and municipalities seem to have rivers delimiting their boundaries (Figure 3.3, comparison between columns (a) and (b)). In this case, the use of watersheds as spatial scales would likely yield similar results. In addition, rivers have long been recognised as delimiters of biogeographic regions and act as dispersal barriers, generating the current distribution patterns of the Amazon biota (Oliveira, Vasconcelos, et al., 2017). Thus, limiting offsets to small spatial scales, such as municipalities, also represents a more ecologically fit decision to keep benefits localized within similar biota. On the other hand, the use of ecoregions (Olson and Dinerstein, 2002) as another potential ecologically-focused offset scale would likely generate different results, as they do not overlap with the administrative boundaries used here (Figure 3.3, columns (c) and (d)).

The current implementation of the FC offset scheme only considers area, as it is a hectare-by-hectare scheme. Thus, the analysis presented here assumed that averted loss and restoration would be equally additional, as I considered the area allocated to conservation as the key additionality metric. The concept of additionality adopted in this chapter is associated with the conservation benefits that would not occur in the absence of the scheme (Maron et al., 2010). This concept does not attempt to weight or rank distinct conservation benefits. Instead, it treats all benefits equally. However, from an ecological perspective, averted loss and restoration will result in distinct conservation benefits: a hectare of preserved old-growth forest is ecologically different from a hectare of secondary forest. For example, while old-growth forests store more carbon than second-growth forests (Brienen et al., 2015; Watson et al., 2018), their net carbon sequestration rate is significantly higher (Pan et al., 2011; Poorter et al., 2016). Conversely, old-growth forests are irreplaceable in terms of species richness and

[1] Ecoregions are defined as relatively large area of land or water containing a characteristic set of natural communities that share a large majority of their species, ecological dynamics, and environmental conditions (Olson and Dinerstein, 2002).

composition (Barlow et al., 2007). To properly account for the ecological additionality of large and small implementation scales, future research could include potential ecological benefits of averted loss and restoration offset options (e.g. biomass or species similarity between buyers and sellers) resulted from different implementation scales.

While this study provided analysis of how spatial scale could be important for conservation schemes, there are some limitations. For example, price usually influences trade activity between buyers and sellers. Particularly for sellers, price is related to forgone opportunity costs but that is not the case for buyers, who expect price to be much lower than sellers' forgone opportunity costs (Giannichi et al., 2018). Perhaps at smaller scales, where opportunity costs are high, there would be even less averted loss and more restoration, as sellers would expect high returns of their surplus, making restoration a less costly offset option for buyers. However, this might not lead to any substantial impact on the overall additionality. Price could not be included in this analysis due to lack of data per property. Some previous studies accounted for price using opportunity costs as a proxy (Bernasconi et al., 2016; Soares-Filho et al., 2016) at the scale of municipalities, but I believe this only reflects sellers' price preferences. More empirical data on price expectations would be useful in future analyses. It is also worth noting that the algorithm elaborated assumed that all sellers were available for trade which might not be true. However, I believe it would be arbitrary and unrealistic to establish any sort of criteria that would exclude non-participant sellers as there are no data that could support this decision.

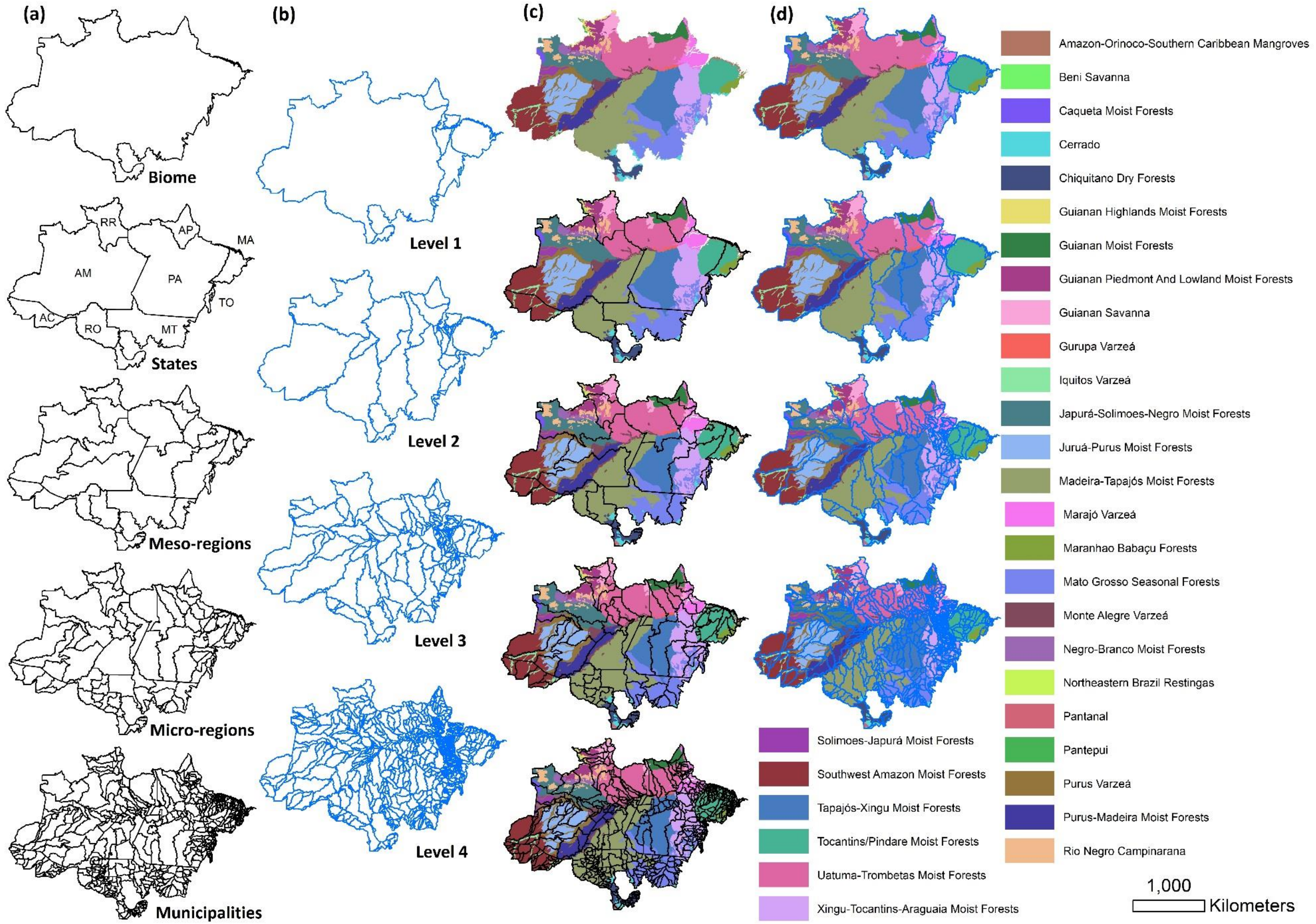
(a)
Biome
RR
AP
MA
AM
PA
TO
AC
RO
MT
States
Meso-regions
Micro-regions
Municipalities
(b)
Level 1
Level 2
Level 3
Level 4
(c)
(d)
Amazon-Orinoco-Southern Caribbean Mangroves
Beni Savanna
Caqueta Moist Forests
Cerrado
Chiquitano Dry Forests
Guianan Highlands Moist Forests
Guianan Moist Forests
Guianan Piedmont And Lowland Moist Forests
Guianan Savanna
Gurupa Varzeá
Iquitos Varzeá
Japurá-Solimoes-Negro Moist Forests
Juruá-Purus Moist Forests
Madeira-Tapajós Moist Forests
Marajó Varzeá
Maranhao Babaçu Forests
Mato Grosso Seasonal Forests
Monte Alegre Varzeá
Negro-Branco Moist Forests
Northeastern Brazil Restingas
Pantanal
Pantepui
Purus Varzeá
Purus-Madeira Moist Forests
Rio Negro Campinarana
Solimoes-Japurá Moist Forests
Southwest Amazon Moist Forests
Tapajós-Xingu Moist Forests
Tocantins/Pindare Moist Forests
Uatuma-Trombetas Moist Forests
Xingu-Tocantins-Araguaia Moist Forests
1,000
Kilometers

Figure 3.3 Maps showing administrative boundaries, watersheds and ecoregions. Column (a) depicts the five administrative boundaries used and column (b) shows four different classification levels of watersheds in the Brazilian Amazon. Level 1 shows the limits of the river basins that the Brazilian Amazon biome comprises (Amazon basin, North Atlantic Basin, Tocantins-Araguaia basin). Level 2 shows the main rivers of these basins. Levels 3 and 4 show different levels of precision of the main rivers inside the Brazilian Amazon biome, with level 4 being the most precise. Columns (c) and (d) superimpose the administrative boundaries and watersheds maps with the ecoregions of the Amazon biome to examine potential overlays. The watershed maps were acquired in the ANA database (Brazil's National Water Agency, available at http://metadados.ana.gov.br/geonetwork/srv/pt/main.home) and ecoregions by TNC (available at http://maps.tnc.org/files/metadata/TerrEcos.xml).

In this chapter I showed that limiting offsets to a small-scale approach yielded greater conservation outcomes. Related conservation schemes, such as some Payment for Ecosystem Services (PES) and REDD+ could also benefit from a more local focus. Typically implemented at national levels, such schemes often face challenges related to governance and distinct jurisdictions rules (Blom et al., 2010). Such challenges result in high transaction costs if buyers (or beneficiaries) and sellers are in different jurisdictions, and scatter potential conservation co-benefits (Salzman et al., 2018). Applying a local focus to nationwide conservation strategies might be a useful way to decrease transaction costs and keep benefits localized, whilst also maintaining national targets. Additionally, keeping restoration near the degraded or impacted site could be particularly helpful for offset schemes in regions where development is predominant and restoration is feasible. Allowing offset schemes to occur more locally might be a way to incentivise the recovery of the lost habitat. Given the vast amounts of degraded land and the recent global efforts to restore degraded landscapes (Verdone and Seidl, 2017), localized strategies to promote regrowth might be a way to achieve ambitious restoration targets. The protection of natural vegetation remnants is important, but alone is not sufficient to deliver long-term conservation goals (Chazdon & Guariguata, 2016). It is crucial that large-scale conservation strategies consider a "think-local" focus to fully attain conservation goals.

Chapter 4: Carbon-biodiversity trade-offs vary according to the implementation scale of an offset scheme

Abstract

Addressing the climate-biodiversity crisis requires solutions that align carbon and biodiversity co-benefits simultaneously. However, carbon and biodiversity are not necessarily spatially interlinked and sharp trade-offs often arise. Such trade-offs have previously been assessed by exploring how ecosystem carbon stocks are related to point estimates of diversity or alpha-diversity. However, the trade-offs involved in protecting carbon stocks and diversity across landscape scales, or beta-diversity remain poorly understood. This is crucial given the urgent global commitments made to achieve the Aichi Targets (established by the Convention on Biological Diversity) by 2020 to avoid further biodiversity loss, and in the Paris Climate Agreement to mitigate climate change, as conservation initiatives are applied across landscapes where there may be substantial variation in diversity and composition. Here, I explore the trade-offs that occur between the protection of carbon and beta-diversity under different implementation scales of an emerging, large-scale conservation initiative – the Brazilian forest offset scheme. I found that at large implementation scales, the most biomass-rich areas are protected, but there is little biodiversity protection across all communities. Conversely, at small implementation scales, highly threatened and very distinctive biodiversity in the context of regional variation was preserved, but this was mostly in biomass-poor areas. These results show that the inclusion of beta-diversity in carbon-biodiversity assessments is crucial to better understand the impacts of conservation initiatives. Specifically, policy makers may be able to alter carbon-biodiversity co-benefits by altering the

implementation scale of conservation initiatives, but will likely face difficult choices as "win-win" solutions may not exist.

4.1 Introduction

There is a growing need in international policy to align multiple conservation objectives, in particular the protection of carbon and biodiversity, to achieve so-called "win-win" solutions and maximise the return on conservation investments (Strassburg et al., 2010; Busch et al., 2011; Phelps et al., 2012b). However, such win-win solutions may be unrealistic, as multiple conservation objectives, such as carbon and biodiversity, are not always spatially co-located (Thomas et al., 2013; Potts et al., 2013). Such spatial mismatch has led to a substantial interest in the assessment of potential trade-offs associated with carbon and biodiversity conservation (Naidoo and Ricketts, 2006; Mccarthy et al., 2012; Phelps et al., 2012b; Gilroy et al., 2014), predominantly in tropical forests where many carbon-focused conservation policies are implemented (Börner et al., 2016).

Several studies have combined carbon and alpha-diversity (i.e. species diversity of a small area, frequently expressed as species richness) metrics to explore carbon-biodiversity relationships and the feasibility of "win-win" solutions. Globally, there is a high spatial congruence between biomass carbon and species richness, although such congruence is unevenly distributed (Naidoo et al., 2008; Strassburg et al., 2010). At continental scales, carbon-biodiversity spatial incongruences are more evident, and many priority areas for carbon conservation do not overlap with biodiversity hotspots (Thomas et al., 2013). Across the tropics, carbon-biodiversity relationships are absent at fine-scales and either weak or absent within continents (Sullivan et al., 2017). These studies suggest that carbon-centred conservation strategies do not automatically conserve biodiversity-rich areas and highlight that win-win solutions are not always feasible and often indicate sharp trade-offs (Phelps et al., 2012a; Thomas et al., 2013; Sullivan et al., 2017).

Locally, such carbon-biodiversity trade-offs may become more apparent and stronger and may be associated with disturbance gradients across the landscape. For instance, among secondary and disturbed primary forests, a positive and strong association between carbon and alpha-diversity is found, whereas in undisturbed forests such association is not statistically significant (Ferreira et al., 2018). In regenerating forests near pastures and old-growth forest mosaics, carbon and alpha-diversity are even more strongly related (Gilroy et al., 2014). Large forest fragments also show a positive relationship between carbon and alpha-diversity, and especially fragments near old-growth forests (Magnago et al., 2015). In agricultural land-use mosaics, such positive carbon-biodiversity relationships are also present, although only evident with high-resolution carbon data (Deere et al., 2018). Such landscape-level studies use species richness (alpha-diversity) to provide evidence on the trade-offs involved in aligning carbon and biodiversity and show that the protection of carbon-rich areas alone might not suffice to also protect biodiversity.

The scales of conservation strategies, however, are larger than points or plots (Sullivan et al., 2017; Boyd et al., 2018; Duchelle et al., 2018). In such cases, to better understand carbon-biodiversity trade-offs, beta-diversity (i.e. how species composition varies through space) is as important as alpha-diversity (Condit et al., 2002; Karp et al., 2012; Socolar et al., 2016). Beta-diversity can be viewed as a measure that compares diversity at two different scales – alpha and gamma diversity (Baselga, 2010), with gamma being the species diversity of a relatively large area (e.g. ecoregion, biome). In conservation, beta-diversity is often distinguished between two patterns: nestedness and spatial turnover (Baselga, 2010). Nestedness occurs when the biotas of sites with smaller numbers of species are subsets of the biotas at richer sites whereas spatial turnover occurs when species present at one site are absent at another site, but are replaced by other species absent from the first. Measuring both phenomena indicate distinct conservation strategies that might target richest sites (nestedness) or multiple sites (turnover) (Socolar et al., 2016). The assessment of beta-diversity and its associated phenomena is important for designing protected area selection, land-use policies, offset schemes, and climate change mitigation strategies (Socolar et al., 2016). However, the use of beta-diversity as a tool to inform conservation decision remains underexplored (Draper et al., 2019), specially across large-scale environmental gradients (Socolar et al., 2016; Bergamin et al., 2017).

In schemes which target avoided deforestation or offset carbon emissions via carbon payments (e.g. REDD+), the implementation scale, whether large or small, does not influence in the overall conservation outcome. Carbon *per se*, is a transferable "currency" in which the carbon losses in one area, could be acceptably compensated for with carbon gains in another area (Phelps et al., 2012a). Conversely, in schemes that include biodiversity or habitat hectares as their main compensatory "currency" (e.g. biodiversity offsets), the implementation scale is crucial to generate meaningful conservation outcomes as the biodiversity losses in one area are not necessarily transferable to equivalent gains in another area (Potts et al., 2013). For instance, as species composition similarity decreases with distance and over large environmental gradients (Anderson et al., 2010; Bergamin et al., 2017), habitat loss over large scales contributes to considerable decline in species turnover, eventually homogenizing biodiversity (Karp et al., 2012; Püttker et al., 2015). It is particularly important to consider these relationships to effectively administer conservation initiatives placed at large scales. The use of species distributions to inform large scale conservation initiatives should reveal important regional patterns to properly assess carbon-biodiversity trade-offs across space (Van De Perre et al., 2018).

This chapter therefore investigates carbon-related and biodiversity trade-offs as co-benefits of an emerging large-scale conservation strategy. I combined a pan-tropical aboveground biomass (Avitabile et al., 2016) and a large-scale beta-diversity dataset, comprising terrestrial angiosperm, arthropods, and vertebrates (Strand et al., 2018), to assess whether large- versus small-scale conservation scheme implementation results in different outcomes for conservation for these two variables. The results obtained in Chapter 3 are used here to compare carbon-biodiversity trade-offs of the Brazilian forest offset scheme under two possible subnational scheme implementation scales: biome and municipality. Subnational jurisdictions (i.e. states and municipalities) are increasingly being used as governance units in which conservation initiatives are implemented (Boyd et al., 2018; Duchelle et al., 2018). The focus of this analysis is the Amazon biome, one of the world's largest stores of biodiversity and carbon (Ter Steege et al., 2006).

4.2 Methods

4.2.1 Assessing environmental co-benefits at large and small implementation scales

The results obtained in the previous chapter were used here to explore potential carbon-biodiversity co-benefits in offset schemes. Chapter 3 provided the extent of potential areas protected under avoided deforestation and forest regrowth as conservation outcomes of an offset scheme implemented at five different scales of implementation and under three different policy scenarios. To compare co-benefits at large and small implementation scales, I used biome and municipality, the largest and smallest scales, respectively, as they generated distinct outcomes (Figure 4.2). Of the three policy scenarios simulated, here I used policy scenario 1 (the one allowing offsets inside all protected areas), as this is the most likely scenario to be implemented in Brazil. In the simulations made, each offset transaction, or "contract", made between a seller with forest surplus and a buyer with forest deficit resulted in areas allocated to avoided deforestation. Buyers who did not offset their deficit with a seller were allocated to offset via regrowth, by abandoning their deforested deficit and allowing vegetation to recover naturally. Regrowth resulted from contract with sellers located inside protected areas were also included in this analysis. Therefore, the resulting areas of avoided deforestation and regrowth in Chapter 3 were used here to estimate the potential biomass stock protected under avoided deforestation and potential biomass accumulation from areas allocated to regrowth.

This analysis assumed that areas under avoided deforestation and regrowth were established as perpetual offset strategies. This is realistic for regrowth as once these areas are abandoned, they can no longer be deforested as these are not forest surpluses. By assuming perpetuity for areas allocated to regrowth, it was also assumed that these areas would eventually achieve their old-growth biomass values (Poorter et al., 2016) as well as a significant recovery of tree and animal diversity (Barlow et al., 2007; Gilroy et al., 2014; Edwards et al., 2017). Avoided deforestation offsets, on the other hand, are not necessarily perpetual, although it is known that perpetual offsets are a real preference of buyers (Giannichi et al., 2018). Currently, there is no study or data available that could inform a time-oriented assumption for avoided deforestation offsets. For this analysis, it was assumed that avoided deforestation contracts would be perpetual and so therefore biomass and biodiversity values for these areas were considered constant across time.

4.2.2 Quantification of carbon-related co-benefits

My main objective was to assess whether avoided deforestation contracts between sellers and buyers resulted in biomass gains (i.e. whether buyers traded lost biomass for greater existing biomass stock in sellers' areas) or biomass losses (if buyers traded lost biomass for lower existing biomass stock). For that, I used a pan-tropical aboveground biomass (AGB) map published by Avitabile et al. (2016) that estimates aboveground biomass per hectare, at 1km resolution, for the Brazilian Amazon (Figure 4.2A). Avitabile et al. (2016) produced a "fused" map by combining existing biomass maps, field data and local high-resolution biomass maps.

First, the 95th percentile of biomass (Mg ha^{-1}) value (hereafter named *Bmax,* Eq. 4.1) were extracted for each rural property i that participated in the offset scheme as buyer and seller. For the sellers, we assumed that the *Bmax* was the maximum biomass stock value of their forest surplus protected under avoided deforestation. For the buyers, we assumed the *Bmax* value was the biomass accumulation potential if buyers decided to abandon their forest deficit, thus choosing regrowth as the offset option. Then, for each avoided deforestation contract j at biome and municipality levels, I calculated the difference between sellers' $s(j)$ and buyers' $b(j)$ *Bmax (*Δ*Bmax,* Eq. 4.1) to assess whether avoided deforestation offsets resulted in potential biomass stock gains (Δ*Bmax* > 0). As offset via regrowth is the buyer's forest deficit natural recovery, it did not involve contracts between sellers and buyers, hence Δ*Bmax* was not calculated. In this case, only the buyers' *Bmax* values were used to assess biomass accumulation potential for each implementation scale.

$$\Delta Bmax_j = Bmax_{seller,s(j)} - Bmax_{buyer,b(j)} \qquad \text{Eq. (4.1)}$$

For each property, *Bmax* values varied between 0 and 487 Mg ha^{-1}, with a small number of buyers and sellers' properties (0.05% and 0.57%, respectively Figure A.4.1, Appendix 4) showing zero *Bmax* value. Such zero values could be due to high degradation of their forested areas or perhaps the resolution of the dataset did not properly capture *Bmax* values for small properties. Following the assumptions made of maximum biomass stock and maximum potential biomass accumulation, I applied a moving window approach to extract statistics of neighbouring values in the entire image. I employed a 10 x 10 km window, in which the maximum pixel value within that window was extracted, generating a coarser image as an output. Exclusively for the properties that showed a *Bmax* value of zero, the values of the coarser image were used.

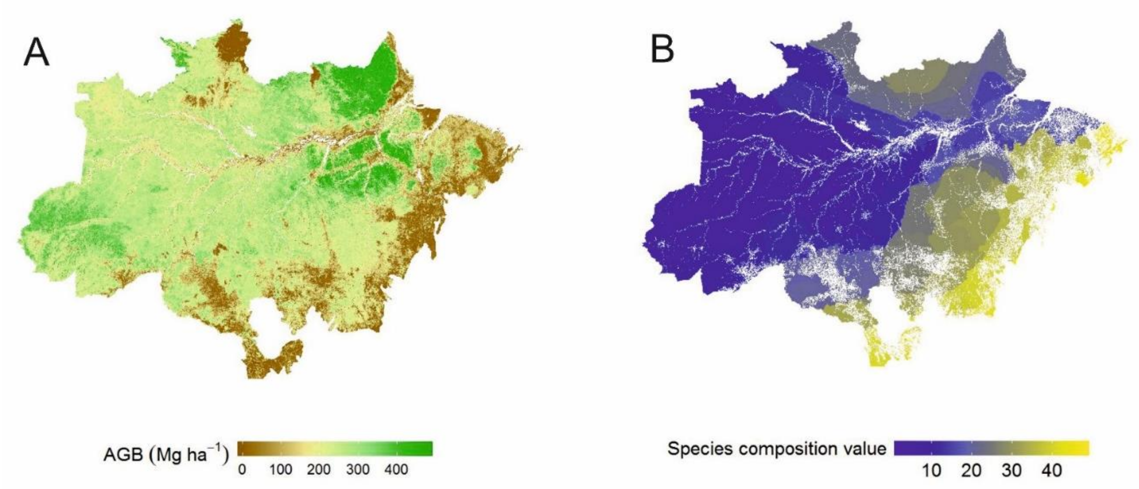

Figure 4.1 Gradients of aboveground biomass (A) and species composition values (SCV, B) used in this study. SCV correspond to regions of unique biota which are represented by discrete values ranging from 1 to 49. Aboveground biomass dataset for the Amazon was derived from Avitabile et al. (2016) and species composition values were acquired from Strand et al. (2018).

4.2.3 Quantification of beta-diversity

Beta-diversity was derived from Strand et al. (2018), which is a comprehensive biodiversity dataset of the Amazon that maps regions of unique biota at 500m resolution based on species occurrence (Figure 4.2B). This biodiversity map compiles occurrence data on terrestrial angiosperm, arthropods, and vertebrates (amphibians, birds and mammals) from several sources, such as researchers, online databases (e.g. Nature Serve, Birdlife International), literature and biodiversity inventories. This compilation computed 113,571 georeferenced species occurrence records. The occurrence records were used to model the spatial variation in species composition to identify regions of unique biota. In summary, the model involved the calculation of species presence/absence per grid cells of 0.5 degrees; a cell-to-cell calculation of Bray-Curtis dissimilarity matrix; and the computation of Non-metric Multidimensional Scaling (NMDS) axis scores of species distribution. The three NMDS scores resulted in an interpolated RGB map to identify regions of unique species composition. Each region of unique species composition is given a colour and a discrete value ranging from 1 to 49 (Figure 4.2B), hereafter as species composition value (SCV). Areas that have no vegetation cover are attributed zero, as if they were voids (Figure 4.2B, areas in white). Details about the methods used and data are available at https://csr.ufmg.br/amazones/biodiversity/.

For this analysis, rivers and waterbodies were masked out. To identify the regions of unique biota wherein the properties of buyers and sellers were located, I extracted the most common SCV within each property i directly from the original dataset (Figure 4.2B). For 9.6% of the buyers, the most common SCV was zero (Figure A.4.2, Appendix 4), most likely because the entire property has been deforested. Sellers did not show any zeros for SCV (Figure A.4.3, Appendix 4). To be consistent with the assumptions about regrowth (see Section 4.2.1), the zero SCV for those 9.6% of buyers had to be substituted. Thus, I employed a 7.5 x 7.5 km moving-window approach, in which the zero values were replaced by the nearest most common SCV. This procedure generated a coarser-resolution dataset of unique species composition (hereafter SCV^*) with values from 1 to 49 (eliminating zero values), which was used to identify the most common SCV for this subset of properties only. Additionally, this reduced-resolution SCV dataset was used to calculate threat ratios (see section 4.2.4 below). All the spatial analysis steps were performed in Google Earth Engine.

As with biomass, I also calculated the difference between sellers' and buyers' SCV (ΔSCV, Eq.2) for each avoided deforestation contract j, to assess whether avoided deforestation contracts at biome and municipality levels resulted in trading similar or dissimilar forest communities based on beta-diversity. Since SCV are discrete values, positive or negative ΔSCV values only indicate that avoided deforestation contracts are trading dissimilar beta-diversity, whereas zero ΔSCV indicates similar communities.

$$\Delta SCV_j = SCV_{seller,s(j)} - SCV_{buyer,b(j)} \qquad \text{Eq. (4.2)}$$

4.2.4 Calculation of protection and threat ratio

To assess whether avoided deforestation and regrowth offsets resulted in the effective protection of threatened biodiversity hotspots, protection and threat ratios were calculated for each forest community, based on the species composition values. The protection ratio (PR) indicates how much area of each SCV area is being protected under avoided deforestation and regrowth and is calculated as follows:

$$PR_i = \frac{\sum_{avoided,i} + \sum_{regrowth,i}}{Area_{SCV_i}} \qquad \text{Eq. (4.3)}$$

where $\sum_{avoided,i}$ is the sum of the area corresponding to avoided deforestation and $\sum_{regrowth,i}$ is the sum of area corresponding to regrowth, both for each SCV value i; and $Area_{SCV_i}$ corresponds to the total area that each SCV occupies in the original dataset. All areas were calculated in hectares and the resulting protection ratio was converted to percentage.

Threat ratios (TR) were calculated to assess the area of each SCV that had undergone past loss (Figure 4.2B, areas in white, attributed zero) as a proportion of the total area each SCV (values 1 to 49) occupied before loss:

$$TR_i = \frac{Area_{SCV_{loss,i}}}{Area_{SCV*_i}} \qquad \text{Eq. (4.4)}$$

where $Area_{SCV_{loss,i}}$ is the area of each SCV that had undergone past loss (i.e. the area corresponding to zero within each region of unique species composition) and SCV_i^* is the total area of each SCV* extracted from the coarser dataset (see section 4.2.3). Threat ratios were calculated in hectares and later converted to percentages corresponding to the proportion of each SCV that had been lost. If a SCV had undergone a loss of > 40%), it was interpreted as highly threatened, as there is evidence that many species, particularly forest specialists, could not tolerate a habitat loss greater than 40% (de Filho and Metzger, 2006; Yin et al., 2017).

4.3 Results

Avoided deforestation and regrowth had distinct distribution patterns at biome and municipality levels (Figure 4.2). Although these are results from the previous chapter, they are important to better understand the patterns observed here related to biomass and biodiversity co-benefits. Biome-level implementation showed a high concentration of avoided deforestation offsets across the southern, northern and central parts of the Amazon, whereas at municipality level, avoided deforestation offsets were highly concentrated in the southern part and relatively moderate in across eastern Amazon. Regrowth was considerably higher across the southern and eastern parts of the Amazon at municipality level. At the biome level, regrowth was only modestly scattered across the entire biome.

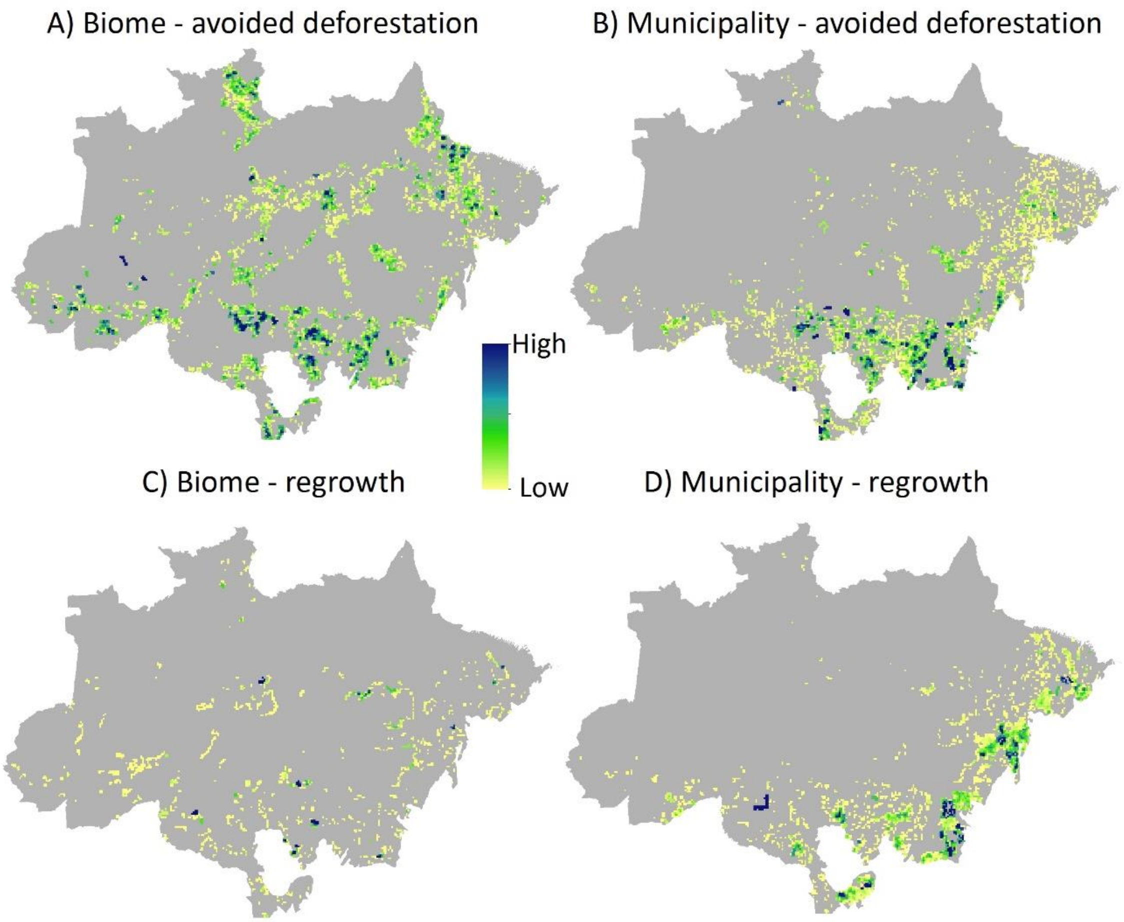

Figure 4.2 Distribution of avoided deforestation and regrowth at large (biome) and small (municipality) scales. Panel A: avoided deforestation areas at biome level; Panel B: avoided deforestation at municipality level; Panel C: regrowth at biome level; and Panel D: regrowth at municipality level. Panels A-D consist of 10km resolution pixels, in which the colour scheme gradient shows high (dark blue) to low (yellow) pixel area coverage of avoided deforestation and regrowth for each spatial scale. Grey shading represents areas where neither avoided deforested or regrowth were observed.

4.3.1 Avoided deforestation biomass co-benefits

Large and small implementation scales showed distinct biomass-biodiversity trade-offs related to the maximum potential biomass stock and accumulation. Figure 4.3A shows the difference between protected biomass under avoided deforestation and lost biomass due to deforestation *(*$\Delta Bmax$) at biome and municipality levels for each avoided deforestation contract. A large implementation scale showed greater biomass-related co-benefits when compared to a small scale (Figure 4.3A, Table 4.1). At biome level, there was a more positive spread of $\Delta Bmax$ and a significantly greater mean when compared to municipality level (biome = 90.87, municipality = 36.28, two sample *t*-test, p-value = 0.0000). In general, this indicates that avoided deforestation offsets at a large implementation scale resulted in biomass gains (i.e. at this scale sellers showed greater *Bmax* values than buyers). On the other hand, the slightly more symmetrical shape of Δ*Bmax* distribution and a mean closer to zero at municipality level (one sample *t*-test, p-value = 0.0000) show that avoided deforestation offsets yielded similar *Bmax* values. Overall, the large implementation scale resulted in the protection of forest with twice as much biomass per hectare, with 0.34 Pg of biomass stock protected under the biome-level implementation compared with 0.17 Pg protected at the municipality level (Table 4.1).

Table 4.1 Area directed to avoided deforestation and regrowth, and potential biomass co-benefits for biome and municipality levels. Avoided deforestation and regrowth are given in million hectares (Mha) and were derived from Chapter 3. Biomass values are given in petagrams (Pg). Biomass stock values show the total of biomass corresponding to the areas of avoided deforestation for biome and municipality levels. Potential biomass accumulation refers to the total biomass that regrowth could accumulate if abandoned long-term. The sum of stock and potential biomass corresponds to the sum of the biomass values for both avoided deforestation and regrowth.

	Avoided deforestation (Mha)*	Biomass stock for avoided deforestation (Pg)	Regrowth (Mha)*	Potential biomass accumulation for regrowth (Pg)	∑ stock and potential biomass (Pg)
Biome	1.28	0.34	0.1	0.007	0.347
Municipality	0.75	0.17	1.32	0.15	0.32

*Results derived from Chapter 3

4.3.2 Potential biomass co-benefits under regrowth

Large and small implementation scales produced distinct outcomes associated with the potential biomass accumulation for areas where the offset option was regrowth. When examining *Bmax* values alone, biome level offsets showed a greater frequency of biomass-rich values (> 300 Mg ha^{-1}) whereas in municipality, there was a high frequency of lower *Bmax* values (< 200), particularly concentrated below 100 Mg ha^{-1} (Figure 4.3B). The respective means (biome = 275.69 ± 111.22, municipality = 141.76 ± 92.69) also highlight such significant difference between large and small scales (two sample *t*-test, p-value = 0.0000). However, in terms of overall frequency and area, regrowth at municipality level generated much greater biomass co-benefits. The potential biomass accumulation at biome level summed 0.007 Pg, given that only 0.1Mha was directed to regrowth (Table 4.1). At the municipality level, however, potential biomass accumulation summed 0.15 Pg, mainly driven by 1.32Mha that were directed to regrowth. Biome and municipality levels showed almost the same biomass benefits when combining avoided deforestation and regrowth offsets. The sum of biomass stock from avoided deforestation and potential biomass accumulation from regrowth were 0.347 Pg and 0.32 Pg for biome and municipality levels, respectively (Table 4.1).

4.3.3 Avoided deforestation biodiversity co-benefits

Biodiversity-related co-benefits also rendered notably distinct outcomes at large and small implementation scales (Figure 4.3C). The distribution of ΔSCV at biome level indicates that large-scale implementation resulted in offsets with dissimilar species composition values, as ΔSCV values significantly differ from zero (Wilcoxon test, p-value = 0.0000). At municipality level, however, the vast majority of ΔSCV values are concentrated around zero (Wilcoxon test, p-value = 0.0003), showing that, at a small scale, avoided deforestation offsets promoted greater biodiversity similarity when compared to a large scale.

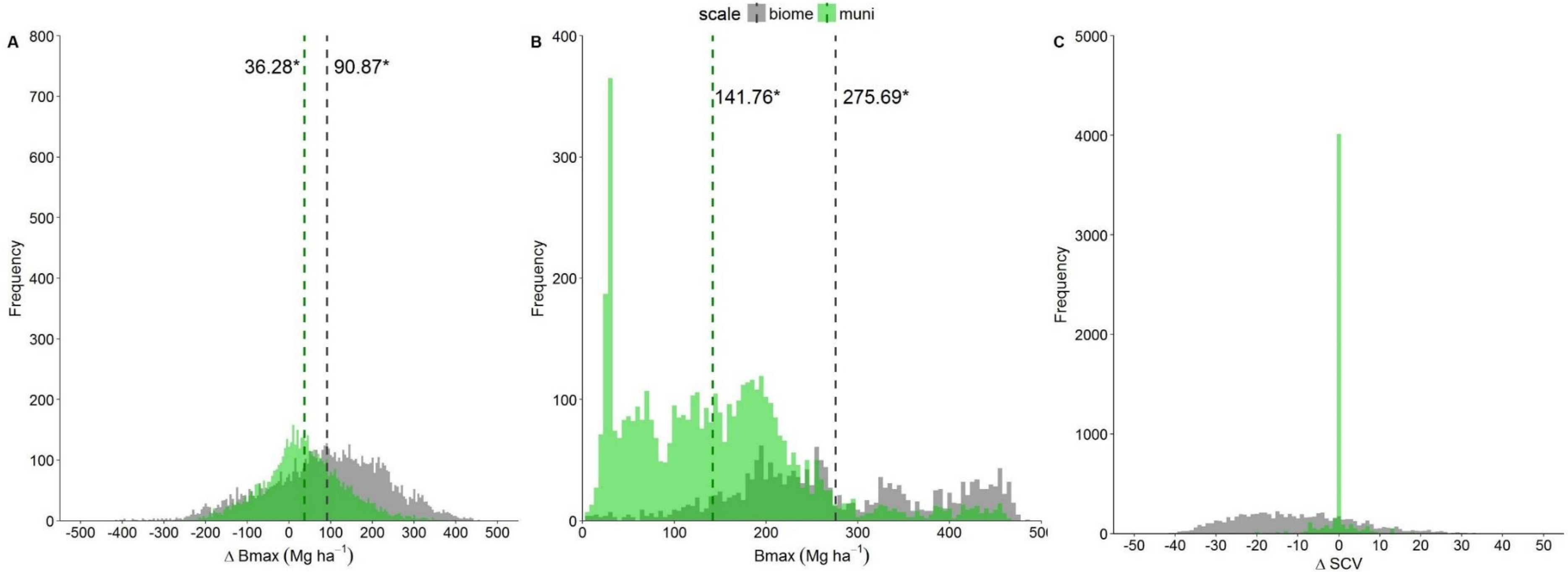

Figure 4.3 Biomass (A and B) and biodiversity (C) differences at large (biome – grey shading) and small (municipality – green shading) offset implementation scales. A) Differences between maximum biomass values (ΔBmax) for each contract made for avoided deforestation offsets. Dashed lines represent ΔBmax mean values for biome (grey) and municipality (green) scales. B) Potential biomass accumulation (Bmax) for deforested areas that were allocated to regrowth as offset option. Dashed lines represent mean Bmax values for biome (grey) and municipality (green) scales. C) Differences between species composition values (ΔSCV) for each avoided deforestation contract. Mean values were not calculated in panel "C" as SCV is a discrete number. Asterisks in panels "A" and "B" represent statistically significant values (p-values = 0.0000).

4.3.4 Threat and protection ratios of beta-diversity under large and small implementation scales

Figure 4.4 shows how much of each SCV was protected under biome- and municipality- level implementation scales, in relation to how threatened each SCV is. The protection ratio shows that biome-level offsets protected no more than 3% of each unique SCV, although such protection was relatively uniform across the 49 discrete scores (Figure 4.4A). Conversely, protection ratios at municipality-level offsets (Figure 4.4B) were much greater, protecting up to 20% of the area of some forest communities. The TR represents how much area of each unique species composition has already been lost due to land cover change. Biome-level implementation protected less than 5% of the area occupied by each of communities that have undergone more than 40% of habitat loss, thus considered highly threatened beta-diversity (Figure 4.4A, points on the right-hand side of the dashed line). On the other hand, municipality- level implementation protected greater areas of highly threatened beta-diversity, protecting 8–20% of the area of communities that have undergone severe loss (70-90% of the area deforested).

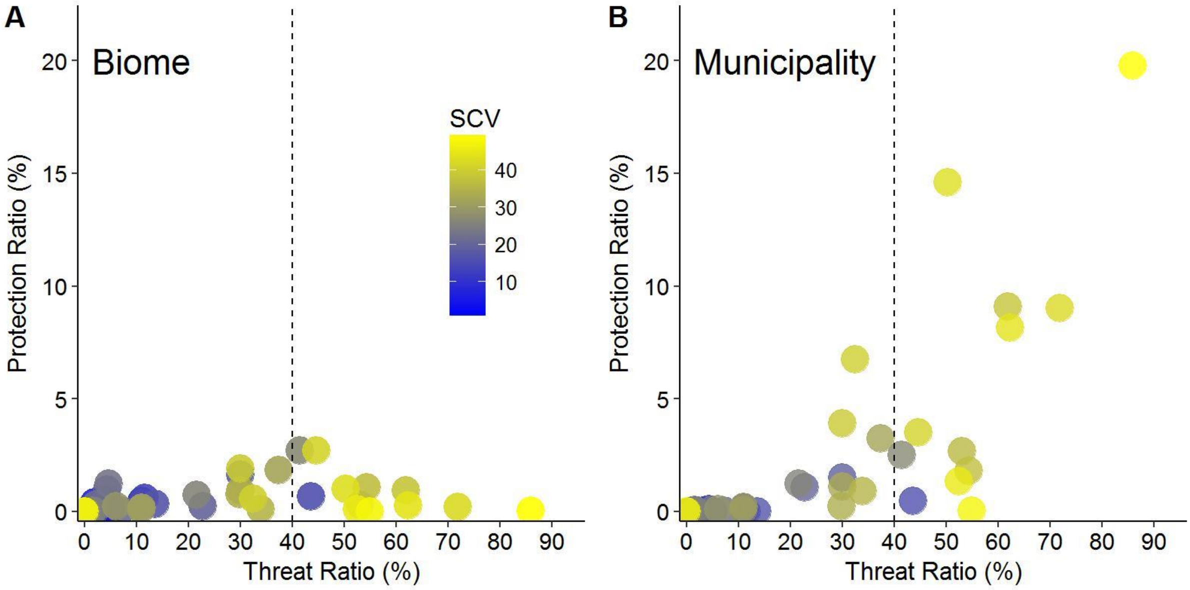

Figure 4.4 Protection and threat ratios for beta-diversity at biome (A) and municipality (B) levels. Protection ratio denotes to the percentage of the area of each species composition value (SCV) that is protected both under avoided deforestation and regrowth in relation to the total area of each SCV. Threat ratio refers to percentage of the area of each species composition value that has undergone past loss in relation to the area each SCV had in the past (see Methods for the calculations). Communities with > 40% of existing deforestation were threshed based on values reported in the literature (see section 4.2.4).

4.4 Discussion

The biomass and biodiversity assessments reveal important trade-offs at large and small scheme implementation scales (Table 4.1, Figure 4.3). In terms of carbon-related co-benefits, large implementation scale drove avoided deforestation offsets to distant biomass-rich areas, resulting in more positive offsets in terms of biomass, when compared to small implementation scale. This could be explained by the fact that, historically, land cover change in the Brazilian Amazon was mostly concentrated in the crescent along the southern and eastern fringe (Skole and Tucker, 1993; Gibbs et al., 2010), in the savanna-forest boundary, areas of low biomass (Saatchi et al., 2007). Thus, biomass-rich areas in the northern and central part of the Amazon are still preserved, which is consistent with the avoided deforestation distribution observed here (Figure 4.2). Conversely, at a small-scale implementation, avoided deforestation offsets did not result in a positive balance, as they had to be made locally, in forest fragments with similar biomass and within the same highly deforested southern-eastern fringe. The use of beta-diversity as a biodiversity indicator also showed clear scale-dependent trade-offs. Firstly, small implementation scale preserved, in general, the same species composition lost with existing one, whilst large scale avoided deforestation offsets showed the opposite. Secondly, small scale also promoted the protection of more biodiversity threatened forest communities (Figure 4.4).

Such distinct scale-dependent trade-offs indicate important considerations when trying to promote win-win solutions in conservation initiatives. For carbon-related co-benefits, it was found that large scale protected 0.34 Pg of biomass whereas small scale protected 50% less, showing that the loss/gain relationship in biomass is easily substitutable (i.e. the loss in one area can be replaced by gains in another, Potts et al., 2013). For biodiversity co-benefits, species composition was non-substitutable at a large-scale implementation, which makes large scale a “win” for biomass but not for biodiversity, as species composition similarity decreases with distance (Anderson et al., 2010; Karp et al., 2012). On the other hand, a small implementation scale could ensure the protection of similar species distributions because it would limit avoided deforestation to occur within several small geographic regions. However, such a win scenario for biodiversity would likely restrict biomass gains.

Regrowth could play an important role to achieve the best outcome possible. Although large implementation scale yielded twice as much biomass stock, potential biomass accumulation from forest regrowth was much greater at small scale. In addition, the combination of biomass stock and potential accumulation was similar for large (~ 0.35 Pg) and small (0.32 Pg) scales. Large implementation scale might result in biomass gains and protect biomass-rich areas, but it is likely to forgo potential recovery of highly fragmented and degraded ones. A large implementation scale could thus be an opportunity to commit to climate change mitigation targets of avoiding and reducing emissions from deforestation, as established in the Paris Agreement (Duchelle et al., 2018), but possibilities around forest regrowth would likely be reduced. On the other hand, an implementation at a small scale could ensure immediate but smaller biomass gains whilst long-term but greater biomass (Poorter et al., 2016; Chazdon et al., 2016) and biodiversity recovery (Barlow et al., 2007; Gilroy et al., 2014; Edwards et al., 2017; Lennox et al., 2018). This is a scenario that could positively address international commitments made to reduce pressures on biodiversity and avoid further biodiversity loss, such as the Aichi Targets (CBD, 2014).

While this analysis showed the importance of considering beta-diversity in large-scale conservation strategies, the input data layer used has limitations. As the beta-diversity map is derived from species occurrence, there are large sampling gaps and deficiencies associated with the biodiversity data use to develop the species composition model. There is a significant area of the Brazilian Amazon that remains uncovered, with no data entry of any of the taxonomic groups used in the input data layer (Oliveira et al., 2017). The knowledge on species composition in the Brazilian Amazon is strongly biased spatially (Oliveira et al., 2016). Although the model used by the authors attempt to correct this error by employing interpolation methods, sampling gaps likely obscures potential higher heterogeneity in terms of species composition. The awareness of this issues is crucial to draw realistic conclusions and adequately inform policy-makers. Other species composition products at biome-scale remain lacking for the Amazon. A potential alternative product that could complement future analysis is a map of ecoregions, which represents regions of outstanding biodiversity (Olson and Dinerstein, 2002). Such analysis could identify whether large or small implementation scales are protecting ecoregions with high levels of diversity, endemism and/or threat.

The input biomass data contain errors. The model employed by Avitabile et al. (2016) to compose the fused biomass map highly relies on the input field and local high-resolution data. Areas where field and high-resolution data were missing are therefore under-represented in this dataset, which compromises the representativeness of AGB variation across the tropics. There are some biomass products available that can provide AGB current estimates for the Amazon biome based on remotely sensed data (Saatchi et al., 2011; Baccini et al., 2012) and others that use plot data to provide current estimates of forest areas and potential biomass for deforested areas (Mitchard et al., 2014; Nogueira et al., 2015). It is important to highlight that remote sensing products show very different spatial patterns of AGB distribution, especially in the Amazon, when compared to field data (Mitchard et al., 2014).

Although this chapter assumed that forests allocated to regrowth would eventually achieve their old-growth biomass values, this remains uncertain. Studies suggest that secondary forests can take nearly 70 years to recover 90% of old-growth forests biomass stock (Poorter et al., 2016). This recovery, however, is highly dependent on water availability (e.g. wetter places shows higher biomass recovery rates) and presence of old-growth forests in the surrounding (e.g. isolated secondary forest patches are likely to have slow biomass recovery rates). The assumption adopted in this chapter is a simplification of a complex process which is not quantified in this study. The values of potential biomass accumulation for regrowth showed here are rough estimates which need further and a more precise assessment.

To the best of my knowledge, this is the first study to explicitly consider beta-diversity to assess carbon-biodiversity trade-offs of a real conservation policy. The findings presented here showed that to protect biomass-rich areas, threatened biodiversity conservation would be compromised. Conversely, to protect threatened biodiversity, low-biomass areas would be automatically protected, along with considerable forest recovery. The use of beta-diversity was crucial to reveal such important spatial patterns in terms of species composition conservation that alpha-diversity assessments would not capture (Van De Perre et al., 2018). A simple qualitative comparison with tree alpha-diversity in the Amazon (ter Steege et al., 2003) shows that areas of high diversity would, overall, overlap with biomass-rich areas, leading to the conclusion that there could be a win-win scenario for carbon-biodiversity co-benefits. However, it may obscure patterns associated with threatened species that are crucial for a thorough biodiversity assessment. Additionally, the use of beta-diversity ensures that regional patterns of species distributions are explicitly accounted for when establishing the implementation scale of conservation initiatives. Given that several conservation initiatives (e.g. REDD+, biodiversity offset schemes, payment for ecosystem services) are often implemented at national or subnational levels, this study indicates that even national initiatives could better balance carbon-biodiversity trade-off if implemented in several smaller regional units.

Policy-makers constantly face challenges when accounting for trade-offs in conservation schemes. On one hand, the Aichi Targets urge – by 2020 – a reduction in rates of biodiversity loss to prevent the extinction of threatened species. In addition, it also promote the protection and restoration of existing habitat contribution to enhance carbon stocks (CBD, 2014). On the other hand, the Paris Climate Agreement states the importance to keep global warming below 2^{o}C by 2030 with avoided deforestation and restoration measures (Duchelle et al., 2018). As the climate-biodiversity crisis needs to be addressed rapidly, there must be an explicit and thorough assessment of the carbon-biodiversity trade-offs involved when establishing the scale of conservation initiatives. The regional implementation of national large-scale conservation initiatives could be a way forward to find acceptable compromises where both carbon and biodiversity co-benefits can be aligned accepting that win-win solutions may not always exist.

Chapter 5: Synthesis and conclusions

This chapter of the thesis will collate the findings from chapters 2–4 and revisit the key objective of each analytical chapter to assess whether they have been achieved. Subsequently, I will provide further critical analysis of the findings and review the potential limitations associated. I will also discuss the research implications of this study for local and global conservation strategies and suggest directions for future work. Finally, the chapter will end with a summary of conclusions that can be drawn from the thesis.

5.1 Overview of findings

The aim of this thesis was to investigate the potential of offset schemes to result in effective conservation gains. To achieve this, I focused on key independent but interlinked elements associated with the design and implementation of offset schemes (e.g. the participation of landowners, the scale of implementation and the potential environmental co-benefits associated) by using a combination of empirical and spatial methodological approaches. The case study used was the largest forest offset scheme in the world, stated in the Brazilian Forest Code, with focus on the Amazon biome. Each of the analytical chapters focused on one specific objective linked to an element of scheme's effectiveness. The first chapter empirically explored the viewpoints of potential buyers and sellers of an offset scheme associated with programme-specific factors. I identified the factors that resulted in sharp divergences between buyers and sellers were contract length and price. In the second and third chapters, using spatial analysis, I tested whether the spatial scales of scheme implementation (e.g. large or small) produced distinct conservation outcomes and then quantified potential carbon and biodiversity co-benefits associated with different spatial scales. In both chapters, large and small spatial scales resulted in trade-offs associated the conservation outcomes of the offset scheme (avoided deforestation and regrowth) as well as the assessed environmental co-benefits (carbon and biodiversity). Although I evidenced such trade-offs associated with spatial scales, the results of this thesis generally support the idea of a "think local" focus to promote more effective and additional conservation outcomes.

In the following paragraphs I summarize the main findings of each analytical chapter and how they contributed to achieve the objectives of this thesis.

5.1.1 Buyers and sellers are differently influenced by programme-specific factors in an offset scheme

To empirically explore the viewpoints of potential participants on programme-specific factors about CRA, I used Q-methodology, which is a semi-quantitative method that provides a structured way to categorise and cluster individual viewpoints (Zabala et al., 2018). I identified three groups of sellers and three of buyers that showed distinct viewpoints about programme-specific factors. In each case, only one group was positive about participating in the scheme. The other two groups of buyers were sceptical about CRA and showed interest in other options such as natural regrowth and offset in protected areas. The other two groups of sellers were not interested in participating for different reasons, such as lack of trust in buyers to proceed with trade and interest of converting the forest surplus into a more profitable use.

I also developed an index to numerically assess the compatibility of buyers and sellers to engage in trade (Trade Compatibility Index – TCI) based on their views about programme-specific factors. I found that the three groups of buyers and sellers showed incompatibilities, mostly related to contract length and price. Sellers preferred short-term contracts, as they associate long-term contracts with missing future and more profitable land-use opportunities, finding which corroborates with other studies in analogous schemes (Bremer et al., 2014; Page and Bellotti, 2015; Yeboah et al., 2015). On the other hand, buyers preferred long-term or perpetual ones, as they seek to solve their environmental liabilities at once and forever, without the need of renewing contracts or finding willing sellers. In relation to price, sellers believed that it should vary according to forgone opportunity costs, especially sellers who manifested interest in deforesting their native vegetation surplus. Buyers, however, stated that offsets should cost well below opportunity costs. Such diverging preferences might challenge the effectiveness of the offset scheme in several ways. Firstly, divergences on contract length might encourage buyers to seek other competing offset strategies in perpetuity, such as offsets in protected areas. Secondly, the mismatches on price expectation may undermine the participation of profit-driven sellers located in areas with high opportunity costs (i.e. areas that typically have undergone high deforestation rates), and potentially result in deforestation. These findings highlighted that participants of conservation strategies cannot be generalized and that such assessments are important to target specific groups of landowners that are unlikely to participate to maximise uptake.

In the discussion of chapter 2, I suggested that a potential strategy to address issues around price and avoid future deforestation is to restrict the spatial scale of trade wherein buyers and sellers interact within sub-regional boundaries with similar opportunity costs and deforestation pressure. In chapter 3, therefore, I tested this premise to assess whether spatial restrictions could potentially impact conservation outcomes of the offset scheme. I also used the contractual preferences identified in chapter 2 to compose different policy scenarios that were combined with the spatial scale restrictions in chapter 3.

5.1.2 The implementation spatial scale results in distinct conservation outcomes

In chapter 3, I tested whether potential implementation spatial scales (large to small) across a range of policy scenarios generated distinct conservation outcomes, i.e. area directed to avoided deforestation and potential forest regrowth. I considered the three main offset options established by the FC: offsets through the acquisition of private land inside protected areas, CRA, and regrowth. By numerically simulating the trade between over 370,000 buyers and sellers across the entire Amazon biome, I showed that offsets placed within a large spatial scale (e.g. biome level) generated a greater area of avoided deforestation (1.28 Mha) but only a small area was allocated to regrowth (0.1Mha). Restricting offsets to occur at smaller spatial scales progressively reduced the area directed to avoided deforestation, while regrowth increased. At the smallest spatial scale (e.g. municipality), avoided deforestation offsets were still observed (0.75 Mha) but the area directed to regrowth was nearly two times greater (1.32 Mha). I also found that the smallest spatial scale resulted in the greatest total area directed to conservation (2.07 Mha, avoided deforestation and regrowth combined), and particularly large shares in already highly deforested regions (e.g. southern and eastern amazon belts).

These results suggest that while large spatial scales may protect more of existing standing forest, restricting offsets to small scales can more effectively contribute the overall additionality of the scheme, by protecting standing forest whilst promoting regrowth, especially in degraded and fragmented areas. I explore these results further in chapter 4 to assess potential environmental co-benefits (e.g. carbon and biodiversity) associated with both large and small spatial scales.

5.1.3 Large-scale implementation protects carbon-rich forests whilst small-scale protects threatened biodiversity

In this chapter I investigated environmental co-benefits (carbon and biodiversity) associated with large and small spatial scales of implementation. I used the area allocated to avoided deforestation and regrowth at large and small spatial scales to quantify biomass storage and potential biomass accumulation and assess potential biodiversity co-benefits. I found that a large spatial scale, avoided deforestation offsets resulted in the protection of biomass-rich forests, potentially avoiding the loss of 0.34 Pg of biomass. Such biomass gains at this scale showed that avoided deforestation offsets were placed in areas with greater biomass values per hectare, that significantly differ from the biomass values observed in regions where most buyers are concentrated. Conversely, at a small spatial scale, such biomass gains were not observed, although avoided deforestation offsets still resulted in the protection of 0.17 Pg of biomass. Nevertheless, regrowth played an important role in small scale offsets, potentially contributing to the accumulation of 0.15 Pg of biomass. The sum of biomass stock and potential accumulation was therefore 0.32 Pg, nearly as much as the total biomass protected at large scale (0.34 Pg).

Using beta-diversity as biodiversity metrics for species composition similarity between buyers and sellers revealed important findings associated with each spatial scale. Firstly, avoided deforestation offsets placed at a small spatial scale protected more similar forest communities than a large scale. This means that offsets made between distant sites did not result in equivalent biodiversity outcomes. In addition, I calculated how much area of avoided deforestation and regrowth offsets combined protected distinct forest communities in relation to the total area each distinct forest community occupied. This analysis demonstrated that a small spatial scale protected more area of highly threatened forest communities (i.e. areas that have already undergone significant habitat loss). Large spatial scale in this case, resulted in little and uniform protection of all forest communities across the biome.

5.2 Implications of this research

The results shown in this thesis have a number of important implications across multiple knowledge levels, including academic and policy-making. Although this research is presented as a case study, its methods and findings could be easily applied to other countries and analogous conservation strategies. Here, I describe potential implications of this thesis' findings to the Brazilian Forest Code; to other conservation schemes implemented globally and to the current debate about effectiveness in private land conservation.

5.2.1 Implications for the Brazilian Forest Code

Brazil has approximately 4.6 million private properties[2] that hold more than 390 Mha of native vegetation (Azevedo et al., 2017). Given the magnitude of these numbers, private land conservation is critical. Knowing the opinion of those who manage these vast amounts of private land – the landowners – is key to the successful implementation of the FC. To the best of my knowledge, I presented the first empirical study that captured viewpoints of landowners about CRA – one of the many forest offset strategies in the FC. Until now, it was unknown whether potential buyers and sellers could be engaged in participation and what factors related to the scheme's design could influence participation. Programme-specific factors such as contract duration, price and transaction costs are easily influenced by policy design (Yeboah et al., 2015). Thus, the results presented in chapter 2 show that CRA design should consider the issues raised by buyers and sellers about contract length and price. Importantly, the viewpoints elicited in this chapter account for a very small share of the rural landowner population. Although the methodology is purposefully designed for small sample sizes, there might be other important viewpoints that were missed in this study – this is discussed further in section 5.3.

In chapter 2, I also showed that many landowners might prefer to acquire private land inside protected areas as their offset strategy. This finding adds to other previous studies (May et al., 2015; Soares-Filho et al., 2016) that consider this offset option problematic, due to a huge oversupply that, in the Amazon biome, could absorb the entire

[2] Data publicly disclosed in the Rural Registration System (CAR) available at http://www.car.gov.br/publico/imoveis/index (last access 22/12/2018).

demand and result in low additionality (i.e. these areas area already protected and it is unlikely that they will face deforestation pressures). The results in chapter 3 contribute to addressing issues related to the oversupply of private land inside protected areas. I showed that restricting the spatial scale of offsets also decreased offsets in protected areas. Given that compensation in protected areas is unlikely to be overruled as it has been already regulated (Brasil, 2016), state-level legislation could restrict offsets to sub-state levels (e.g. municipalities) to resolve issues around the oversupply of private land in protected areas. Such spatial restriction could also benefit total overall additionality, as documented in chapter 3. The current way that the FC legislates CRA and other offset mechanisms is perceived and non-additional as many offsets take place where native vegetation is already protected by (Freitas et al., 2017). I demonstrated that offsets placed with municipalities boundaries resulted in a greater area allocated to conservation. I also highlight that this chapter included limitations, such as a simplification of buyers' decision to determine their offset strategy. This, and other limitations of this chapter are also discussed further in section 5.3.

The findings in chapter 4 highlight that small scale implementation has the potential to protect highly threatened biodiversity, particularly in regions that have undergone nearly 90% of habitat loss in the eastern Amazon, in the states of Maranhão and Tocantins. This finding also calls attention to a sub-state implementation of the offset strategies as it could help Brazil meet the goals established in the National Biodiversity Strategy and Action Plan submitted to the Convention on Biological Diversity (CBD). For example, by 2020 as part of the Aichi Targets, Brazil has committed to conserve at least 30% of the Amazon biome through the protection of areas, such as legal reserves and prioritize the restoration of highly degraded biomes (Brazilian Ministry of Environment, 2017).

Brazil has made important commitments in the Paris Agreement by submitting ambitious targets for avoided deforestation, forest restoration and biodiversity conservation under the NDCs (Nationally Determined Contributions) in order to contribute to the 2°C goal (Brazil, 2015). As stated in the document, the Forest Code is a key element to achieve zero illegal deforestation in the Amazon and restore over 12 Mha of forests by 2030. Thus, the implementation of FC at municipality level can contribute to effectively achieve these targets.

5.2.2 Implications for global market-based instruments for conservation

One of the biggest challenges in the implementation of conservation strategies is the definition of the "right" spatial scale, as social ecological processes operate at multiple scales, and the definition of a single unit of implementation might fail to include important dynamics (Baylis et al., 2016). The combination of all the findings presented here can provide useful insights to this debate. While I showed that conservation strategies implemented at large scale might yield positive conservation outcomes, greater gains were observed at small scales, suggesting that smaller implementation units might be a way forward to improve effectiveness of conservation strategies worldwide. Although small units of implementation might not provide the ideal "win-win" scenario for conservation gains, it revealed important dynamics related to biodiversity conservation and additionality that are key to schemes' success (Maron et al., 2013). In additional, these results are consistent with PES strategies, for example, that seem to be more effective in terms of social and ecological gains when implemented at local levels (Grima et al., 2016).

Each analytical chapter, in isolation, has also important key insights that contribute to the private land conservation debate. For example, in chapter 2, I showed that buyers and sellers have distinct perceptions about a conservation scheme. Such distinction between these two groups is often overlooked when evaluating landowners' participation in conservation schemes (Bastian et al., 2017). The results of this chapter highlight the importance of acknowledging that buyers and sellers of MBIs show different interests and to consider them as single entity might undermine scheme effectiveness. In addition, the findings of chapters 3 and 4 provide similar contributions to implementation of conservations strategies, in particular REDD+ and biodiversity offsets. The use administrative units (e.g. municipality, county, state) could be a useful and straightforward way to assess the effectiveness of conservation strategies. In REDD+, for instance, governance units are increasingly promoted to implement projects within more legally defined territories (Boyd et al., 2018). The carbon-biodiversity trade-offs associated with the different administrative units documented in chapter 4 could help the assessment of future REDD+ project implementation and provision of biodiversity co-benefits. Such carbon-biodiversity trade-offs have already been explored but only at landscape levels (Gilroy et al., 2014; Ferreira et al., 2018).

In the context of biodiversity offsetting schemes, there is evidence that averted loss offsets could contribute to the protection of important existing habitat whilst regrowth near the impacted area can promote ecological equivalence as biodiversity and ecological processes are spatially correlated (Hartig and Drechsler, 2009; Kiesecker et al., 2009; Maron et al., 2010; Gordon et al., 2011). The results shown in chapter 3 and 4 are consistent with such patterns. Avoided deforestation offsets across large spatial scale protected biomass-rich forests while offsets at small scales promoted more ecological equivalence between forest communities. The findings of chapter 3, in particular, contribute to the challenge of achieving additionality in biodiversity offset schemes (Maron et al., 2013) by showing that offsets near the impacted site (e.g. at a small spatial scale) yielded more additional offsets for both potentially restoring highly degraded areas and avoiding future habitat loss in regions of high deforestation pressure. These findings highlight that using administrative boundaries as implementation units could also be useful to determine the spatial location of biodiversity offsets, as well as the use of conservation planning strategies, which are currently adopted by biodiversity offsets planners (Kiesecker et al., 2009).

Although the findings of this thesis suggest that small-scale implementation of offset schemes have more additional outcomes, such statement should be carefully evaluated. As small-scale implementation tends to allocate more areas to regrowth, it is expected an increase in the total secondary forest area. In tropical forests, if old-growth forests remain unprotected together with business-as-usual scenario, these forests will likely be deforested and reduced in area. This shift can have serious implications to climate change. In the Amazon, for example, the recovery of secondary forests biomass is associated with water availability: in wetter places, secondary forests are more resilient than in drier places (Poorter et al., 2016). As models have predicted a consolidation of the dry season and rise in temperatures across the Amazon (Esquivel-Muelbert et al., 2019), secondary forests will likely be more vulnerable under hotter and drier conditions, which may potentially hinder the recovery of these areas (Poorter et al., 2016). Other factors also contribute to hinder secondary forest recovery, such as land-use intensification (e.g. swidden agriculture) and absence of forest cover in the surroundings (Jakovac et al., 2015; Poorter et al., 2016). Policy-makers should consider the vulnerability of secondary forests under small-scale implementation and take both reactive and proactive conservation approaches (Brooks et al., 2006, see Chapter 3, section 3.4). A reactive approach should be implemented to regenerate lost and/or degraded forests alongside a proactive approach, to protect existing and irreplaceable forest within the landscape matrix, especially in drier areas. This is could potentially be a way forward to effectively achieve meaningful conservation outcomes at smaller scales.

Overall, the findings showed in this thesis provided key insights to private land conservation in general, that, although assessed as a case study, could be easily extrapolated to other contexts around the globe. Private land conservation is an emerging and highly important conservation debate that still faces challenges to achieve effective conservation gains (Drescher and Brenner, 2018). I believe that, by the integration of empirical and spatial assessments, I provided useful tools that could guide future strategies and advance the academic debate.

5.2.3 Contributions of methodological steps

This research employed some methodological steps that could be replicated in future studies. In chapter 2, for example, I developed an index to numerically compare the compatibility of the viewpoints identified with the Q-methodology, the TCI. This index could be employed in other Q-methodology studies that seek to analyse potential compatibilities between two antagonist groups, such as buyers and sellers of MBIs. As the TCI uses the normalised factor scores provided by the Q-methodology and fit them into an equation, every Q-methodology study could easily apply it.

To simulate trade between buyers and sellers in chapter 3, I developed an algorithm that considers the area of forest surplus to offset areas of forest deficit. Other offset mechanisms, such as habitat banking and biodiversity offsets, also use the same principal (habitat area) to establish offsets. Studies or conservation practitioners that aim to establish offsets between buyers and sellers could benefit from this algorithm and apply it according to their needs. In addition, other studies that consider other the trade of ecosystem services, such as carbon, could replace the area parameter for Mg of carbon, for example.

5.3 Suggestions for future research

The work presented in this thesis has been in many ways exploratory, and therefore provides a number of possible avenues for future research. In chapter 2, I focused on the viewpoints of landowners of an agricultural frontier in the southern Amazon. Nevertheless, Brazil is an extreme diverse country in terms of land-use and social aspects, thus important viewpoints were likely missed in this study. Other Q-methodology studies that explore the diversity of landowners' opinions about the FC are inexistent. It would be highly useful to state-level regulation of CRA to be informed by Q-methodology studies performed in different states of Brazil.

In MBIs, the value of payments for a given environmental good is often determinant to engage buyers and sellers in trade (Kosoy et al., 2008). To determine the price of an ecosystem service or nature goods (e.g. hectares of standing forest, clean water), economic valuation is typically performed via willingness to pay (WTP) and/or willingness to accept (WTA) assessments (Bateman et al., 2011). In the absence of these assessments, studies employ the use of proxies, such as land rental prices, to estimate the value of services for buyers and sellers (Börner et al., 2010; Bernasconi et al., 2016). One limitation stated in chapter 3 was the absence of price in the analysis. To date, there is no robust empirical valuation of how much buyers and sellers would be willing to pay or accept for the offset strategies in the FC. One study attempted to perform such valuation (Soares-Filho et al., 2016), however, given the unrepresentative sample size, such valuation cannot reflect general preferences. Economic valuations are often time consuming given that samples should necessarily be representative of the population (Bateman et al., 2011). Although laborious, an empirical economic valuation of the offsets options stated in the FC could be substantially informative to perform more detailed trade modelling between buyers and sellers and provide useful results to the implementation of the FC. For example, price variation of WTP and WTA could be spatially modelled to identify regions of high trade activity between buyers and sellers if WTP and WTA are similar. Where trade activity is low (e.g. discrepant WTP and WTA), this could indicate areas were forest surpluses are unlikely to be protected under avoided deforestation offsets and, therefore, be more vulnerable to deforestation. A combination with data on future deforestation projections (Aguiar et al., 2016) could make such model more robust.

Although I focus on the Amazon, the methods developed in chapter 3 could be replicated in other biomes and provide national-level assessments of the conservation trade-offs associated with different spatial scales of implementation. Until now, country-level appraisals of the FC have solely considered the extent of forest deficit and surplus across the properties to make inferences about additionality (Freitas et al., 2017) and estimate overall costs of the CRA market (Soares-Filho et al., 2016). The use of the methods presented in chapter 3 will allow a comprehensive and comparative investigation across all biomes. Potentially, this could reveal distinct conservation trade-offs that could be biome-specific and eventually encourage tailor-made conservation actions that are could be implemented in accordance with each biome's needs.

In chapter 3 and 4, it was assumed that unprotected legal reserve surpluses would be deforested and legal reserve deficits that were not offset in protected areas nor with CRA would be automatically abandoned and regrown. Both simplifications are limitations of this study. Land-use models, perhaps built with more empirical information from buyers and sellers could provide results that better aid the spatial planning of offset strategies. For instance, by interviewing landowners and asking how likely sellers are to keep their LR surpluses without any compensation and how likely buyers are to abandon their LR deficit to comply with the FC could help identify areas where more action to protect LR surpluses are needed or where to focus restoration actions. This kind of human empirical information is essential to build robust agent-based models that simulates land-use change (Bakker et al., 2014). There is a growing need in the conservation field to incorporate analysis that include human behaviour at the individual level to better address how people interact with the environment (Rounsevell et al., 2012).

More broadly, it would be particularly interesting and informative to also compare outcomes of spatial planning approaches with outcomes of small administrative units to determine the spatial location of the biodiversity offsets. The determination of the location of offsets in biodiversity offsetting is often case-specific. This adds complexity to trade and impedes reliable comparisons across different offsetting actions that challenges implementation (Bull et al., 2014; Gonçalves et al., 2015). The comparison between a well-established approach (spatial planning) with a novel one could result in important implications for one of the biggest implementation challenges faced by biodiversity offsetting. Spatial planning approaches at landscape-level consider a number of ecological processes and elements to determine the location of offsets, such as biodiversity, threatened species, protection of old-growth forests etc. (Kiesecker et al., 2009). As such elements are dependent on their spatial scale (Hartig and Drechsler, 2009), I would therefore expect that landscape-level spatial planning and small administrative units presented similar results (e.g. similar area of old-growth forests protected and conservation of similar biodiversity components). If such results are indeed similar, some biodiversity offsets could then use small administrative units as a more objective way of placing offsets.

In chapter 4 I showed how implementation at a small spatial scale resulted in the protection of highly threatened beta-diversity. The use of beta-diversity is still underexplored to inform conservation strategies when compared to alpha-diversity (Socolar et al., 2016). It would be interesting to compare the use of both species richness and beta-diversity across large environmental gradients, such as the Amazon, to assess whether they would be contradicting or complementary in providing biodiversity assessments.

5.4 Final remarks

In this thesis I investigated the potential of conservation strategies to result in effective conservation gains. For this, I used the Brazilian Forest Code, which is considered the largest forest offset scheme in the world and has the potential to avoid the deforestation of 92 Mha of primary forest and/or restore 18 Mha of degraded land. The empirical analysis of landowners' viewpoints of programme-specific factors showed that heterogeneous perceptions about the scheme and sharp divergences between opinions of buyers and sellers might undermine scheme's conservation goals. These results suggest that policy interventions that target groups of landowners unlikely to participate could be useful to improve the scheme's effectiveness. One potential way of targeting is to restrict the spatial scale of the scheme. I tested this hypothesis and showed that restricting the spatial scale of the scheme has clear trade-offs. At a large spatial scale, the scheme resulted in the protection of greater areas of standing forest through avoided deforestation. However, restricting the spatial scale of the scheme to smaller units resulted in more area directed to conservation, when combining offsets from both avoided deforestation and forest regrowth, especially in highly deforested regions. Such findings suggest that restricting the spatial scale of conservation schemes might contribute to improving their additionality. In terms of potential environmental co-benefits, such as carbon and biodiversity, I also demonstrated potential trade-offs associated with different spatial scales. While a large spatial scale promoted the protection of biomass-rich areas, it resulted in little protection of biodiversity across all forest communities. Conversely, at a small spatial scale, highly threatened biodiversity was protected but mostly overlapping with biomass-poor areas. In essence, these results indicate that the overall effectiveness of conservation schemes could be optimised by design and implementation of strategies at local levels. Although I showed that effectiveness may be accompanied by trade-offs, the findings presented here support a “think-local” focus. This thesis contributes to our understanding of how to improve the implementation of conservation strategies around the world and achieve more effective conservation gains.

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Appendices

Appendix 1: Ethics Form, Risk Assessment and field survey

A1.1: Ethics Form

University Research Ethics Committee - application for ethical review

Please email your completed application form along with any relevant supporting documents to ResearchEthics@leeds.ac.uk (or to FMHUniEthics@leeds.ac.uk if you are based in the Faculty of Medicine and Health) at least 6 weeks before the research/ fieldwork is due to start. Dentistry and Psychology applicants should follow their School's procedures for submitting an application.

Ethics reference (leave blank if unknown)	Student number (if a student application)	Grant reference (if externally funded)	Module code (if applicable)
	200518375		

Faculty or School Research Ethics Committee to review		Arts and PVAC (PVAR)
		Biological Science (BIOSCI)
	X	ESSL, Environment and LUBS (AREA)

the application (put a 'X' next to your choice)		MaPS and Engineering (MEEC)
		School of Dentistry (DREC)
		School of Healthcare (SHREC)
		School of Medicine (SoMREC)
		School of Psychology (SoPREC)

Indicate what type of ethical review you are applying for:	X	Student project (PhD, Masters or Undergraduate)
		Staff project (externally or internally funded)

Section 1: Basic project details			
1.1 Research title	Empirical analysis of tradable permits in private forest conservation		
1.2 Research start date (dd/mm/yy)	Proposed fieldwork start date (dd/mm/yy)	Proposed fieldwork end date (dd/mm/yy)	Research end date (dd/mm/yy)
01/02/2015	01/06/2016	15/07/2016	31/01/2018

Yes	No	
x		1.3 I confirm that I have read and understood the current version of the University of Leeds Research Ethics Policy. *The Policy is available at http://ris.leeds.ac.uk/ResearchEthicsPolicies.*
x		1.4 I confirm that I have read and understood the current version of the University of Leeds Research Data Management Policy. *The policy is available at http://library.leeds.ac.uk/research-data-management-policy.*
x		1.5 I confirm that I have read and understood the current version of the University of Leeds Information Protection Policy. *The policy is available at http://it.leeds.ac.uk/info/116/policies/249/information_protection_policy*

x		1.6 I confirm that NHS ethical review is not required for this project. *Refer to http://ris.leeds.ac.uk/NHSethicalreview for guidance in identifying circumstances which require NHS review*
	x	1.7 Will the research involve NHS staff recruited as potential research participants (by virtue of their professional role) or NHS premises/ facilities? *Please note: If yes, NHS R&D management permission or local management permission may also be needed. Refer to http://ris.leeds.ac.uk/NHSethicalreview.*

Section 2: Contact details	
2.1 Name of applicant	Marta Lisli Ribeiro de Morais Giannichi
2.2 Position (eg PI, Co-I, RA, student)	PhD student
2.3 Department/ School	School of Geography
2.4 Faculty	Faculty of Environment
2.5 Work address (usually at the University of Leeds)	University of Leeds LS2 9JT School of Geography – Garstang Building
2.6 Telephone number	07470300141
2.7 University of Leeds email address	bs10mlg@leeds.ac.uk

Section 3: Summary of the research
3.1 In plain English provide a brief summary of the aims and objectives of the research. (max 300 words). The summary should briefly describe • the background to the research and why it is important, • the questions it will answer and potential benefits,

- the study design and what is involved for participants.

Your answers should be easily understood by someone who is not experienced in the field you are researching, (eg a member of the public) - otherwise it may be returned to you. Where technical terms are used they should be explained. Any acronyms not generally known should be described in full.

Background

Privately owned forests account for 959Mha globally, an area almost the size of USA. Private forest land is susceptible to deforestation pressure due to agriculture intensification. To halt deforestation and its underlying reasons, economic incentives have been advocated as a tool to promote conservation via monetary compensation of landholders who are willing to engage in conservation practises.

However, effective design and implementation of economic incentives schemes are dependent upon understanding the factors influencing landholders' decision-making process. To better comprehend this context, we chose Brazil as a case study. The Brazilian forestry framework has a combination of regulation and economic incentives that can contribute to deforestation decrease via a tradable permit scheme promoting conservation of set-aside areas in private lands (named CRA).

Questions and benefits

I. What are the factors determining private landholders' participation in CRA?

II. What is the potential market value per hectare of set-aside areas that would trigger participation?

III. What is the expected minimum number of participants that would secure conservation in considerable proportions?

This research seeks to gather empirical data from private landholders in the Amazon to assess their willingness to participate. Results will provide insights for the implementation of CRA and conservation strategies in Brazil and other tropical nations facing similar challenges.

Study Design

- First fieldwork: conduct pilot interviews with different types of landholders (small, medium and large) located in two distinct biomes: Amazon and Cerrado. The main objective is to collect socio-economic data and perform interviews to assess what factors influence participation in CRA. I expect to interview in this campaign a total of 180 volunteer farmers.
- Second fieldwork: This second campaign will apply objective surveys with landholders located in 10 municipalities to rank most important participation factors for future statistical and spatial analysis. I expect to survey around 650 farmers.

3.2 Who is funding the research?	CNPq – The Brazilian National Council for Scientific and Technological Development

Section 4: Research data You may find the following guidance helpful: • Research data management guidance • Advice on planning your research project • Dealing with issues relating to confidentiality and anonymisation	
4.1 What is the data source? (Indicate with an 'X' all that apply)	
X	New data collected for this research
	Data previously collected for other research
	Data previously collected for non-research purposes
X	Data already in the public domain
	Other, please state: ____.
4.2 How will the data be collected? (Indicate with an 'X)	
X	Through one-to-one research interviews
	Through focus groups
	Self-completion (eg questionnaires, diaries)
	Through observation
	Through autoethnographic research
	Through experiments/ user-testing involving participants
	From external research collaborators
	Other, please state: ____.
4.3 How will you make your research data available to others in line with: the University's, funding bodies' and publishers' policies on making the results of publically funded research publically available (while not compromising requirements around data protection legislation)? (max 200 words)	

My research sponsor, CNPq, does not have any specific demand about making data publicly available. However, following the University's recommendations on data access, sharing and re-use (https://library.leeds.ac.uk/info/461/research_data_management/304/data_management_planning/7) I intend to use one of the repositories indicated in re3data Registry of Research data repositories, such as Zenodo or Figshare, which are long-term data storage repositories. For data that might be sensitive and cannot be made available as open data, I will submit to the University's Institutional Repository (IR) which has restricted access and data is stored minimum of 10 years beyond project end's date. Also, another possibility of sharing data is when publishing make available Supplementary Information containing data that can be open to the Scientific community.	
4.4 How do you intend to share the research data? (Indicate with an 'X)	
	Depositing in a specialist data centre or archive
X	Submitting to a journal to support a publication
	Depositing in a self-archiving system or an institutional repository
	Dissemination via a project or institutional website
	Informal peer-to-peer exchange
	No plans to report or disseminate the data
	Other, please state: ____.
4.5 How do you intend to report and disseminate the results of the study? (Indicate with an 'X)	
X	Peer reviewed journals
	Internal report
X	Conference presentation
	Publication on website
	Other publication
	Submission to regulatory authorities
	No plans to report or disseminate the results

	Other, please state: ____.

Section 5: Protocols		
Which protocols will be complied with? (Indicate with an 'X'). There may be circumstances where it makes sense not to comply with a protocol, this is fine but should be clarified in your application.	X	Data protection, anonymisation and storage and sharing of research data
		Informed consent
	X	Verbal consent
		Reimbursement of research participants
		Low risk observation

Section 6: Additional ethical issues	
6.1 Indicate with an 'X' in the left-hand column whether the research involves any of the following:	
	Discussion of sensitive topics
	Prolonged or frequent participant involvement
	Potential for adverse environmental impact
	The possibility of harm to participants or others (including the researcher(s))
	Participants taking part in the research without their knowledge and consent (eg covert observation of people in non-public places)
	The use of drugs, placebos or invasive, intrusive or potentially harmful procedures of any kind
	Food substances or drinks being given to participants (other than refreshments)
	Vitamins or any related substances being given to participants
	Acellular blood, urine or tissue samples obtained from participants (ie no NHS requirement)

	Members of the public in a research capacity (participant research)
	Participants who are particularly vulnerable (eg children, people with learning disabilities, offenders)
	People who are unable to give their own informed consent
	Researcher(s) in a position of authority over participants, eg as employers, lecturers, teachers or family members
	Financial inducements (other than reasonable expenses and compensation for time) being offered to participants
	Cooperation of an intermediary to gain access to research participants or material (eg head teachers, prison governors, chief executives)
	Potential conflicts of interest
	Internet participants or other visual/ vocal methods where participants may be identified
	The sharing of data or confidential information beyond the initial consent given
	Translators or interpreters
X	Research conducted outside the UK
	An international collaborator
	The transfer of data outside the European Economic Area
	Third parties collecting data
X	Other ethical clearances or permissions

6.2 Provide details of any ethical issues the research may involve other than those mentioned previously and explain how these issues will be addressed. (max 200 words)
• Research interviewees will participate in my fieldwork on an entirely voluntary basis. At no point will I try to coerce a participant into agreeing to a research interview. • I will ensure that all research interviewees are entirely comfortable with answering the questions posed in the interview. I will brief them before they give their verbal consent to be interviewed. • I will also avoid using any means of suasion to bias a research interviewee's comments towards particular outcomes.

• I shall ensure confidentiality of information provided by our research interviewees. Comments from my interview material I use in published or other publicly disseminated works will be anonymised. I shall make this verbally clear to interviewees verbally when I meet with them. • Where any politically, economically, socio-culturally sensitive issues do arise in research interview situations, I will exercise due care and caution, being mindful to treat the interviewee's comments with the utmost respect, and re-stating that his or her comments will be treated in a completely confidential manner.

Section 7: Recruitment and consent process For guidance refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants and the research ethics protocols.
7.1 State approximately how much data and/ or how many participants are going to be involved.
Data on socio-economic information and factors particular to the scheme to be investigated from around 800 landholders. Potential presence of rare or endangered species on set-aside areas within private properties reported by landholders will be recorded for assessing potential conservation value.
7.2 How was that number of participants decided upon? (max 200 words) *Please note: The number of participants should be sufficient to achieve worthwhile results but should not be so high as to involve unnecessary recruitment and burdens for participants. This is especially pertinent in research which involves an element of risk. Describe here how many participants will be recruited, and whether this will be enough to answer the research question. If you have received formal statistical advice then please indicate so here, and describe that advice.*
The state where the research will be conducted has 82,000 private landholders. It is unrealistic to have a 10% representative sample size of all landholders. Therefore I aim at interviewing 1%. This is sufficient to answer my research questions. As my research design considers contrasting landholders within the sample size, 1% would be sufficient to cover representativeness issues, reflecting accurately members of the state farmers' population. Still, 1% corresponds to 800 landholders. Graduate students from local university (UNEMAT) will be recruited and trained by me to perform surveys in different municipalities to achieve sample size goals.
7.3 How are the participants and/ or data going to be selected? (max 200 words)

The participants will be visited in their farms and they will be asked if they are willing to answers some questions for research purposes. The farms were selected according to contrasting socio-economic factors (e.g. mean income per capita, mean farm size, main land use) of the municipalities in which the farms are located.
7.4 For each type of methodology, describe the process by which you will obtain freely given informed consent for the collection, use and reuse of the research data. *Guidance is available at http://ris.leeds.ac.uk/InvolvingResearchParticipants. The relevant documents (information sheet and consent form) need to be attached to the end of this application. If you are not using an information sheet and/ or seeking written consent, please provide an explanation.*
For all both interviews and surveys I will obtain a verbal informed consent. Participants are much likely to be illiterate, semi-illiterate or present difficulties in reading and interpreting information in the areas interviewed. Thus to avoid any embarrassments, the verbal consent was chosen. Apart from taking notes I will also record interviews after obtaining participants explicit agreement to be able to register their verbal consent. Additionally, from my own experience in the fieldwork region, there is a particular alarm when a non-acquainted person asks for the individual's signature. Thus asking for a written consent from participants might create an uncomfortable situation, which can lead to a lack of trust between researcher and interviewee, damaging data collection process. Nevertheless, to be conservative, I prepared a written consent and will carry with me if I feel it will not cause any uncomfortableness. Before the interviews it will be clearly explained to them (by reading the information sheet and recording their consent) that data will be used for academic purposes, their identities will not be recorded and only people directly involved with the research will have access to the raw data.
7.5 Describe the arrangements for withdrawal from participation and withdrawal of data/ tissue. *Please note: It should be made clear to participants in advance if there is a point after which they will not be able to withdraw their data. See also http://ris.leeds.ac.uk/ResearchDataManagement.* (max 200 words)
Research participants are voluntary and will have freedom to leave or end the interview whenever they wish, and there is no need for participants to give any reason by withdrawing from the interview. All data collected at any point of the research project will be kept anonymised. After responding the interview, they will be informed that their raw data will be kept safely in the University's Repository, emphasizing anonymity. They will also be informed that after this raw data is registered, processed and part of the thesis and possibly published in journals, they will not be able to withdraw their participation.
7.6 Provide details of any incentives you are going to use and explain their purpose. (max 200 words) *Please note: Payment of participants should be ethically justified. The FREC will wish to be reassured that research participants are not being paid for taking risks or that payments are*

set at a level which would unduly influence participants. A clear statement should be included in the participant information sheet setting out the position on reimbursement of any expense incurred.
No incentives will be provided for participants. Their contribution will be explicitly voluntary and this will be clarified to them.

Section 8: Data protection, confidentiality and anonymisation *Guidance is available at http://ris.leeds.ac.uk/ConfidentialityAnonymisation*	
8.1 How identifiable will the participants be? (Indicate with an 'X').	
	Fully identifiable
	Identity of subject protected by code numbers/ pseudonyms
X	Fully anonymised
	Anonymised but potentially identifiable
	Data only in aggregated form
	Other
8.2 Describe the measures you will take to deal with issues of confidentiality, including any limits to confidentiality. (max 300 words)	
The State Environmental Agency already has data about landholders in a system that is called Rural Environmental Registry. This registry contains information about landholders' property location, size, land use etc. This data is available online in the Environmental Agency platform and is already being used in this thesis to locate landholders and identify certain patterns within the study site. However, data on their views on this specific scheme have not been collected neither how this is located spatially. Limits to confidentiality involve the association of the content of interviews with the geographically sensitive data (e.g. properties' coordinates with income). These raw data are subject to complete confidentiality and I will make sure participants understand and agree that their processed and analyzed data are going to be disclosed for academic purposes. None of the information I want to collect has the potential to be harmful or used against the participants. I will make this clear to them. Their raw data will not be disclosed academically (publication and thesis) neither the geographical location of the raw and individual socio-economic data, therefore it is not harmful for them in any way and does not offer them any risks. Still, I will make sure to apply	

a correction filter in the geographical coordinates that corrects the point to a distance of 10km away from the point, so as the sensitive data is not associated with the coordinate. I will not use quotes as data gathered will be quantitative.
8.3 Describe the measures you will take to deal with issues of anonymity. (max 200 words)
The identity of participants will not be recorded as this is not relevant to the interviews. Participants will be aware of that. The participants are not public personas, they are farmers in Mato Grosso, a state with colossal dimensions and a very high number of farmers. It is extremely unlikely that information given by one individual interviewed can be connected to their identity. Thus ensuring anonymity of individuals is totally feasible and realistic.
8.4 Who will have access to the research data apart from the research team (eg translators, authorities)? (max 100 words)
Because this research concerns the implementation of a novel scheme that is previewed in the environmental law, I would expect that governmental institutions might want to have access to some of the data if the work gets published. However, they will not have access to the raw data as it is classified as sensitive and confidential data, only the data that will eventually become public via journal publications or the thesis itself in the form of supplementary information.
8.5 Describe the process you will use to ensure the compliance of third parties with ethical standards. (max 100 words)
During the training process with the graduate students that will undertake interviews on my behalf, I will include in the training program ethical issues that they must be aware of such as confidentiality and anonymity, process of withdraw and its limitations, data usage for publication, interviewees voluntariness to participate, clearly stating aims, delivering and/or reading the participants' information sheet and dealing with informed consent.
8.6 Where and in what format(s) will research data, consent forms and administrative records be retained? (max 200 words) *Please note: Mention hard copies as well as electronic data. Electronic data should be stored securely and appropriately and in accordance with the University of Leeds Data Protection Policy available at http://www.leeds.ac.uk/secretariat/data_protection_code_of_practice.html.*
The data collected (as the data that I am currently processing) is stored in a particular an L: drive of high storage capacity purchased by my supervisor. While on fieldwork, I will take a School's laptop with me and raw data will be stored in the same L: drive via VPN and remote access to my desktop before I return to Leeds. The participants' responses will be both

recorded and registered on forms by myself, which already covers the demand for hard copies. Consent forms and administrative records are stored in my M: drive.
8.7 If online surveys are to be used, where will the responses be stored? (max 200 words) *Refer to:* *http://it.leeds.ac.uk/info/173/database_and_subscription_services/206/bristol_online_survey_accounts and http://ris.leeds.ac.uk/SecuringResearchData for guidance.*
N/A
8.8 Give details and outline the measures you will take to mitigate any foreseeable risks (other than those already mentioned) to the participants, the researchers, the University of Leeds or anyone else involved in the research? (max 300 words)
This study is of no risk at all to any of the research participants. All research data will be protected and kept confidential and each interview participant will be treated individually and the identity of interview participants will remain anonymous. For the researcher and others I do not foresee any risks.

Section 9: Other ethical issues		
Yes	**No**	(Indicate with an 'X')
X		9.1 Is a health and safety risk assessment required for the project? *Please note: Risk assessments are a University requirement for all fieldwork taking place off campus. The risk assessment forms and further guidance on planning for fieldwork in a variety of settings can be found on the University's Health & Safety website along with further information about risk assessment: http://www.leeds.ac.uk/safety/fieldwork/index.htm. Contact your Faculty Health and Safety Manager for further advice. See also http://ris.leeds.ac.uk/HealthAndSafetyAdvice.*
	X	9.2 Is a Disclosure and Barring Service check required for the researcher? *Please note: It is the researcher's responsibility to check whether a DBS check is required and to obtain one if it is needed.*

	X	9.3 Is there scope for incidental findings, ie unplanned additional findings?

9.4 If so, what sort of findings, and what processes will be put in place to deal with these? (max 200 words)
9.5 Any other relevant information
No.
9.6 Provide details of any ethical issues on which you would like to ask the Committee's advice.

Section 10: Further details for student projects (complete if applicable) Your supervisor is required to provide email confirmation that they have read, edited and agree with the form above. It is a good idea to involve your supervisor as much as possible with your application. If you are unsure how to answer any of the questions do ask your supervisors for advice.			
10.1 Qualification working towards (indicate with an 'X')			
	Bachelor's degree	Module code:	
	Master's degree (including PgCert, PgDip)		
X	Research degree (ie PhD)		
10.2 Primary supervisor's contact details			
Name (title, first name, last name)	Guy Ziv		

Department/ School/ Institute	School of Geography
Telephone number	+44 (0) 113 34 37994
University of Leeds email address	g.ziv@leeds.ac.uk
10.3 Second supervisor's contact details	
Name (title, first name, last name)	Tim Baker
Department/ School/ Institute	School of Geography
Telephone number	+44 (0) 113 34 38352
University of Leeds email address	t.r.baker@leeds.ac.uk

Yes	No	10.4 To be completed by the student's supervisor
X		The topic merits further research
X		I believe that the student has the skills to carry out the research

Section 11: Other members of the research team (complete if applicable)	
Name (title, first name, last name)	
Role (eg PI, Co-I)	
Department/ School/ Institute	
Telephone number	
University of Leeds email address	
Name (title, first name, last name)	

Role (eg PI, Co-I)	
Department/ School/ Institute	
Telephone number	
University of Leeds email address	
Name (title, first name, last name)	
Role (eg PI, Co-I)	
Department/ School/ Institute	
Telephone number	
University of Leeds email address	

<table>
<tr><td colspan="3">Section 12: Supporting documents</td></tr>
<tr><td rowspan="6">Indicate with an ‘X’ which supporting documents have been included with your application.

Wherever possible the research title on consent forms, information sheets, other supporting documentation and this application should be consistent. The title should make clear (where appropriate) what the research is about. There may be instances where a different title is desirable on information to participants (for example – in projects which necessarily involve an element of deception or if giving the title might skew the results of the research). It is not imperative that the titles are consistent, or detailed, but where possible then they should be.

Supporting documents should be saved with a meaningful file name and version control, eg 'Participant_Info_Sheet_v1' or 'Parent_Consent_From_v2'. Refer to the examples at http://ris.leeds.ac.uk/InvolvingResearchParticipants.</td><td>X</td><td>Information sheet(s)

Please note: Include different versions for different groups of participants eg for children and adults if applicable. Refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants for guidance in producing participant information sheets.</td></tr>
<tr><td>X</td><td>Consent form(s)

Please note: Include different versions for different groups of participants eg for children and adults if applicable. Refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants for guidance in producing participant consent forms.</td></tr>
<tr><td></td><td>Recruitment materials

Please note: Eg poster, email etc used to invite people to participate in your research project.</td></tr>
<tr><td></td><td>Letter/ email seeking permission from host/ gatekeeper</td></tr>
<tr><td>X</td><td>Questionnaire/ interview questions</td></tr>
<tr><td>X</td><td>Health and safety risk assessment

Please note: Risk assessments are a University requirement for all fieldwork taking place off campus. The risk assessment forms and further guidance on planning for fieldwork in a variety of settings can be found on the University’s Health & Safety website along with further information about risk assessment: http://www.leeds.ac.uk/safety/fieldwork/index.htm. Contact your Faculty Health and Safety Manager</td></tr>
</table>

		for further advice. Also refer to *http://ris.leeds.ac.uk/HealthAndSafetyAdvice*.
		Data management plan *Refer to http://library.leeds.ac.uk/research-data-manage*.

Section 13: Sharing information for training purposes		
Yes	**No**	(Indicate with an 'X')
X		I would be content for information in the application to be used for research ethics and research data management training purposes within the University of Leeds. All personal identifiers and references to researchers, funders and research units would be removed.

Section 14: Declaration

1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it.
2. I undertake to abide by the University's ethical and health & safety policies and guidelines, and the ethical principles underlying good practice guidelines appropriate to my discipline.
3. If the research is approved I undertake to adhere to the study protocol, the terms of this application and any conditions set out by the Research Ethics Committee.
4. I undertake to ensure that all members of the research team are aware of the ethical issues and the contents of this application form.
5. I undertake to seek an ethical opinion from the REC before implementing any amendments to the protocol.
6. I undertake to submit progress/ end of project reports if required.
7. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
8. I understand that research records/ data may be subject to inspection for audit purposes if required in future.
9. I understand that personal data about me as a researcher in this application will be held by the relevant FRECs and that this will be managed according to the principles established in the Data Protection Act.

	Applicant	Student’s supervisor (if applicable)
Signature		
Name	Marta Giannichi	Guy Ziv
Date	23/03/2016	23/03/2016

A1.2: Ethics Approval

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Marta Lisli Ribeiro de Morais Giannichi

School of Geography

University of Leeds

Leeds, LS2 9JT

ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee

University of Leeds

Dear Marta

Title of study: **Empirical analysis of tradable permits in private forest conservation**

Ethics reference: **AREA 15-099**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
AREA 15-099 MartaGiannichi_Ethical_review_GZ.doc	1	24/03/16
AREA 15-099 MartaGiannichi_Information Sheet.docx	1	24/03/16
AREA 15-099 MartaGiannichi_Participant_consent_Portuguese_formlowrisk.doc	1	24/03/16

AREA 15-099 Survey_1.xlsx	1	24/03/16
AREA 15-099 Marta_Giannichi_High-Risk-Fieldwork-RA-form-GZ.doc	1	24/03/16

Committee members made the following comments about your application:

With respect to Journal Supplementary Information you might find the following article useful:

- NISO/NFAIS. (2013). Recommended practices for online supplemental journal article materials http://www.niso.org/publications/rp/rp-15-2013

In general the feeling on that email list is that for data it is probably better to store these in trusted repositories such as the University of Leeds Institutional Repository for Research Data rather than as Supplementary Information on publishers' websites.

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie

Senior Research Ethics Administrator, Research & Innovation Service

On behalf of Dr Andrew Evans, Chair, AREA Faculty Research Ethics Committee

CC: Student's supervisor(s)

A1.3: Information Sheet

Information Sheet

IMPORTANT: THE INFORMATION BELOW WILL BE PRESENTED ORALLY TO PARTICIPANTS

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Title of research project: Empirical analysis of tradable permits in private forest conservation.

Some information about the researcher: I am a researcher in Tropical Forest Conservation in University of Leeds, UK carrying out a research project in tropical forest conservation that is expected to last 4 years in total. I am a Biologist, Brazilian and have lived in Mato Grosso for some time. I have no affiliations with any government body nor authorities. I am an independent worker.

What is the purpose of this project?

The main objective is to understand farmers' perspectives towards the Brazilian Forest Code, more specifically their predisposition to participate in *Cota de Reserva Ambiental* (tradable permit scheme to conserve private forest land) and what factors might influence their participation.

Why have I been chosen?

Because you are a farmer/landholder, with either exceeding or deficit of native vegetation in your Legal Reserve. This makes you a buyer or a seller of *Cota de Reserva Ambiental* in Mato Grosso and your understanding about this is important to the future implementation and enhancement of public policies as you are the manager of our natural resources. Just like you, other 600 farmers will be interviewed.

What do I have to do?

Orally answer a few questions about socio-economic aspects of yourself (age, education, income), followed by questions more related to your property (size, land use, amount of vegetation). Later on I will focus more on your knowledge on the regulations in the Forestry Code and if you would participate in *Cota de Reserva Ambiental* and for what price. If you do not know or feel uncomfortable with any of the questions, do not hesitate to interrupt and/or withdraw from the interview. I need to register what you say, otherwise I will certainly forget! The best way for me to do is, is to record and take notes during the interview. But I will only do this if you explicitly agree, either orally or signing a term. Whatever you feel more comfortable with. The interviews are expected to last from 30 to 60 minutes and they will happen only once. There are no lifestyle restrictions as a result of participating.

Do I have to take part?

Absolutely not. You are contributing to this project as a volunteer and it is entirely up to you to answer the questions. If you decide to take part, please clearly state orally.

Are these interviews anonymous and confidential?

Yes. There is absolutely no need to reveal your identity.

What are the possible disadvantages and risks of taking part?

Absolutely not. All the information will remain anonymous and the information will be carefully used just for academic purposes.

What are the possible benefits of taking part?

There is no direct benefits of taking part. However, your answers can contribute to a better implementation of the Forestry Code and *Cota de Reserva Ambiental,* which can provide you an alternative source of income if you are a seller, and a more efficient solution for compliance if you are a buyer.

What will happen to the results of the research project?

Your answers will be analysed after I go back to the university in a way that all the farmers that contributed can help my research to draw conclusions about the present and the future implementation of the Forest Code and *Cota de Reserva Ambiental*. All the recorded interviews will be used strictly for analysis purpose, which means that what you say will be heard just by me and the people directly involved in this research.

What I say can become public?

Probably not the way you are thinking! If my project reveals interesting results, it can be published in an academic journal. But again, what is published are the analyses, figures and numbers of the interviews and not what you exactly said. Also, everything is anonymous and confidential.

Can I withdraw at some point?

During the interviews you can withdraw at any moment. However, when your answers are taken back to the university and start writing my analyses, unfortunately you will not be able to change your mind. So please be sure you are willing to contribute.

Who is organising this project?

School of Geography, University of Leeds. This is where I do my doctorate research.

Can you know more about what I am doing and get in touch with me?

Of course! If you have any questions and want to know more about this research you can contact me by email or phone.

Marta Giannichi

School of Geography

LS2 9JT Leeds

Tel: + 44 (0) 7470 300 141

e-mail: bs10mlg@leeds.ac.uk

A1.4: Risk Assessment

Fieldwork Risk Assessment (High Risk Activities)

Fieldwork Project Details	
Faculty School/Service	School of Geography, Faculty of Environment
Location of Fieldwork	Mato Grosso State, Brazil.
Brief description of Fieldwork activity and purpose *(include address, area, grid reference and map where applicable)*	The purpose of this fieldwork is to conduct surveys and interviews with private landholders in a four municipalities in Mato Grosso. I will be visiting farmers at their properties and asking them questions. The main purpose of this fieldwork is to gather empirical data from private farmers in different Biomes in Mato Grosso. Maps attached to this form.
Fieldwork itinerary *e.g. flight details, hotel address*	**Please find attached to this document:** - **Fieldwork itinerary;** - **Flight details;** - **Maps** Hotel addresses are below as well as details of sponsor. **Sponsor details:** CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) Coordenação de Execução de Bolsas no Exterior SHIS Quadra 01 Conjunto B - Bloco B, Térreo Edifício Santos Dumont Lago Sul, Brasilia - DF CEP: 71605-170

	Contact person: Renee Silva Phone: +55 61 3211-4022 e-mail: renee.silva@cnpq.br Fieldwork is arranged to happen from June 1st to July 15th 2016. Arrival in Cuiaba is expected on the 5th of June and return to Leeds on 15th of July. Upon arrival in Cuiaba I will rent a car and head to the municipalities either the day I arrive or the following day, depending on the time of the arrival. The municipalities visited as their order of appearance are: 1) Paranatinga Hotel Bandeirantes Av. Brasil, 895 – União CEP: 78870-000 Phone: +55 66 3573-1258 2) Santa Rita do Trivelato Hotel Matrinxã Rua 28 Dezembro, s/n lt 1423 Centro CEP: 78453-000 Phone: +55065 3529-6154 3) Juina Hotel Caiabi Avenida Mato Grosso, 665 – Centro CEP: 78320-000, Brasil Phone: +55 66 3556-1270 4) Castanheira Same as above as they are 45 minutes' drive.
Organiser Details	**Contact details** *Name, Email, Telephone*

Fieldwork Activity Organiser / Course Leader	Marta Lisli Giannichi bs10mlg@leeds.ac.uk 07470300141
Departmental Co-ordinator	Guy Ziv School of Geography University of Leeds Leeds, UK g.ziv@leeds.ac.uk +44 (0) 113 34 37994
Nature of visit *Size of Group, lone working, staff, postgraduate, undergraduate*	Marta Lisli Giannichi - PhD student
Participant Details *Attach information as separate list if required*	**Contact details** *Name, Address, email, telephone, Next of Kin contact details*
	PhD student: Marta Lisli Giannichi bs10mlg@leeds.ac.uk
	71 Cliff Road LS6 2EZ 07470300141 Next of Kin: Heloisa Giannichi (sister) heloisagiannichi@gmail.com Rua Voluntarios da Patria 4040 ap43 CEP 02402-500
	Phone: +55 11 2959-6331 mobile: +55 11 97623-4598
	Field assistant: Alfredo Luiz dos Santos Filho alfredoluizfilho@gmail.com Rua Ciridiao Durval 100 ap72

	CEP: 04360-020 Phine: +55 11 981607478
	Next of Kin: Ana Leticia dos Santos (sister) analeticia.arq@hotmail.com Rua Manuel Cherem 239 ap44 CEP: 04360-030 Phone: +55 11 97475-8210
	Important note: the field assistant is a Brazilian journalist, experienced interviewer and driver. He does not have any affiliations with any academic institution.

HAZARD IDENTICATION

Identify all hazards specific to fieldwork trip and activities, describe existing control measures and identify any further measures required.

HAZARD(S) IDENTIFIED	CONTROL MEASURES *(e.g. alternative work methods, training, supervision, protective equipment)*
Nature of the site *School, college, university, remote area, laboratory, office, workshop, construction site, farm, etc* Farms across Mato Grosso possibly in remote areas	Mato Grosso has roads in good conditions, some paved some unpaved (please see map above). According to the official transport institution in Brazil, the unpaved roads in Mato Grosso are well maintained all year long, and specially in better conditions during the dry period (April to October). In this campaign it will be visited farms reachable by both paved and unpaved roads. To be sure about road conditions before travelling local farmers will be consulted as well as the website of Motorway Police. Also, fieldwork is already scheduled to happen during the dry season to avoid muddy and blocked roads and minimize risks.
Environmental conditions *Extremes of temperature, altitude, exposure to sunlight, potential weather conditions, tidal condition etc* Hot and dry conditions	The particular fieldwork does not involve walking long distances as I will be getting around by car. Nevertheless, I will be careful to not expose myself in the sun for long, drink plenty of treated water, wear sun cream and pay attention to any signs of fatigue.
Site specific conditions *e.g. cliffs, screes, bogs, featureless landscapes, local endemic infectious diseases, zoonoses etc* Cerrado and Amazon biomes	Fieldwork will take place both in Cerrado and Amazon biomes, but particularly in farms. There will be no situation in which it will be necessary to walk long distances across the landscapes. Any venomous wildlife (snakes, scorpions) are unlikely to be encountered. Brazil is experiencing at the moment a Zika outbreak. Zika is a mosquito-borne virus transmitted by *Aedis aegypt*, a hematofagus mosquito that reproduces easily in places with stagnant water. The symptoms are mild and last usually from 2 to 7 days. Like other similar viral infection, such as dengue fever and chikungunya, zika symptoms are fever, rashes and muscular pains. The main concern about

		the scientific community about zika is its potential correlation with microcephaly in pregnant women. The Mato Grosso Health State Agency has only registered 9 cases of zika virus until mid-December 2015 and is investigating other potential 68 cases. The main focuses are Cuiaba (state capital), Varzea Grande, Rondonopolis and Tesouro. These municipalities are not part of this fieldwork campaign, apart from Cuiaba, that is the landing point. Neither treatment nor vaccines are available and prevention is based on personal protection using long-lasting repellents. For this fieldwork, I will wear repellent containing DEET (the most effective ones) every day and reapply every 4 hours, according to CDC (Centers for Disease Control and Prevention). I will also wear long trousers and long-sleeve T-shirts to improve efficiency. Obviously, I am not pregnant and neither intend to be within the next couple of years.
Process *Operating machinery, electrical equipment, driving vehicles, handling or working with animals etc* Driving vehicles		The farms will be reached by car. I will be driving a small pickup truck that will be rented in Cuiaba airport. By the time the car is rented I will make sure its insurance covers for breakdowns and accidents. I will be accompanied by a field assistant, who is Brazilian and an experienced driver to avoid driving long hours. We will not take any route that leads to roads under poor conditions for regular cars. We will be equipped with GPS to locate the farms and a Mato Grosso Atlas to guide us through the roads. Whenever possible, I will be checking roads conditions online via the Federal Motorway Police website and we have mapped all the help stations alongside the roads. Emergencies numbers are also recorded in our mobile phones.
Transport *Mode of transport while on site, to and from site, carriage of dangerous goods etc* - Plane - Car		By plane: From Leeds to Sao Paulo and from Sap Paulo to Cuiaba (capital of Mato Grosso). By car: From Cuiaba to the municipalities chosen and then return to Cuiaba. The car will be rented in the airport. By plane: From Cuiaba to Sao Paulo and from Sao Paulo to Leeds.

Equipment *manual handling risks, operation of machinery, tools, use of specialist equipment etc*		We will be equipped with GPS, tablets to register the interviews, recorder, camera and field computers. The manipulation of this equipment does not present any high risk to safety and health.
Violence *potential for violence (previous incidents etc)*		From my experience interviewing landholders, there has not been any situation which I thought there was a serious risk involved. Sometimes landholders refuse to answer questions, but this is not qualified as violence.
Low risk		
Individual(s) *medical condition(s), young, inexperienced, disabilities etc*		I have plenty of experience in working with farmers. I have been working with this type of stakeholders since 2010. I am Brazilian, therefore fluent in Portuguese. I have lived in Mato Grosso before so I know where to go and where not to go. I am familiar with the appropriate approach towards farmers and feel very confident about it.
Experienced		
Work Pattern *time and location e.g. shift work, work at night*		All interviews will be conducted during the day.
Day time		
Permissions Required *Contact details, restrictions and details of permissions*		As part of the ethical review, the participants will be requested to sign consent forms whenever possible.
Consent forms		
Other Specific Risk Assessments *e.g. COSHH, Manual Handling, Lone Working if so what is identified in these assessments? Are there training requirements? (cross reference where appropriate)*		N/A

Health Questionnaire Completed *Is it required and has it been completed, who by and where is it recorded*		Yes (online) at http://www.its.leeds.ac.uk/healthandsafety/
Health Surveillance Required *Is it required and has it been completed, who by and recorded*		N/A
Vaccinations Required *Obtained and certificate where applicable*		I have all the vaccines suggested (yellow fever, rabies, tetanus and hepatitis.
First Aid Provision *Requirement for first aid or specialist first aid equipment, access to medical equipment and hospitals*		I will carry an extensive first aid kit in the field at all times as well a set of prescribed medications (basic antibiotics) to deal with minor illnesses straight away. In Cuiaba there is good university hospital for emergencies and tropical diseases (Hospital Universitario Julio Muller R. Luis Philippe Pereira Leite, s/n - Alvorada, Cuiabá - MT, 78048-902, Brasil) and all the municipalities in the state have a municipal hospital.

Additional Supporting Information		
Pre-departure Briefing *Carried out and attended*		N/A
Training *Identify level and extent of information; instruction and training required consider experience of workers, details of relevant training*		I have plenty of experience in carrying out interviews with landholders. During my MSc (2010 – 2011) I went to Peru to investigate participation amongst Brazil nut collectors in the Amazon and during years I lived in Mato Grosso state working for a timber company,

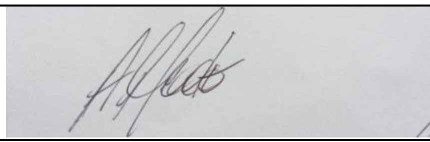
		taking care of stakeholders and surrounding communities' relationships.
FCO advice *Include current FCO advice for travel to the area where applicable*		**Summary** Still current at: 9 February 2016 Updated: 20 January 2016 Latest update: Health section - cases of Zika virus have been reported in 2015 and 2016; you should follow the advice of the National Travel Health Network and Centre, particularly if you're pregnant or planning to become pregnant, and seek advice from a health professional. Cases of Zika virus have been reported in 2015 and 2016. You should follow the advice of the National Travel Health Network and Centre, particularly if you're pregnant or planning to become pregnant. Seek advice from a health professional if you have any further questions or concerns. Protests take place regularly, often without warning, in a number of Brazilian cities, including Rio de Janeiro, São Paulo and Belo Horizonte. There have been violent incidents and injuries. Avoid demonstrations, monitor local media and follow the guidance of local authorities. Strikes affecting transport and security may take place at short notice across Brazil. These are often short but may cause disruption. Monitor local media for updates and advice. Levels of crime and violence are high, particularly in major cities. You should be particularly vigilant before and during the festive and Carnival periods. Bank card fraud is common. See Crime There is an underlying threat from terrorism. See Terrorism

		217,003 British nationals visited Brazil in 2014. Most visits are trouble free. If you're a single parent or guardian travelling with a child, you may need additional documentation. See Entry requirements Drug trafficking is widespread in Brazil, and incurs severe penalties. See Local Laws and Customs The Overseas Business Risk service offers information and advice for British companies operating overseas on how to manage political, economic, and business security-related risks. The number of dengue fever cases in Brazil as a whole has increased considerably in 2015, especially in the south-east and central-west. Cases of Chikunyunga virus have been confirmed in Brazil and the number of reported cases in the region is increasing. For more details about this outbreak, see the website of the National Health Network and Centre. You should take steps to avoid being bitten by mosquitoes. Take out comprehensive travel and medical insurance before you travel.
Supervision *Identify level of supervision required e.g. full time, Periodic telephone/radio contact*		Dr Beatriz Marimon will act as a local support for this fieldwork. She is a professor at UNEMAT (Mato Grosso State University). Beatriz Marimon biamarimon@unemat.br UNEMAT BR 158, s/n, Caixa Postal 08 Antiga FAB
Periodic telephone contact		

	CEP: 78690-000 Nova Xavantina, MT - Brasil - Phone: +55 66 34382389
Other Controls *e.g. background checks for site visits, embassy registration*	I will contact my sister every day by phone and she will know my daily itinerary. If I do not contact her every 24 hours, she will contact local authorities.
Background checks with family member	
Identify Persons at Risk *This may include more individuals than the fieldwork participants e.g. other employees of partner organisations* *Copy of other Organisation's risk assessment attached?*	
Additional Information *Relevant to the one working activity including existing control measures; information instruction and training received, supervision, security, increased lighting, emergency procedures, access to potable water etc.*	I have comprehensive travel and medical insurance (from the University). On-site fieldwork assistant also has private health insurance.

Residual Risk *Is the residual risk acceptable with the identified controls?*	Yes	
	No	

Assessment carried out by	Name:	Marta Lisli Giannichi
	Signature:	
	Date:	February 16 2016

Names of person(s) involved in Fieldwork *N.B: This can take the form of a signed class register when large group work*	Name:	Alfredo Luiz dos Santos Filho
	Signature:	
	Date:	March 17th 2016
Fieldwork Activity Organiser / Course Leader *e.g. PI, etc*	Name:	Guy Ziv
	Signature:	
	Date:	18/3/2016

Flight details

Leeds to Sao Paulo

BA1345M 31MAY 2 LBALHR SS1 1925 2025 /DCBA /E

BA 247S 31MAY 2 LHRGRU SS1 2150 0520 01JUN 3 /DCBA /E

Sao Paulo to Cuiaba

JJ3487X 05JUN 7 CGHCGB SS1 1430 1543 /DCJJ /E

Cuiaba to Sao Paulo

JJ3761M 10JUL 7 CGBCGH SS1 1915 2215 /DCJJ /E

Sao Paulo to Leeds

BA 246M 15JUL 6 GRULHR*SS1 1610 0720 16JUL 7 /DCBA /E

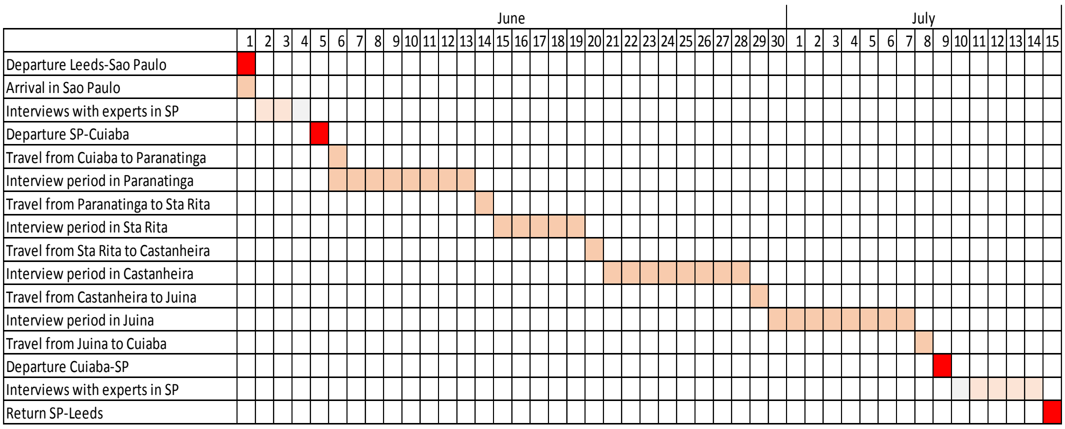
BA1342K 16JUL 7 LHRLBA*SS1 1245 1350 /DCBA /E

WPMUSD«

31MAY DEPARTURE DATE-----

	BASE FARE	EQUIV AMT	TAXES/FEES/CHARGES		TOTAL
1-	GBP929.00	USD1321.00	565.50XT		USD1886.50ADT
XT	37.90BR	321.40YQ	103.80GB	102.40UB	
	929.00	1321.00	565.50		1886.50

Fieldwork itinerary


June
July
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Departure Leeds-Sao Paulo
Arrival in Sao Paulo
Interviews with experts in SP
Departure SP-Cuiaba
Travel from Cuiaba to Paranatinga
Interview period in Paranatinga
Travel from Paranatinga to Sta Rita
Interview period in Sta Rita
Travel from Sta Rita to Castanheira
Interview period in Castanheira
Travel from Castanheira to Juina
Interview period in Juina
Travel from Juina to Cuiaba
Departure Cuiaba-SP
Interviews with experts in SP
Return SP-Leeds

Municipality	N Properties	Days
Paranatinga	50	8
Santa Rita	30	5
Castanheira	40	7
Juina	60	10
Total	**180**	**30**
Interviews/day	**5**	

Itinerary	Km
Cuiaba-Paranatinga	400
Parantainga-Sta Rita	250
Sta Rita-Castanheira	700
Castanheira-Juina	50
Juina-Cuiaba	750
Distancias internas	400
Total	**2550**

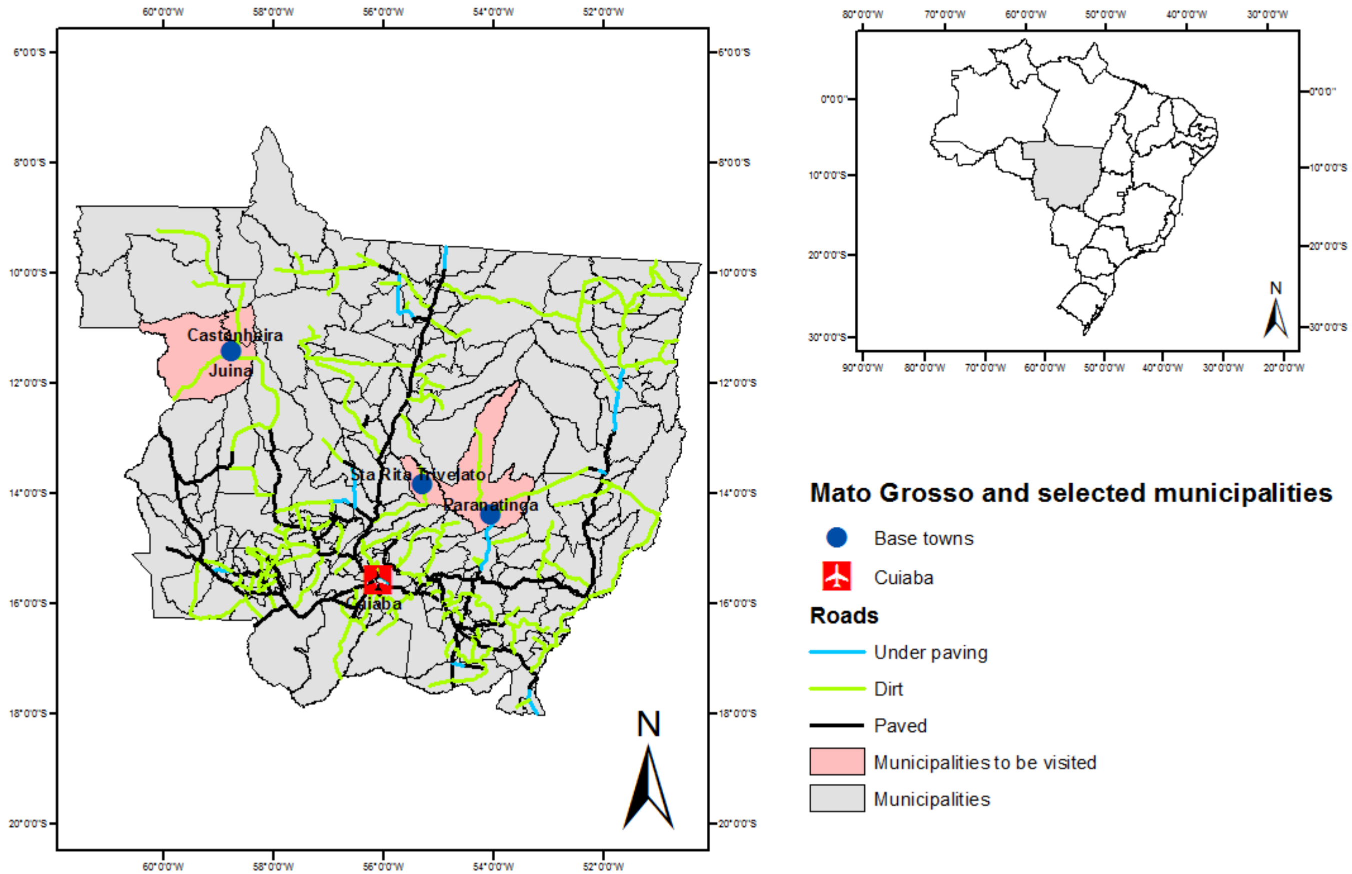
June

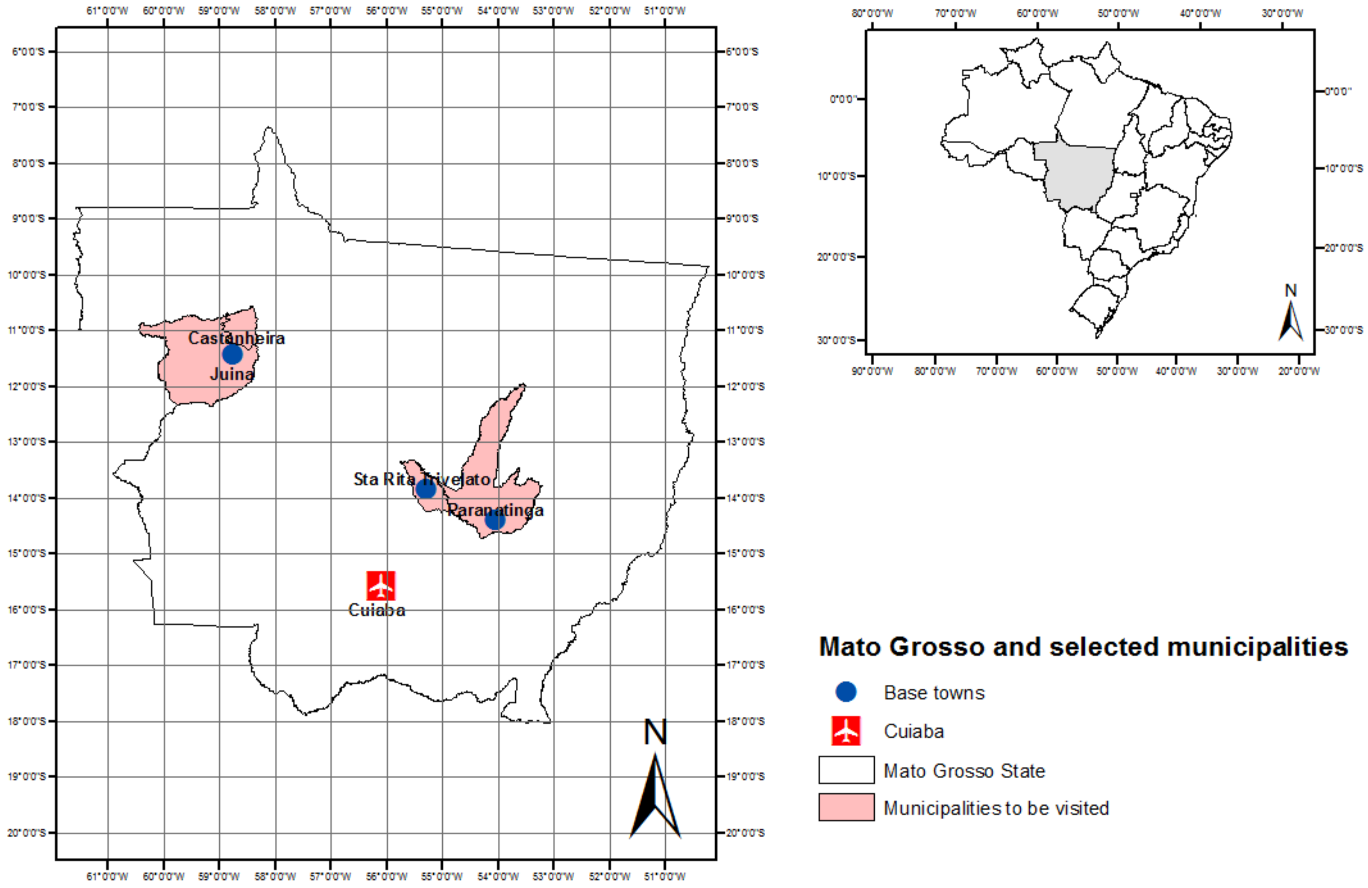
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

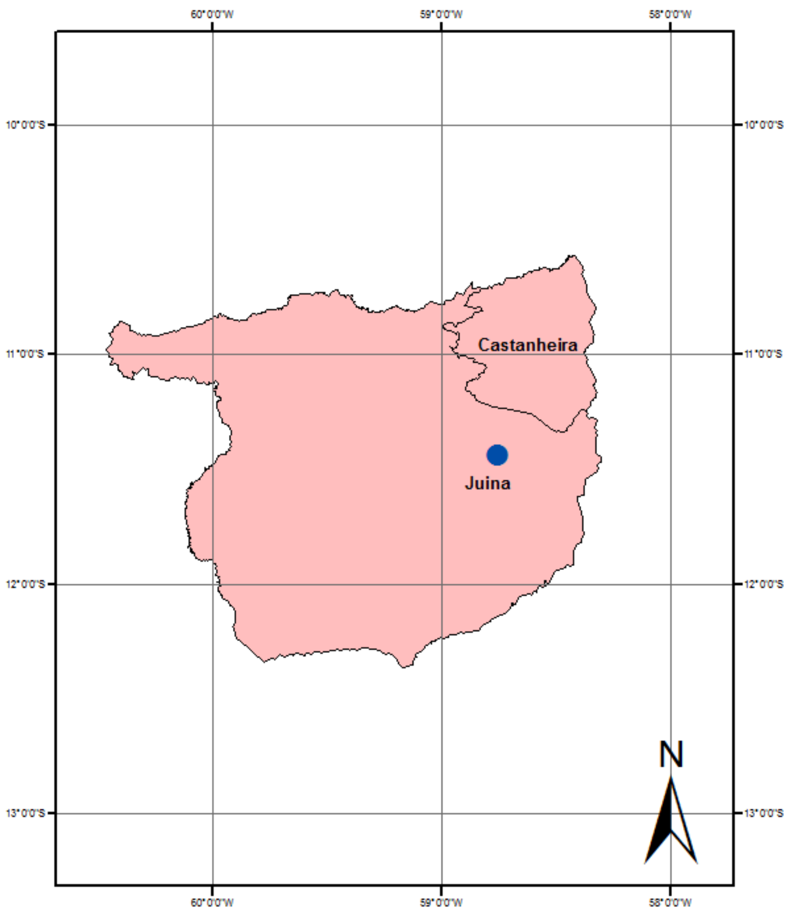
July

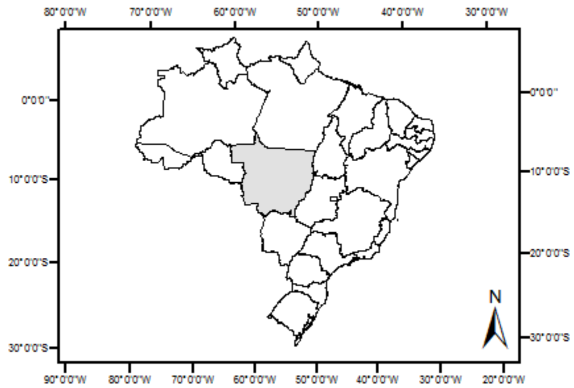
M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

days travelling by plane
days interviewing specilists in Sao Paulo
fielwork days
days off


Mato Grosso and selected municipalities
Base towns
Cuiaba
Roads
Under paving
Dirt
Paved
Municipalities to be visited
Municipalities
N


Castanheira
Juina
Sta Rita Trivelato
Paranatinga
Cuiaba
N
Mato Grosso and selected municipalities
Base towns
Cuiaba
Mato Grosso State
Municipalities to be visited



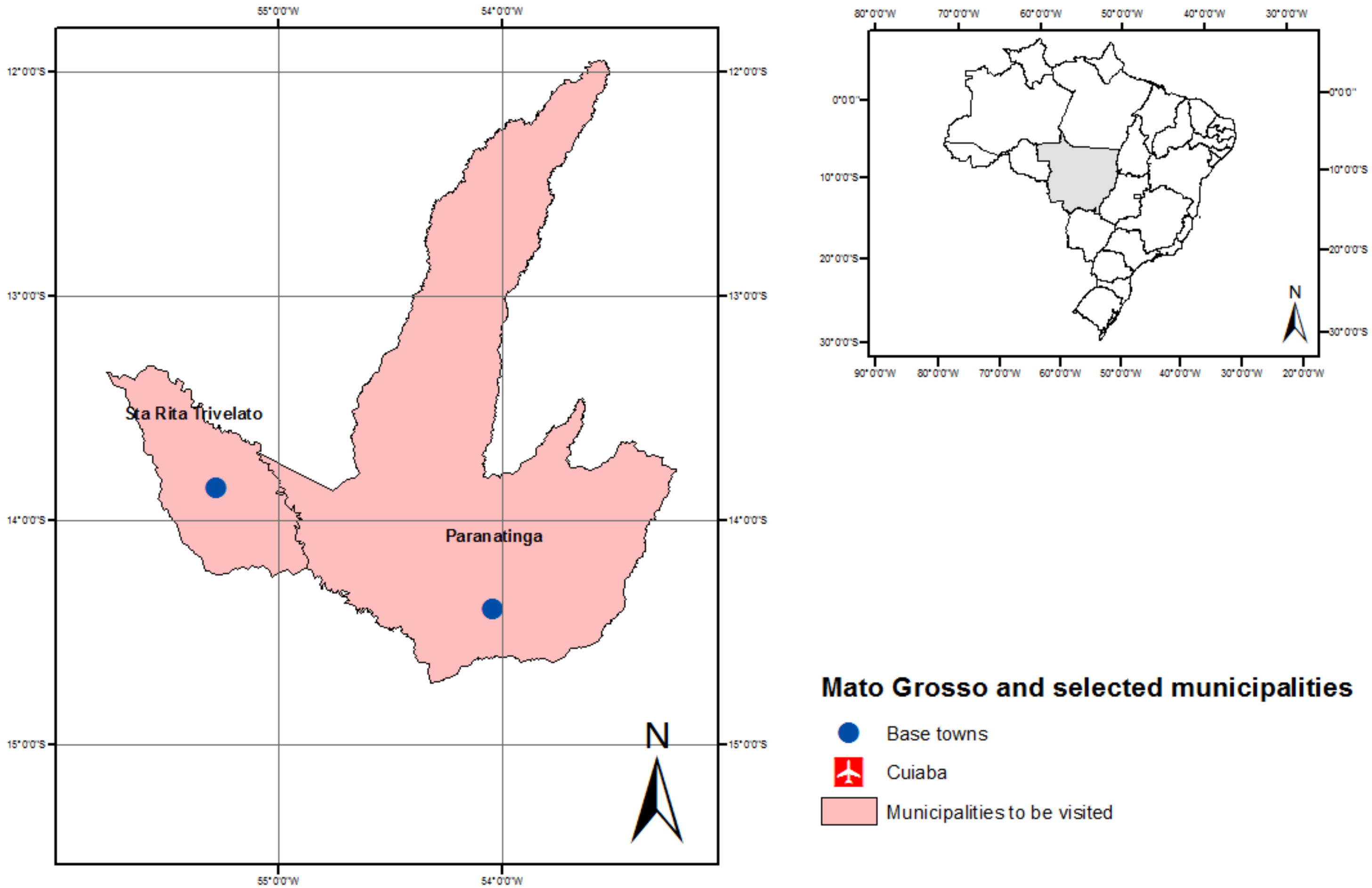


Mato Grosso and selected municipalities

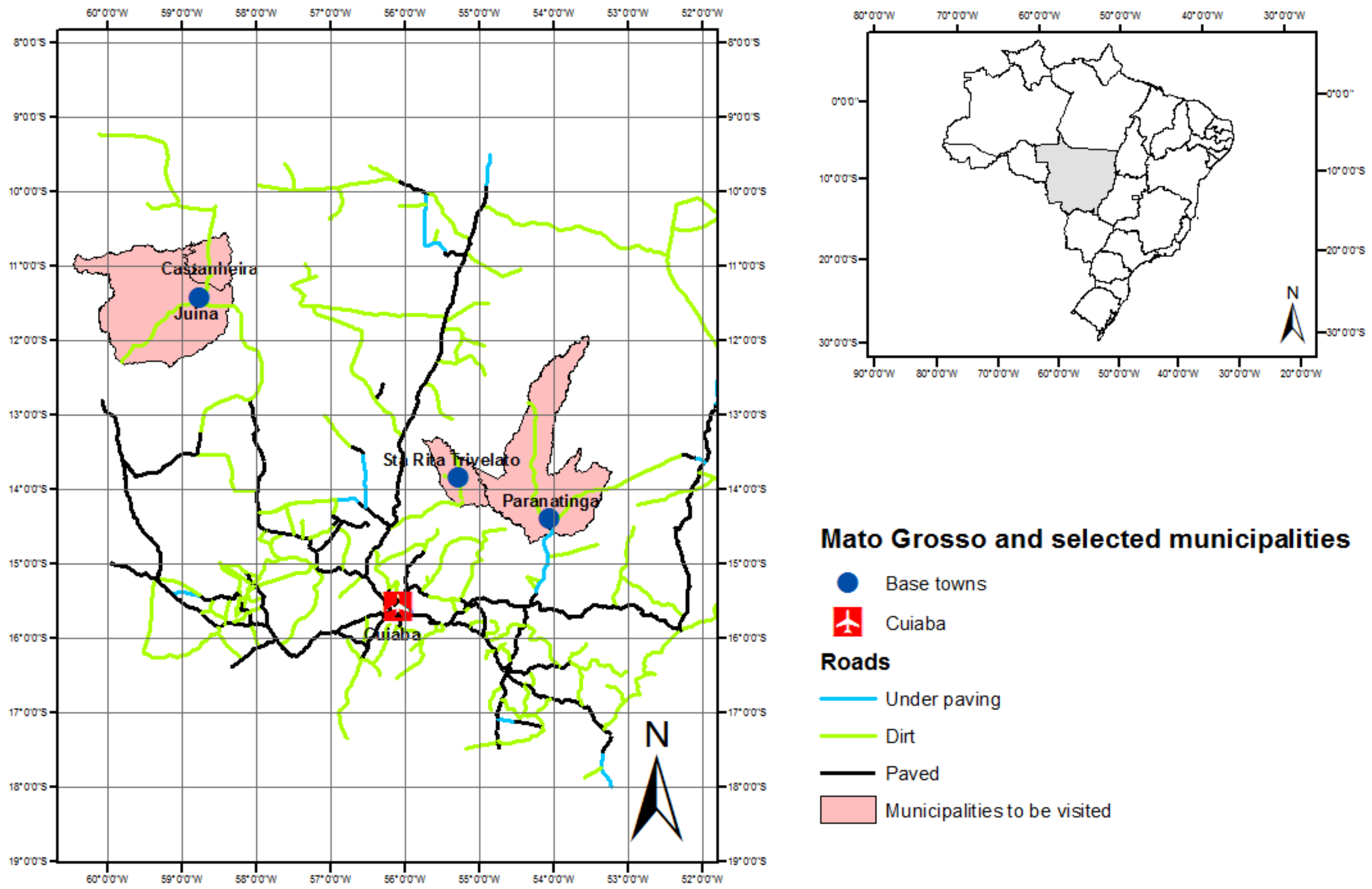
Base towns

Cuiaba

Municipalities to be visited



Sta Rita Trivelato
Paranatinga
Mato Grosso and selected municipalities
Base towns
Cuiaba
Municipalities to be visited
N


Castanheira
Juina
Sta Rita Trivelato
Paranatinga
Cuiaba
N
N
Mato Grosso and selected municipalities
Base towns
Cuiaba
Roads
Under paving
Dirt
Paved
Municipalities to be visited

A1.5: Survey sheet

This survey was fully applied in Portuguese. For this thesis, I included the English version as this thesis must be submitted entirely in English.

UNIVERSITY OF LEEDS

Landowners Survey - Phase 1

1. Ethics:	Information sheet given:	Prior consent:	Signature		
2. Date and time:					
3. Municipality:					
4. Biome:	Cerrado	Amazon			
5. GPS Coordinates:	X (Lon):	Y (Lat):	Direction to plot relative to coordinates (e.g. N, SW):		
Socioeconimic data					
6. Age:					
7. Gender:	Male	Female			
8. Education:	Illiterate	Literate	Middle School incomplete	Middle School complete	
	High School Inomplete	High School Complete	Agrotechnician	Agronomist engineer	
	Veterinarian	Zootechnician	Forest engineer	Other	
9. Access to communication:	TV	Mobile phone	Radio	Internet broad	Internet dial
10. House electronics:	Open antena TV	Parabolic TV	Cassete	DVD	Radio
	Computer	Access to internet	None		
11. Type of farm:	Owner	Settled	Renter	Partner	Occupier
	Producer with no land	Family Farm	Other:		
12. Bank account holder:	Yes	No			
13. Income per hectare (R$):					
14. Income (min. wage):	<1	1>2	2>3	3>5	>5
Property details					
15. Registered in CAR:	Yes	No	Registration number:		
16.Total farm area (ha):	Small (<100)	Medium (100-1000)	Large (>1000)		
17. Legal reserve (%):	0 - 20	20 - 50	50 - 80	80 - 90	>90
18. Secondary forest (% of LR):	0 - 20	20 - 50	50 - 80	>80	
19. Travel time to nearest market:	<30min	30>1h	1h>2h	>2h	
20. Land use:	Pasture	Soy	Corn	Cotton	Other:
21. Classification of farmer:	Buyer	Seller			

Appendix 2: Supplementary Information Chapter 2

A2.1 Environmental Reserve Quotas (CRA)

According to the Brazilian Forest Code, every landowner must set aside areas of native vegetation within their rural properties, named Legal Reserve (LR). The proportion depends on which biome the property is located. In the Amazon, this percentage is 80%; in Cerrado 35% (within the boundaries of the Legal Amazon); and 20% in other biomes (Brasil 2012). Although instituted as forest title to incentivise conservation and ecosystem services provision, CRA is currently only seen as a compensation strategy to offset LR deficit (Soares-Filho *et al.* 2016). Some authors have highlighted CRA's potential to become a national market for PES (Godecke *et al.* 2014; Silva *et al.* 2016), if implemented successfully, and, possibly integrating to other conservation strategies, such as REDD+ (Soares-Filho *et al.* 2016).

In essence, CRA basic rules are clear: those with forest surplus (named sellers) can issue CRA which cover their exceeding LR and those with deficit (named buyers) can acquire quotas to offset their deficits (Brasil 2012). One quota corresponds to one hectare and offers can be made in trading platforms. Compensation with CRA is only allowed if the selling and buying properties are located in the same biome, preferably in the same state (Soares-Filho *et al.* 2014) and only for landowners who carried out deforestation prior to 2008. Landowners who deforested after this cut-off date must seek on-site compensation, either allowing natural regrowth or actively reforesting to make up their deficit. For those who have LR surplus (sellers), the exceeding vegetation in their LR can legally be deforested by the landowner, as long as it is approved by the state Environmental Agency. Therefore, CRA has potential to secure areas that may be legally deforested in the near future.

Small properties (< 360 ha on average for Mato Grosso) that predominantly utilize family labour are not required to compensate/recover their LR debt. On the other hand, if they have any amount of native or recovering vegetation declared as LR, they are entitled to offer CRA acting as sellers.

CRA still awaits regulation and there are many uncertainties involved. For instance, it is currently unclear if trading volume will be enough to generate a market or if it would require a public intervention to generate an initial demand (e.g. creating "banks" by purchasing forest surpluses to supply future potential private demand) (May *et al.* 2015). The successful implementation of CRA relies on the full registration and validation of the National Rural and Environmental Registry System (acronym CAR). This system allows landowners to self-document their georeferenced properties boundaries, LR area, remaining forest area, arable area and much more land and landowner information (May *et al.* 2015). CAR is still gathering data and currently there are many inaccuracies. Mato Grosso was the first state to have a state-level rural registry system implemented (Richards and VanWey 2015). Once a landowner has their land holdings validated, the registration is approved if it meets environmental regulations, including having LR percentage according to the minimum established by law. If not, the landowner must present their strategies to meet environmental regulations, which CRA can take place (May *et al.* 2015).

A2.2 Methods

For this study, I followed the methodology outlined in Figure A2.1, with further detail provided in the following text.

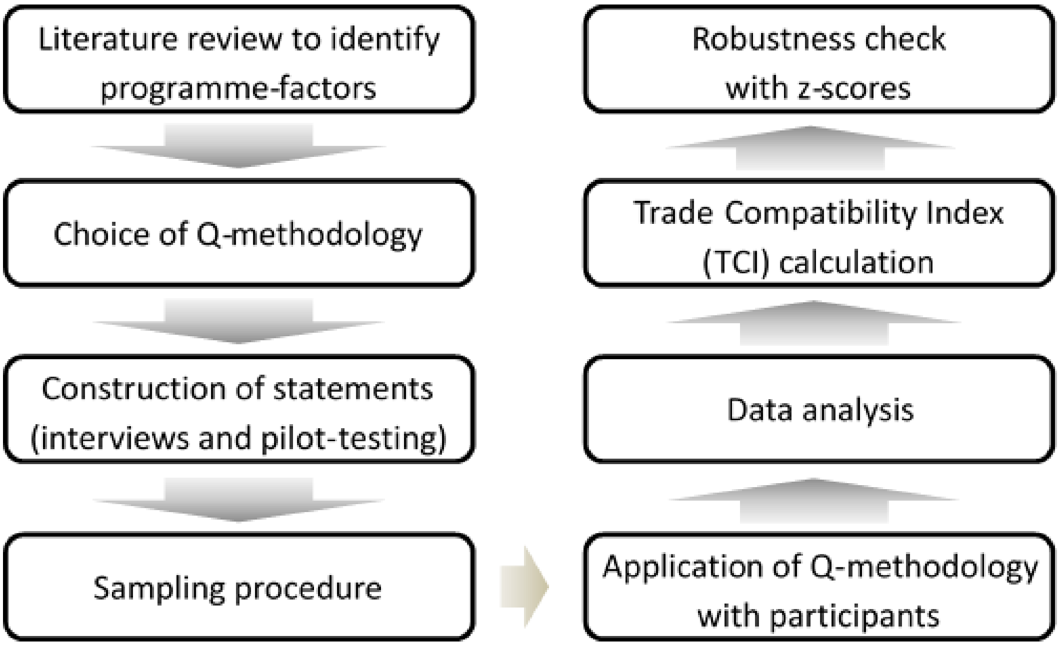


Figure A2.1 Diagram of methodological steps taken in this study. Each box corresponds to a section in this methods section.

A2.2.1 Literature review to identify programme-specific factors

To define thematic categories (or programme-specific factors) I carried out a literature review covering which factors are important in determining participation in schemes such as PES (Payment for Ecosystem Services), AES (Agri-environmental Schemes) and TDR (Tradable Development Rights). The programme-specific factors used in the Q-set were reported in this literature as influential in participation of such schemes.

A2.2.2 Choice of Q-methodology

Q-methodology is designed to capture the underlying subjectivity within individuals' viewpoints (Zabala and Pascual 2016), allowing the construction of interpretative narratives about groups of people and their perspectives. Participants are purposively selected to promote diversity as opposed to quantity (Armatas *et al.* 2014) and presented a set of statements (Q-set) representing a wide range of possible opinions on a topic. Participants are asked to sort onto a grid which represents their level of agreement or disagreement (Figure A.2.2) (Davies and Hodge 2012). Using a data reduction technique (PCA or Centroid Factor Analysis) (Zabala and Pascual 2016), analysis reveals factors which represent groups of participants who presented a similar sorting pattern (Previte *et al.* 2007). This so called 'q-analysis' generates a hypothetical sorting distribution representative to each group, to be subsequently interpreted.

A2.2.3 Q-set design: construction of statements

The Q-set is the population of statements filtered after the elaboration of the concourse. The concourse is a universe of statements representing the object of the study (Stephenson 1935): in this case the landholders' views about CRA. The initial concourse was generated by structured sampling (Sandbrook *et al.* 2011; Pereira *et al.* 2016; West *et al.* 2016), a process which resulted in 131 statements created based on a combination of resources such as the scientific literature, Federal and State laws, reports, and interviews with representatives from key institutions (e.g. State Environmental Agency) and landowners. The refinement of the Q-set was done firstly by the authors, to edit and remove ambiguous statements, which generated 41 statements (29 common to both groups and 12 group-specific). After another round of refinement consulting with experts and pilot testing face-to-face with six landowners, the final Q-set comprised 39 statement

(32 common to both and 7 group-specific) covering the following thematic dimensions: contract length; eco-effectiveness; information on the scheme; role of intermediaries; payment vehicle; price; transaction costs; trust; and demotivation. Original versions in Portuguese are available in Table A2.1.

A2.2.4 Sampling procedure

I considered four criteria when sampling municipalities: (1) location (e.g. Amazon or Cerrado); (2) accessibility via major roads (BR-163, BR-158 and BR-070); (3) predominant land use (crop or pasture) and (4) different farm size classes (e.g. small, large). To validate our decision, we interviewed two key policy actors of the state (Federation of Agriculture and Livestock – FAMATO and Institute of Agro-economics – IMEA). This sampling procedure resulted in six municipalities: Querência, Paranatinga, Sorriso, Sinop, Alta Floresta and Lucas do Rio Verde. It is important to note that these municipalities were selected as bases for the interviews. However, many interviewed landowners have parcels in other surrounding municipalities.

Table A2.1 Contacted local and regional organisations in base-municipalities.

Municipality	Contacted associations and cooperatives
Querencia	Local Association of Rural Employers
	Local Association of Rural Employees
	Coopquer (local cooperative of seed producers)
	IPAM (Local NGO)
	Town Hall
	Town Chamber of Deputies
Paranatinga	Local Association of Rural Employers
	Local Association of Rural Employees
Sorriso	Local Association of Rural Employers
	Local Association of Rural Employees
	CAT (local NGO - Clube Amigos da Terra)
	Coacen (regional agroindustrial cooperative)
Sinop	Local Association of Rural Employers
	Local Association of Rural Employees

	Local Agriculture and Environment Agency
	Embrapa (Brazilian Agricultural Research Coorporation)
Alta Floresta	Local Association of Rural Employers
	Local Association of Rural Employees
	ICV (local NGO)
	IOV (local NGO)
Lucas Rio Verde	Local Association of Rural Employers

The local organisations were contacted and after an explanation of the research objectives, they were asked to provide contacts of affiliated landowners. Landowners were contacted by phone, provided a brief explanation of the research and asking to schedule a face-to-face interview. 52.2% of those asked took part in the research.

Table A2.2 Original Portuguese version of the statements and their correspondent translated version in English.

Statement number	Statement	Statement in Portuguese
S1/B1	Five years is the maximum period I'd contract CRA.	Eu assinaria um contrato de, no máximo, CINCO anos.
S2/B2	I think a 10 year contract is good length to guarantee stability and a fair price for contracting CRA.	Um contrato de 5 a 10 anos seria um bom período para garantir estabilidade e preço justo.
S3/B3	I'd rather sign long-term contracts, from 15 years onwards.	Eu preferiria assinar somente contratos de longo prazo, a partir de 15 anos.
S4/B4	The CRA scheme will significantly help animal and plant conservation.	A Cota de Reserva Ambiental ajudará, principalmente, na conservação de plantas e animais.
S5/B5	The CRA scheme will help protect forested areas.	A Cota de Reserva Ambiental ajudará a proteger muitas áreas com florestas.
S6/B6	I'd deforest all native vegetation on my property if the Forest Code allowed.	Eu desmataria toda a vegetação nativa da minha propriedade se o Código Florestal permitisse.
S7/B7	Before this interview, I already had a good knowledge of the regulations and requirements in the new Forest Code.	Antes dessa pesquisa, eu já tinha um bom conhecimento do regulamento e obrigatoriedades do Código Florestal.
S8/B8	Before this interview, I was well-informed of the possibility to trade forest credits (CRA).	Antes dessa pesquisa, eu já estava bem informado da possibilidade de compra e venda de CRA.
S9/B9	I think the CRA rules are too complicated.	Eu acho as regras de CRA muito complicadas.
S10/B10	I think CRA will not work.	Eu acho que a CRA não vai dar certo.

S11/B11	I know intermediaries institutions of CRA such as BVRio and Biofilica.	Eu conheço instituições intermediárias de CRA, como BVRio e Biofilica.
S12/B12	I don't know what my responsibilities are as a seller/buyer.	Eu não sei quais são minhas responsabilidades como vendedor/comprador
S13/B13	I would be willing to pay an annual fee for an intermediary institution that monitor the contract yearly.	Estou disposto a pagar uma taxa para uma instituição acompanhar o contrato ano a ano.
S14/B14	Having an intermediary makes the whole process more expensive.	Ter uma instituição intermediando o processo tornaria o negócio mais caro.
S15/B15	To me it would be impossible to go through all the CRA process without an intermediary.	Seria impossível passar por todo o processo de compra e venda de CRA sem uma instituição intermediária.
S16/B16	I do not know where to find buyers and I need somebody to do that for me.	Eu não sei onde encontrar compradores de CRA e preciso que alguém faça este trabalho para mim.
S17/B17	I prefer to negotiate CRA contract with a buyer myself, without intermediaries.	Eu prefiro negociar um contrato diretamente com o vendedor, sem intermediários.
S18/B18	I prefer to receive annual payments for the duration of the contract.	Eu prefiro receber CRA em parcelas anuais pela duração do contrato.
S19/B19	I only feel safe to receive the payment via an intermediary.	Eu só me sinto seguro de receber o pagamento através de um intermediário.
S20/B20	The price will depend on my land use.	O preço irá depender do meu uso da terra atual.
S21/B21	The associated expenses (negotiation, fencing (as seller) etc.) are a significant barrier for me to participate in CRA	As despesas associadas à CRA (negociação, cercamento, averbação na matrícula, etc.) inviabilizariam a minha participação.

S22/B22	I would trust an unknown landholder to proceed with a CRA contract.	Eu confiaria assinar um contrato com um proprietário desconhecido.
S23/B23	I would visit the property of the buyer, no matter how far it is, before selling credits	Eu faço questão de visitar a propriedade do comprador, mesmo que seja longe.
S24/B24	I do not see any real incentive for me to sell my exceeding Legal Reserve	Eu não vejo nenhum incentivo para que eu emita CRA na minha Reserva Legal excedente.
S25/B25	I think the Forest Code will change again, so will wait and do nothing in the next few years	Eu prefiro esperar porque acho que o Código Florestal irá mudar novamente.
S26/B26	I would only sell/buy CRA for perpetuity.	Eu só venderia CRA por contrato perpétuo.
S27/B27	CRA must have a fiscal incentive for aiming at conservation.	O CRA deve ter um incentivo fiscal por visar a preservação de áreas vegetadas.
S28	The per-hectare price of CRA should be at least how much I would get renting my land	O preço da CRA, por hectare, deve ser, no mínimo, igual ao que recebo por arrendar minha terra.
B28	The per-hectare price of CRA should be **at most** how much I make per hectare	O preço da CRA, por hectare, deve ser, no máximo, igual ao que eu ganho por hectare.
S29	The per-hectare price of CRA should be at least how much I would get selling my land	O preço da CRA, por hectare, deve ser igual ao que eu receberia para vender minha terra.
B29	The per-hectare price of CRA should be at most how much I would pay purchasing vegetated land in my region.	O preço da CRA, por hectare, deve ser inferior ao que eu pagaria para comprar uma área vegetada na minha região.
S30	For a higher price, I would sell to any landowner regardless of his location in my state	Por um preço maior preço, eu venderia CRA para qualquer proprietário.

B30	For a lower price, I would buy from any landowner regardless of his location in my state.	Por um preço menor eu compraria CRA de qualquer proprietário, sem me importar com a distância.
S31	CRA will only be attractive for who has Legal Reserve well above the minimum.	CRA só será atrativo para quem tiver Reserva Legal bem acima do exigido.
B31	CRA will only be attractive for who has Legal Reserve well below the minimum.	CRA só será atrativo para quem tiver Reserva Legal bem abaixo do exigido.
S32	The longer the contract the higher the price should be.	Quanto maior a duração do contrato, maior deve ser o preço da CRA.
B32	The longer the contract the lower the price should be.	Quanto maior a duração do contrato, menor deve ser o preço da CRA.
S33	I wouldn’t deforest my exceeding Legal Reserve.	Eu não desmataria minha Reserva Legal excedente.
S34	I see CRA as an investment so I will definitely be part of this market.	Eu vejo CRA como um investimento então definitivamente fará parte deste mercado.
S35	An intermediary institution as a mediator reduces the risk of default.	Uma instituição mediando os pagamentos minimiza o risco de calote.
S36	The requirement of fencing makes CRA unattractive to me	A possibilidade de ter que cercar a área faz com que CRA não seja atrativa para mim.
S37	The costs for travelling, documentation, certificates and other associated expenses must considered as part of the CRA price	O custo de intermediários, documentação, cartório, cerca e outras despesas devem ser embutidas no preço da CRA.
S38	My exceeding LR is not significantly large so I wouldn’t be willing to issue CRA	Meu excedente de Reserva Legal não é grande o suficiente para eu ser vantajosa a emissão da CRA.

S39	Only CRA credits are not enough to make up the effort I made to conserve my exceeding Legal Reserve.	Somente o CRA é insuficiente para recompensar o esforço por conservar o excedente de Reserva Legal.
B33	If buying from another private landholder I'd like it to be from a conservation priority area.	Eu daria preferência de compra para áreas com prioridade em conservação.
B34	I am very afraid of getting fined for non-compliance with the Forest Code.	Eu estou muito preocupado em ser multado por não atender ao Código Florestal.
B35	I am afraid to run the risk of the sellers not keeping their obligations to preserve the land appropriately.	Eu tenho receio de o vendedor não cumprir suas obrigações de preservar a área contratada.
B36	I would prefer to buy vegetated land from another private landholder to be in compliance as opposed to renting CRA.	Eu prefiro comprar uma área vegetada para me regularizar.
B37	I would prefer to buy a land within a protected area and donate to the government as opposed to renting CRA.	Eu prefiro comprar uma área dentro de UC para me regularizar.
B38	I prefer natural regeneration than buying CRA.	Eu prefiro a regenaração natural a comprar CRA.
B39	To reforest my deficit is my least option.	Reflorestar o meu passivo ambiental é a última opção.

A2.2.5 Application of Q-sort

Interviews were audio-recorded and comprised three parts: (1) explanation of CRA; (2) collection of demographic and property information; (3) q-sort and justification. In total, the interviews lasted on average 1 hour. Before getting participants' consent, they were informed about the objectives of the study and how their data were going to be used. Following approved ethical procedures for this specific study, we ensured participants complete anonymity and they were informed that were free to withdraw from the investigation at any time. They all participated voluntarily.

It was not assumed that participants had good knowledge of the CRA scheme. To cover this issue, every participant received a verbal explanation, together with some written material. Before moving on to the Q-sort, they were encouraged to raise any questions to clarify doubts they had about the scheme. Q-sorts were carried out only after the participant was comfortable with all the information provided.

Prior to the Q-sort, it was not known if the participant was a farmer with LR deficit or surplus. We classified them according their own declaration of LR area during the demographic survey. If the participant stated that his/her LR was below the minimum level required by the law for that biome, they were classified as buyers. If the declared LR was above the minimum for that biome, then they were classified as sellers.

During Q-sorting, the researcher explained to each participant they would receive 39 statements to be ranked onto a fixed 'quasi-normal' distribution grid based on their level of relative strong agreement and strong disagreement (Figure A2.2), bearing in mind the question: *What are your views about CRA?* For the middle of the grid (-1, 0, +1) was given a neutral connotation, meaning statements placed on this area did not provoke strong feelings. Participants then were encouraged to provide the reasoning behind their sorting once they were satisfied with the ranking, information which is particularly important Q-sort interpretations.

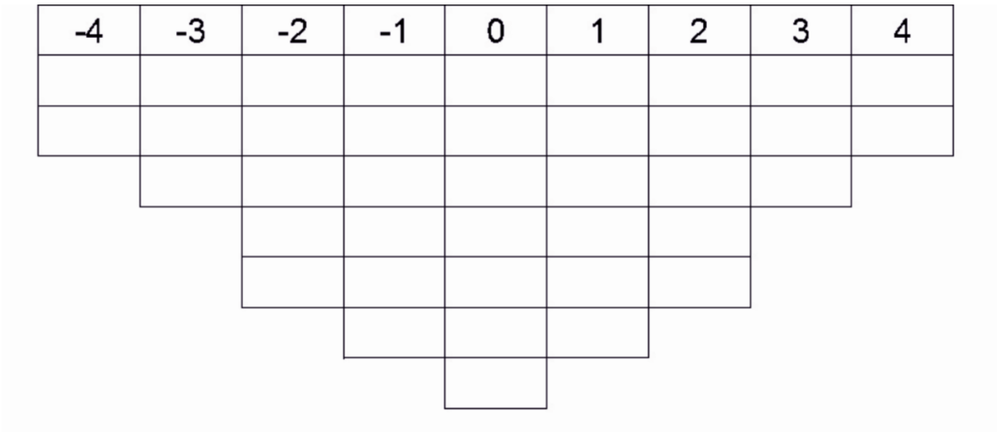


Figure A2.2 Grid distribution used in this study. Strong disagreement is denoted by -4 and strong agreement +4.

A2.2.6 Data analysis

PCA initially correlates each Q-sort and reveals communalities between them, and their components. This analysis extracted eight unrotated components with eigenvalues greater than one for buyers and 10 for sellers. However, this resulted in a large number of components, including components that did not further help to discriminate groups of buyers/sellers. Scree plots were used to visually aid the decision-making process, displaying how many additional components actually contribute to our understanding of buyers/sellers groups. The scree plots indicated three components for extraction, for buyers and sellers, and varimax rotation was used to highlight the majority viewpoints of the participants and to maximise the amount of study variance (Watts and Stenner 2012).

Before extraction and rotation, loadings were calculated (Tables A2.3 and A2.4) to indicate how much one Q-sort is related with a group. These loadings are used to identify Q-sorts that are most representative to each component, a process called flagging. Flagging can be manual or automatic. We applied the latter, since we did not have considerable knowledge about participants. The process of automatic flagging considers two standard criteria: (1) Q-sorts loading higher than the threshold for a p-value < 0.05, and (2) Q-sorts with square loading higher than the sum of square loadings for all other factors (for a detailed explanation please see (Zabala 2014).

A2.2.6.1 Choice of PCA

There is extensive debate amongst Q-methodologists about the use of PCA or Centroid Factor Analysis for factor extraction (Howard *et al.* 2016), however, both are widely accepted. Many of the reviewed Q-studies involving environmental and rural topics used PCA to analyse Q-sorts (Hall 2008; Hermans *et al.* 2012; Thompson *et al.* 2013; Kvakkestad *et al.* 2015; Hamadou *et al.* 2016; Howard *et al.* 2016; Simpson *et al.* 2016; West *et al.* 2016). However, we also ran centroid factor analysis (using PQMethod software version 2.35; available at http://schmolck.userweb.mwn.de/qmethod/) but the solutions provided contained void factors with no significant loaders after rotation, which led to a considerable exclusion of many Q-sorts. To avoid these exclusions, we chose to perform our analyses with PCA.

A2.2.6.2 Calculation of factor loadings and z-scores

Q-sort loadings were considered to be significant at a p-value < 0.05 for a given factor if: (1) loadings were higher than $1.96/\sqrt{N}$, where N is the number of statements; and (2) loadings were higher than the sum of square loadings for all other extracted factors (Brown 1980; Zabala 2014). Only the Q-sorts that meet these criteria are considered for future calculations.

To compare meaningful differences between the ranks, z-scores were calculated. Z-scores (Table A2.5) are a measure that indicates how much one factor agrees or disagrees with each statement. They are calculated based on the weighted average of the statement ranks given by each of the significant Q-sorts: the Q-sorts with the higher loadings are attributed more weight (Zabala 2014). The z-scores are then converted to the same array of discrete values used in the original distribution.

Table A2.3 Loadings of sellers' groups. A: independent conservationists; B: environmental disbelievers; C: willing deforesters. Asterisks indicate flagged Q-sorts.

Participant	A	B	C
S1	-0.3	0.03	0.59*
S2	-0.02	0.62*	0.44
S3	0.54*	0.08	0.27

Participant	A	B	C
S4	0.03	0.26	0.5*
S5	0.38	0.18	-0.41
S6	0.55*	0.12	0.27
S7	0.45	0.08	0.53*
S8	0.51*	0.34	0.04
S9	0.09	0.39	0.59*
S10	0.36	0.64*	-0.14
S11	0.56*	0.15	-0.09
S12	0.5	0.57*	-0.02
S13	0.46	0.27	0.45
S14	0.46*	0.08	-0.04
S15	0.36	0.46*	0.17
S16	0.34	0.6*	-0.23
S17	0.44*	0.3	0.07
S18	-0.08	0.49	0.58*
S19	0.15	0.51*	0.24
S20	0.59*	0.3	0.02
S21	0.35	0.59*	0.37
S22	0.63*	0.01	-0.03
S23	0.36	-0.03	0.53*
S24	0.2	0.31	0.66*
S25	0.14	0.5*	-0.17
S26	0.75*	-0.03	-0.16
S27	0.41	0.37	0.26
S28	0.31	-0.03	-0.28
S29	-0.2	0.73*	0.13
S30	0.54*	0.39	-0.05
S31	0.81*	0.01	-0.08
S32	0.78*	0.02	-0.07

Participant	A	B	C
S33	0.54*	0.29	0.08
S34	0.68*	0.38	-0.01
S35	0.05	0.56*	0.19

Table A2.4 Loadings of buyers' groups. D: the CRA outsiders; E: the cautious buyers; F: the compensation seekers. Asterisks indicate the loadings kept for calculations.

Participant	D	E	F
B1	0.52	0.09	0.56*
B2	0.41	0.62*	0.18
B3	-0.19	0.69*	-0.17
B4	0.28	-0.14	0.63*
B5	0.09	0.75*	-0.04
B6	0.6*	0.38	-0.24
B7	0.36	0.15	0.39*
B8	0.19	0.66*	-0.09
B9	-0.3	0.67*	0.38
B10	-0.14	0.46*	-0.11
B11	0.63*	0.12	0.41
B12	0.16	0.08	0.65*
B13	0.32	0.41*	0.18
B14	0.71*	0.31	0.03
B15	0.04	0.6*	0.18
B16	0.71*	0.04	-0.02
B17	-0.23	-0.02	0.76*
B18	0.29	0.26	-0.28
B19	0.5*	0.24	0.1
B20	0.31	0.63*	0.02
B21	0.16	0.43*	0.02
B22	0.52*	-0.35	0.22

Participant	D	E	F
B23	0.77*	-0.11	0.06
B24	0.64*	-0.03	0.15

Table A2.5 Z-scores of statements identical to both groups of sellers and buyers.

Statement	A	B	C	D	E	F
1	-0.354	0.854	-0.912	-0.087	-1.233	-1.334
2	1.388	-0.979	-1.452	0.015	-0.948	-0.432
3	-0.460	-1.356	-0.111	-0.641	-0.180	0.978
4	2.137	0.991	-0.237	0.785	1.674	1.747
5	2.126	0.462	-1.119	0.115	-0.270	1.503
6	-2.116	-1.950	-0.5833	-0.692	-2.330	-0.924
7	0.042	0.952	0.305	0.697	0.718	0.719
8	-1.740	-0.766	-1.319	-0.498	-0.383	0.062
9	-0.182	-0.043	1.179	-0.359	0.466	-0.619
10	-0.816	0.173	0.661	-0.796	0.155	-1.396
11	-1.024	-1.002	-1.812	-0.189	-0.881	-1.687
12	0.810	1.079	0.673	-0.236	-0.505	0.054
13	0.631	0.032	-0.906	-1.505	-1.128	0.582
14	-0.221	0.942	1.240	0.188	0.958	-0.661
15	0.530	-0.134	1.142	0.330	-0.796	-0.004
16	0.649	0.893	0.237	-0.173	-0.127	0.558
17	-0.308	0.166	0.712	0.145	0.444	-1.196
18	-0.094	0.912	-0.205	-0.398	0.044	-0.993
19	0.188	-1.403	0.539	-0.704	-1.115	0.076
20	0.359	-0.394	2.274	0.445	-0.134	-0.133
21	-0.183	-0.549	0.691	-0.040	0.117	-0.585
22	-0.698	-1.490	-1.191	-0.192	-1.565	0.043
23	0.133	-1.028	-0.897	-1.607	1.349	0.310
24	-0.695	1.904	-0.173	0.376	0.960	-0.919
25	-0.271	0.812	0.409	-0.436	0.993	0.105
26	-1.604	-1.686	-0.465	-0.697	1.000	2.008
27	1.153	1.223	1.450	1.831	1.007	0.882

A2.2.7 Trade Compatibility Index (TCI)

The TCI was created to provide a metric to assess whether a pair of sellers and buyers has similar views on programme-specific factors, suggesting a potential trade. By examining the normalised scores and z-scores spread of sellers and buyers groups, we observed some mismatches that could be explored more systematically, hence the development of the *TCI*. The index ranges from 0 to 1 representing how much a pair of sellers (A, B, C) and buyers (C, D, F) mutually agrees or disagrees with all thematic categories or each set of statements separately.

The idea behind TCI is to provide a mathematical tool to compare pairs of groups (or factors) using normalised scores. The latter are discrete values corresponding to the same values of the sorting grid (in our case from -4 to +4). Normalised scores are calculated based on z-scores (Zabala 2014; Zabala and Pascual 2016). Although z-scores provide a more statistically correct measurement, they have different minimum and maximum values for sellers and buyers (e.g. SELLERS z-scores min: -2.11 max: 2.27 | BUYERS min: -2.38 max: 2.36). This would require them to be normalised in a way that minimum and maximum values are the same for both groups to allow comparisons. As normalised factor scores already provide the same minimum and maximum normalised values, we chose to use these values in TCI.

To explore potential mismatches within the category of statements relating to aspects of programme design, we calculated one TCI value per different combination of thematic category by subsetting specific statements of the thematic categories we wanted to include in the model. For example, to calculate whether there is a mismatch in contract length, we only included statements relevant to this category within our TCI calculations (Table SI7, column headed "Contract length"). I was then interested in how statements about price might alter levels of agreement, so included these in our next iteration of TCI calculations (Table SI7; columns headed "Price" and "Contract length and price"). Finally I repeated the process by adding statements one by one. This resulted in slightly different TCI results as more statements from a particular thematic category were added. I tried several different combinations of thematic categories to assess to assess whether overall TCI results were sensitive to the order thematic categories were added or removed from the calculations. However, in most of the combinations the two most compatible and incompatible pairs remained the same, except when contract and price were removed from overall calculations (Table A2.7; column headed "All minus price"), suggesting these thematic categories are particularly important.

A2.2.8 Robustness check of overall TCI

To assess whether overall TCI values were representative of the agreement and disagreement between sellers and buyers using the normalised factor scores, we did a non-parametric Spearman correlation using the z-scores for sets of statements identical to both groups (n=27), while excluding comment statements with opposite meanings. The Spearman test simply correlates all statement's z-scores from each pair of sellers and buyers without specifically considering the significance of defining statement scores. This means that in the Spearman correlation test, no statement's z-scores are attributed a "weight" that defines its importance in defining a particular group. Thus to allow an accurate comparison, we excluded the parameter p_i^X from TCI calculations. TCI results range from 0 to 1 and the higher the value the more incompatible the pair is whereas correlations are the opposite.

When comparing the ranked results (Table A2.6), the only difference between the z-scores and normalised scores rank was between pairs AF and BD. Using normalised scores, the most compatible pair is AF and the second most compatible is BD. They shift positions for the z-scores. This robustness check supported the TCI results and highlighted its accuracy because TCI accounts for significantly distinguishing statement scores[3] (p-value ≤ .05) whilst correlation does not.

[3] Distinguishing statements are those that reflect if all groups (or one) think significantly different from one another (Zabala 2014)

Table A2.6 TCI results robustness check using Spearman correlation test using z-scores and normalised factor scores.

	AD	AE	AF	BD	BE	BF	CD	CE	CF
TCI (normalised factor scores)	0,765	0,875	0,617	0,656	0,7	0,93	0,84	0,765	0,96
Rank (normalised)	5	7	1	2	3	8	6	4	9
Correlation (z-scores)	0,4	0,13	0,45	0,57	0,44	0,01	0,33	0,41	0,05
Rank (z-scores)	5	7	2	1	3	8	6	4	9

Table A2.7 Trade Compatibility Indexes (TCI) values for pairs of sellers and buyers. Set of statements corresponding to each thematic category were added step-wise in the calculations. The column "Demotivation (all)" includes all statements. Shaded cells correspond to non-significant TCI values. A represents independent conservationists; B environmental disbelievers; C willing deforesters; D CRA outsiders; E cautious buyers; and F compensation seekers.

Pairs	Contract length	Price	Contract length and price	Intermediaries	Trust	Transaction costs	Payment vehicle	Information	Eco- effectiveness	Demotivation (all)	All minus contract	All minus price	All minus contract and price
AD	0.125	0.125	0.125	0.125	0.225	0.225	0.225	0.208	0.214	0.234	0.25	0.267	0.3
AE		0.125	0.125	0.25	0.25	0.25	0.25	0.271	0.271	0.297	0.296	0.296	0.321
AF		0.438	0.438	0.225	0.188	0.188	0.188	0.179	0.172	0.167	0.166	0.141	0.089
BD	0.125	0.25	0.2	0.2	0.2	0.2	0.2	0.229	0.214	0.232	0.275	0.391	0.313
BE	0.375	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.175	0.275	0.218	0.25
BF	0.625	0.438	0.469	0.375	0.375	0.375	0.391	0.389	0.375	0.4	0.375	0.391	0.354
CD	0.188	0.375	0.25	0.25	0.25	0.25	0.25	0.35	0.354	0.339	0.4	0.333	0.406

CE	0.375		0.375	0.438	0.438	0.438	0.438	0.275	0.292	0.304	0.292	0.303	0.292
CF	0.625	0.563	0.583	0.525	0.525	0.525	0.525	0.446	0.469	0.417	0.391	0.375	0.333

Appendix 3: Supplementary Information Chapter 3

A3.1 Compensation options and Environmental Reserve Quota (CRA)

The Brazilian Forest Code (FC) is the environmental legislation that controls and regulates native vegetation across the national territory within private properties. The FC states that every private property should set-aside areas of native vegetation with the purpose of conservation. The first type are the permanent protected areas, such as riparian and hilltop areas. These areas are protected by law and are not subject to legal deforestation. The second type, called Legal Reserves, are areas of native vegetation that should be also maintained. The extent of Legal Reserves varies according to biome where the property is located. In the Amazon, for example, this percentage is 80%, although there are some exceptions (see section S4).

For the landowners who are not in compliance with this limit (named buyers), there are a few compensation strategies available. One option could be to offset the forest deficit by acquiring private land inside protected areas and donating to the environmental agency. This strategy has been seen as problematic due to low additionality (as the offset occurs in areas already protected by law) and to over-surplus (Soares-Filho et al., 2016). Others consider positive as this could be an important resource to under-capitalized environmental agencies (Andrade, J., May, P.H. & Bernasconi, 2013). Currently, properties inside protected areas need to be habilitated to be sold as a compensatory strategy. In 2017, there were seven properties habilitated to compensation, summing 295,975 hectares but it is likely that this number will increase as compliance starts to be adopted (Saretta, 2017). A particular issue that involves this type of compensation is the possibility of multiple buyers offsetting in one very large property inside a protected area, this is called condominium and is allowed by the Ministry of Environment (Brasil, 2016).

Another option is the environmental reserve quota. Buyers who deforested their legal reserve until 2008 can compensate their deficit in other private properties that kept their Legal Reserve above the minimum (sellers). Sellers issue quotas (1 hectare = 1 quota) and their acquisition is lease-based. The native vegetation still belongs to the sellers, who leased their surplus to sellers. Trade must happen within the same biome and the same state. If outside state boundaries, it must happen inside priority conservation areas (figure S1). Considering that sellers have the right to legally deforest their surplus, CRA has the potential avoid future forest loss but still awaits regulation.

Lastly, buyers have the option of on-site compensation. They can actively reforest their deficit or allow natural regrowth via abandonment.

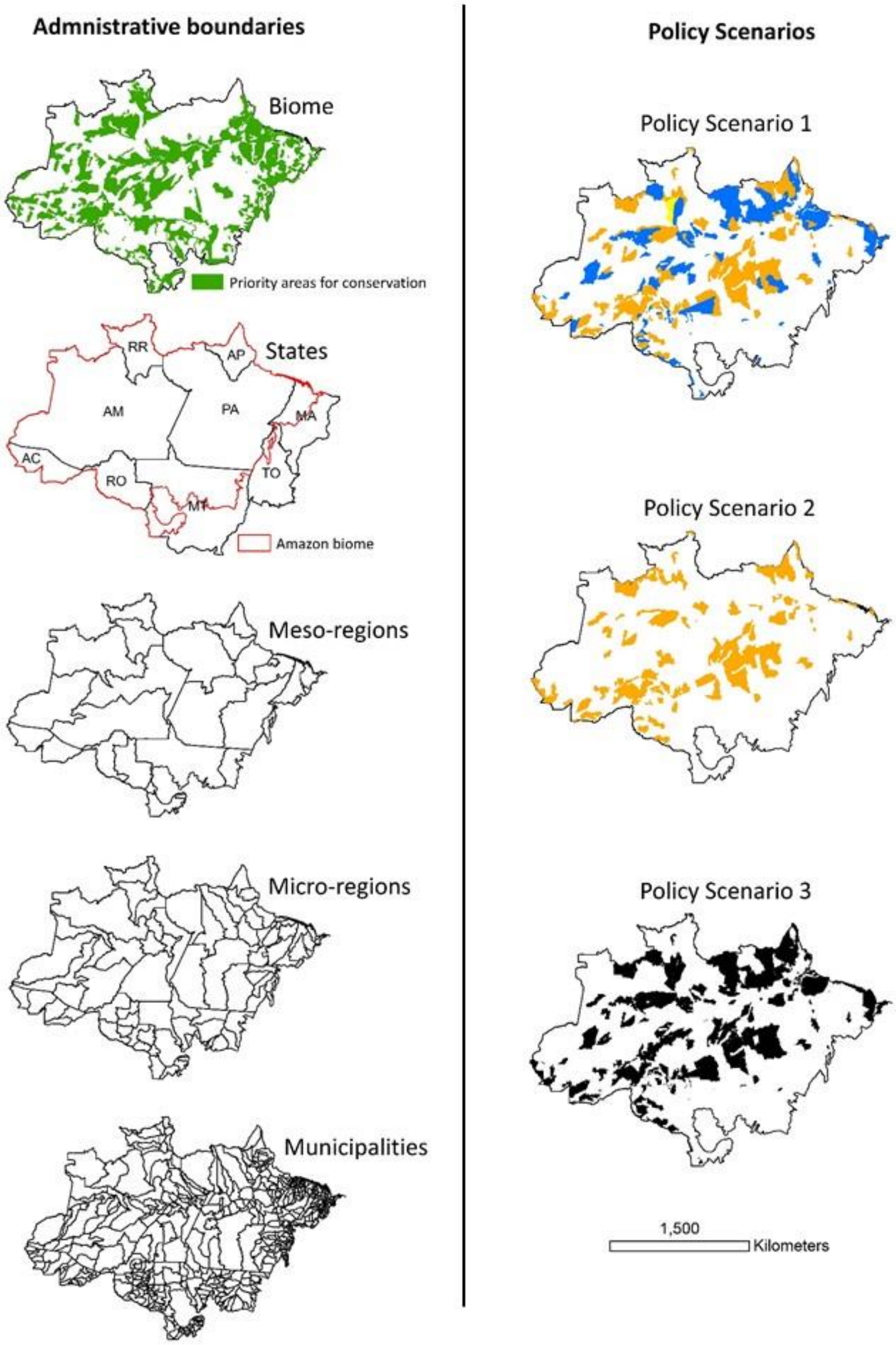


Figure A3.1. Left-hand column represents administrative boundaries used as the five spatial scales in which we simulated off-site compensation, from the largest to the smallest. The Amazon biome covers nine states in Brazil: Acre (AC), Amapá (AP), Amazonas (AM), Maranhão (MA), Mato Grosso (MT), Rondônia (RO), Roraima (RR) and Tocantins (TO). Maranhão, Mato Grosso and Tocantins are only partly covered by the Amazon, and therefore only properties located in the Amazon biome were considered in these three specific states. Areas covered in green at biome level represent priority areas for conservation, which were only used to simulate compensation in the entire biome (between states). Right-hand column represents the policy scenarios considered for each administrative boundary. Policy scenario 1 considered properties inside all PAs (federal – orange, state – blue, and municipal – yellow), scenario 2 only properties inside federal PAs, and scenario 3 does not account for PAs at all (black).

A3.2 Land tenure data preparation

Amazon land tenure was derived from Freitas et al. (2017), which is a database that integrates georeferenced land use categories including both private and public land. This land tenure map adopts a spatial resolution of 50m and contains the different categories of land use for all types of rural properties in Brazil. To meet the aims of this study, I first selected properties within the Amazon biome. Then, I excluded from this analysis polygons classified as non-processed land, as they encompass water bodies, roads and urban areas. Because participation in CRA is dependent upon clear land titling, we excluded properties classified as non-designated land. Although they cover a large portion of the Amazon (~55Mha), their clear designation and regularization process is slow and unclear (Freitas et al., 2017; Azevedo-Ramos and Moutinho, 2018). I have also eliminated one category called simulated land. This category covers areas that are not registered in any official database therefore the authors decided to estimate land in these geographical voids. Hence is also uncertain if these lands have land titling. Land tenure data is available both at shapefile and raster formats. Manipulation was done using R studio, version 3.4.1.

A3.3 Land cover data

GFC data

I used Global Forest Change datasets (Hansen et al., 2013) to have an updated estimate of open land inside protected areas to explore potential regrowth. The most recent year available is 2016. Tree cover 2016 was calculated as tree cover in the year 2000 minus yearly loss until 2016, plus forest gain. As the main interest here was in open area, pixels representing forest loss from 2000-2016 were reclassified as open land. To match the Amazon land tenure map, forest/non-forest pixel size were resampled to 50m resolution and overlaid with the tenure map to calculate open area per property. I also used GFC forest cover of 2000 to apply in our classification of buyers and sellers (see next section). GFC data was processed in Google Earth Engine and exported as raster files to be further manipulated in ArcMap 10.3.1. We employed a threshold of 10% for canopy tree cover – the same established by United Nations Food and Agricultural Organization (Hansen et al., 2010) to also account for Cerrado areas within Amazon.

Table A3.1 Summary of datasets used and their respective source.

Layer	Source
Rural Properties	Tenure Map of Brazil (F.L.M. de Freitas et al., 2017)
Land cover	TerraClass 2008, 2014 (Almeida et al., 2016)
Forest and non-forest cover inside protected areas	Global Forest Change 2000-2016 (Hansen et al., 2013)
Permanent Protected Areas (hilltop and riparian areas)	CSR, UFMG (Soares-Filho et al., 2014)
Economic-ecological zoning and Priority areas for conservation	MMA[4]

TerraClass

TerraClass is a project of the Brazilian Space Research Agency that maps land use and land cover changes across the Brazilian Amazon. TerraClass explicitly accounts for classes, such as secondary forest and regenerating pasture (which can both be accounted as native vegetation remnants) hence the preference for this dataset. TerraClass has 15 different land cover classes (see Almeida *et al.*, 2016). This analysis does not require that level of detail so I reclassified the dataset, which resulted in: (1) Forest, (2) Secondary Forest, (3) Savannah, (4) Pasture, (5) Crop, and (6) Others. The main classes of deforested land were reclassified into pasture, crop and others. The classes corresponding to native vegetation were preserved as their original classification: forest, secondary forest and savannah. TerraClass has one specific class called “regenerating pasture”, which contains vegetation at successional stage. This category was reclassified into Secondary Forest. I resampled pixels to 50m resolution and then calculated for each property the area covered by each land cover class in ArcMap 10.3.1. I used the years 2008 and 2014 for this analysis. The FC states that only landowners who deforest until 2008 are eligible for off-site compensation. Thus the vegetation cover in 2008 was necessary to classify eligible buyers and 2014, eligible sellers.

[4] http://www.mma.gov.br/gestao-territorial/zoneamento-territorial/zee-nos-estados. Last accessed: 21/02/2018

Hilltop and riparian areas

Riparian vegetation and hilltop areas, if covered by natural vegetation, cannot be legally deforested. Riparian areas along rivers and streams have hierarchical levels of protection: the wider the river or stream, the larger the buffer of riparian protection (Brasil, 2012). To have a precise estimate of the native vegetation occurring in these areas, I used the raster map provided by Soares-Filho *et al.* (2014), which contains the hierarchical buffers. Then, I calculated for each property the area corresponding to riparian buffers to later discount from our estimates of avoided deforestation (see main text) as these areas are not subject to legal deforestation. For the calculation of the total native vegetation per property these areas were included as the Forest Code allows the computation of riparian areas as part of Legal Reserve and can be used as forest surplus in CRA. Hilltop areas also follow a hierarchical protection, but that is related to the slope and elevation (Brasil, 2012). I applied the same procedure of the riparian areas here, also using the raster map by Soares-Filho et al. (2014). Hilltop areas that overlap with native vegetation were computed as Legal Reserve for the same reason as riparian areas and also discounted from the estimate of avoided deforestation.

At the end of this stage, the database contained private properties outside PAs with their respective natural vegetation remnants in 2008 and 2014; and private properties inside PAs with their respective amount of open land in 2016.

Importantly, to calculate potential avoided deforestation in our analysis, I discounted riparian and hilltop areas, as they are protected by law and cannot be deforested.

Economic-Ecological Zoning and Priority Areas for Conservation

The Ministry of Environment (MMA) establishes a zoning system with areas of specific designation, called which The Economic-Ecological Zoning (ZEE). There are three main zones: (1) agricultural expansion; (2) controlled uses; and (3) special uses. In areas designated to agricultural expansion, Legal Reserve is reduced to 50% in the Amazon (instead of 80%). Priority areas for conservation are areas with strong conservation recommendations and supposedly conservation actions. The implication of these areas to CRA is that at biome level, only sellers located in priority areas can offer their Legal Reserve surplus.

A3.4 Classification of buyers and sellers

To classify the properties into buyers and sellers is not a trivial task. The Forest Code states many exceptions to the rules, which makes it complex. To facilitate understanding, I depict this process in figure A3.1, but below I also provide a detailed explanation.

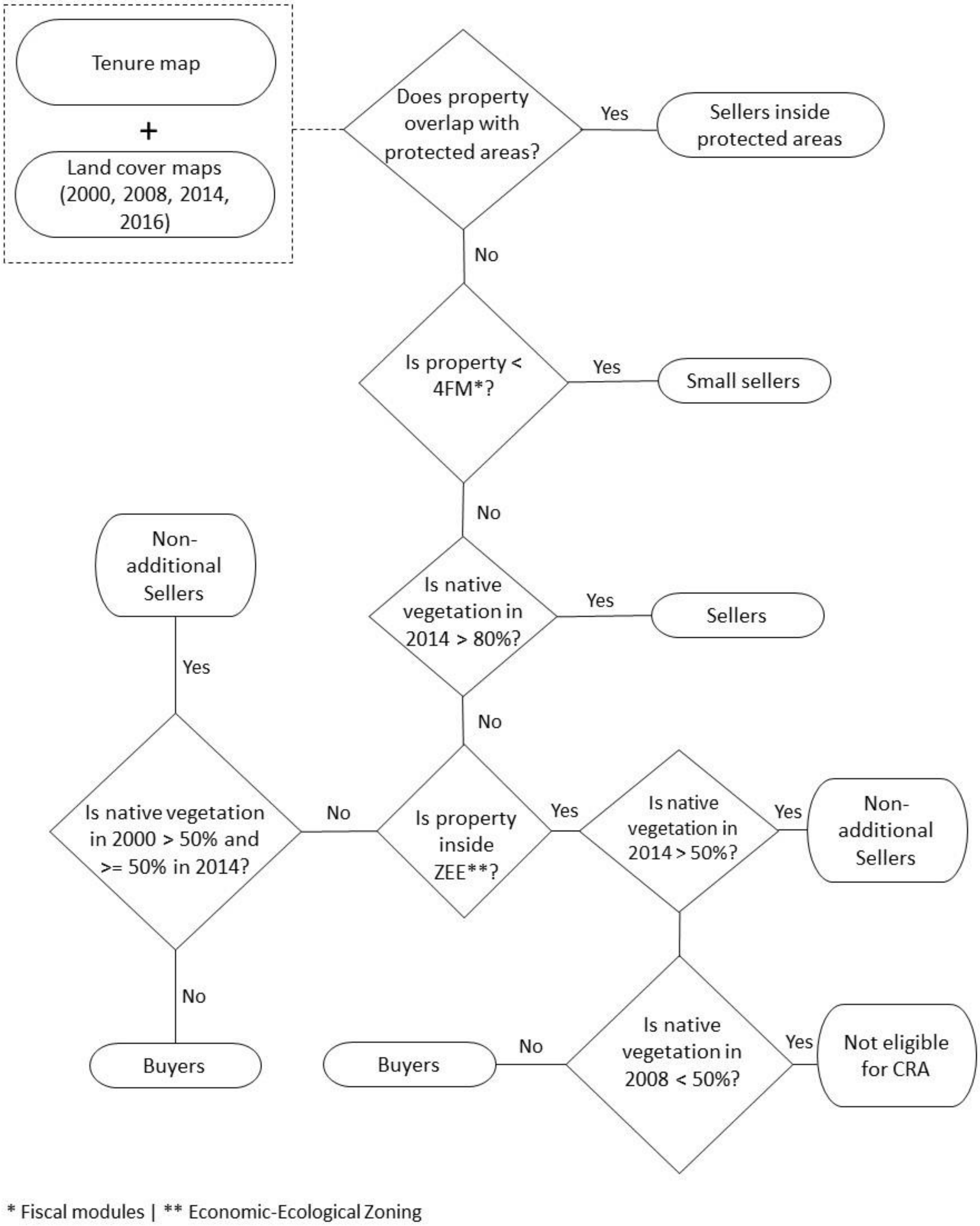


Figure A3.2 Depiction of the decision tree used in the classification of buyers and sellers using the land tenure dataset and land covers datasets from 2000, 2008, 2014 and 2016 with the later just to calculate potential regrowth inside protected areas.

Eligible sellers

As a general rule, all properties in the Amazon must maintain a minimum of 80% as standing vegetation. If a property has above 80% as native vegetation today (using TerraClass 2014 as a proxy), this property is considered a seller. However, there are some exceptions. If a property is located in the agricultural expansion zones and has Legal Reserve above 50%, it is a seller. All small properties, those who are inferior to four fiscal modules (a standard national unit that varies according to the municipality, between 50 and 100 in the Amazon) are also considered sellers and can offer whichever amount of native vegetation they have. Settlements are also considered sellers as they can offer their joint Legal Reserve for compensation. They are treated the same way as small landowners. Lastly, back in 2000, the Forest Code stated that the minimum Legal Reserve percentage was 50%. Article 68 says that landowners that supressed their Legal Reserve respecting the minimum percentage that was valid at that time and still maintain the same or a higher amount of native vegetation, can also offer their “surplus” in CRA market. To apply this exception I used the year 2000 of GFC dataset to calculate native vegetation for each property. Private properties that overlap with protected areas were also classified as sellers. In this case, the entire property is accounted as surplus. Thus, total surplus is a sum of all native vegetation above 80% or 50%, native vegetation in smallholdings and settlements, and private land inside protected areas.

Eligible buyers

I used TerraClass 2008 to classify properties eligible for CRA compensation. Landowners who illegally deforested their native vegetation below the 80% minimum until 2008 are allowed to participate in CRA. In general, all landowners who have below 80% of native vegetation in 2008 are considered buyers. If the property is located in the agricultural expansion zones and has Legal Reserve below 50%, the property is also classified as buyer.

A3.5 Matching algorithm

I developed an algorithm to simulate trade between potential buyers and sellers, considering area equivalence as the only condition that results in trade. For policy scenarios 1 and 2, the Legal Reserve deficit was attempted to be offset first with private land inside protected areas.

Buyers were sorted from the largest deficit to the smallest, under the assumption that those with larger deficits would seek this kind of compensation as it is unlikely that one landowner is going to forgo, for example, nearly 50,000 ha of productive hectares (which is the case of one buyer in Rondônia). Each buyer looked for an area inside conservation units that was equivalent or up to 1.2 times larger than their deficit. Once a buyer found a matching area, the deficit was offset and the seller became unavailable to other buyers. The best matching area was the closest value to the buyer's deficit. This was iterated for each of the five administrative boundaries. Buyers who did not find an area inside protected areas that met this criterion remained available to interact with regular sellers in CRA.

The CRA market algorithm had the same best matching principle, except that one hectare of deficit was offset with one hectare of forest surplus. Buyers and sellers were allowed a maximum of three contracts under the assumption that both tried to maximise their trade costs seeking for the minimum number of contracts and maximum utility of their deficit/surplus. Once a buyer found a surplus that met the best matching criteria, the deficit was offset. While buyers and sellers had not reached the maximum number of contracts, they were still participating in CRA with their remaining deficit/surplus.

Buyers and sellers with deficit and surplus smaller than 1 hectare were excluded from the protected areas and CRA trade. We assumed these landholders will not opt for neither of the compensation possibilities given the high transaction costs associated with them (May et al., 2015; Soares-Filho et al., 2016), just to offset a very small area.

The matching algorithm was elaborated in RStudio 1.0.143 (R Core Team, 2017) and the best match function used the package foreach ({Microsoft} and Steve Weston, 2017).

A3.6 Efficiency frontiers

Efficiency frontiers were calculated in several steps, for each policy scenario. First, we used the sum of avoided deforestation and regrowth resulted from each administrative boundary to calculate their respective percentages based on the total deficit. Second, we calculated the frontiers' slope B by taking the difference between the highest percentage (x_2) and the lowest (x_1) of regrowth, and divided by the difference between the highest (y_2) and the lowest (y_1) percentage of avoided deforestation:

$$B = \frac{x_2 - x_1}{y_2 - y_1}$$

Third, we used B to find A, which is the intercept of y when x corresponds to zero:

$$y = A - Bx$$

where, y the percentage of avoided deforestation at a given administrative boundary, B the slope, and x the respective percentage of regrowth at the same administrative boundary. After this step, we have the highest (or the most efficient) value of y when $x = 0$.

Finally, to plot the other x,y point of the efficiency line, the same step above was iterated, but to calculate the y value that corresponded to the highest percentage of regrowth. In the end, we had the efficiency lines with two x,y points, for each administrative boundary.

A3.7 Sensitivity analysis

To know whether changes in the assumptions established here would substantially change the patterns found in our results, we submitted our simulations to a sensitivity analysis. Firstly, I tested if changing the buyers' criteria of offsetting in private land inside protected areas that were up to 1.2 the size of their deficit would influence the amount of offset and, consequently, on CRA market. I ran the matching algorithm for compensation in both federal and state protected areas (policy scenario 1) at biome level. Besides the 1.2 limit, we tested five other limits (Table A3.2).

The only limit that showed a substantial change in the total offset available for CRA was one. This means that buyers were looking for sellers inside protected areas that matched exactly their deficit. Other tested limits did not show a substantial impact on the amount of offset from total deficit. From 1.1 to 2.5 there was only 4% difference, on average, in total offset across each administrative boundary. For that reason, I decided to maintain our limit of 1.2 in simulations inside protected areas.

Table A3.2 Extent of offset and regrowth in private lands inside protected areas under different tolerance limits equal or above deficit size. For example, limit of 1 means area is equal to deficit; limit of 2 means the area is twice as large as the deficit. The percentage column indicates the percentages of offset inside protected areas from forest deficit.

Administrative boundary	Limit	Offset from total deficit (ha)	% from forest deficit	Regrowth (ha)
Biome	1	182621.5	3.6	21798.75
	1.1	1293285	26.1	97246.5
	1.2	1361218	27.5	100790.5
	1.5	1462255	29.5	121265.5
	2	1485974	30	121332
	2.5	1497175	30.2	121445.5
State	1	0	0	0
	1.1	971628.9	19.6	88051.75
	1.2	1018956	20.6	97427.5
	1.5	1139265	23	107282.8
	2	1168476	23.6	107992.8
	2.5	1181521	23.8	112055.5
Meso	1	0	0	0
	1.1	613907.2	12.4	60535.25
	1.2	683844	13.8	69148.5
	1.5	744025	15	79429.25
	2	776258.6	15.6	81044.25
	2.5	797744.4	16.1	87708.75
Micro	1	0	0	0
	1.1	392533	7.9	44031.75
	1.2	477018.7	9.6	60189.25
	1.5	532734.1	10.7	68165
	2	583361.9	11.7	70536.75

	2.5	600399	12.1	75856
Muni	1	0	0	0
	1.1	205632.3	4.1	27513.25
	1.2	248841.6	5	32701.25
	1.5	312027.9	6.3	38770.75
	2	350980.8	7.1	41576.25
	2.5	366486.3	7.4	49332.25

I also tested if increasing the number of contracts for sellers would have an impact on regrowth or avoided deforestation. I simulated trade across the five administrative boundary allowing sellers to have up to 10 contracts and maintained the limit of 3 contracts for the sellers. I tested this limit under policy scenario 3 because there were no interference of regrowth inside protected areas resulting in a precise idea of the extent of regrowth when increasing the contract numbers.

Increasing the number of contracts did not change the pattern observed when the limit in the number of contracts for sellers was three (Figure A3.3). Avoided deforestation still decreased as administrative boundary became smaller and the opposite happened with regrowth. However, there were some very minor changes in the extent of regrowth and avoided deforestation at biome, state and municipality levels (Table A3.3). Regrowth at biome level increased in 6 hectares, at state level decreased in 85,531 hectares and at municipality level 6,650. Avoided deforestation decreased only at state level, in 38,134 hectares

Because this 10-contract increase did not substantially change the patterns observed, I did not test other scenarios. Nevertheless, it is known that as the market systems takes place, intermediaries may influence the extent of regrowth and avoided deforestation. Some surpluses are considerably large and can offset the demand of several large buyers. As suggested by previous studies, the over-surplus might have negative impacts on avoided deforestation (May et al., 2015; Soares-Filho et al., 2016).

Table A3.3 Changes in regrowth and avoided deforestation across all administrative boundaries, after increasing to 10 the number of contracts for sellers and maintaining 3 for buyers. We considered only **Policy Scenario 3** for this comparison. To better understand changes, we also give regrowth and avoided deforestation areas obtained from the 3 contracts limits for both buyers and sellers.

Administrative boundaries	Regrowth (ha)			Avoided deforestation (ha)		
	3 contracts	10 contracts	Change	3 contracts	10 contracts	Change
Biome	433	439	+6	1,646,512	1,646,512	0
State	215,898	130,367	-85,531	1,480,401	1,442,266	-38,134
Meso-region	323,538	323,538	0	1,201,593	1,201,593	0
Micro-region	685,852	685,592	0	1,068,577	1,068,577	0
Municipality	1,315,092	1,308,442	-6,650	846,073	846,073	0

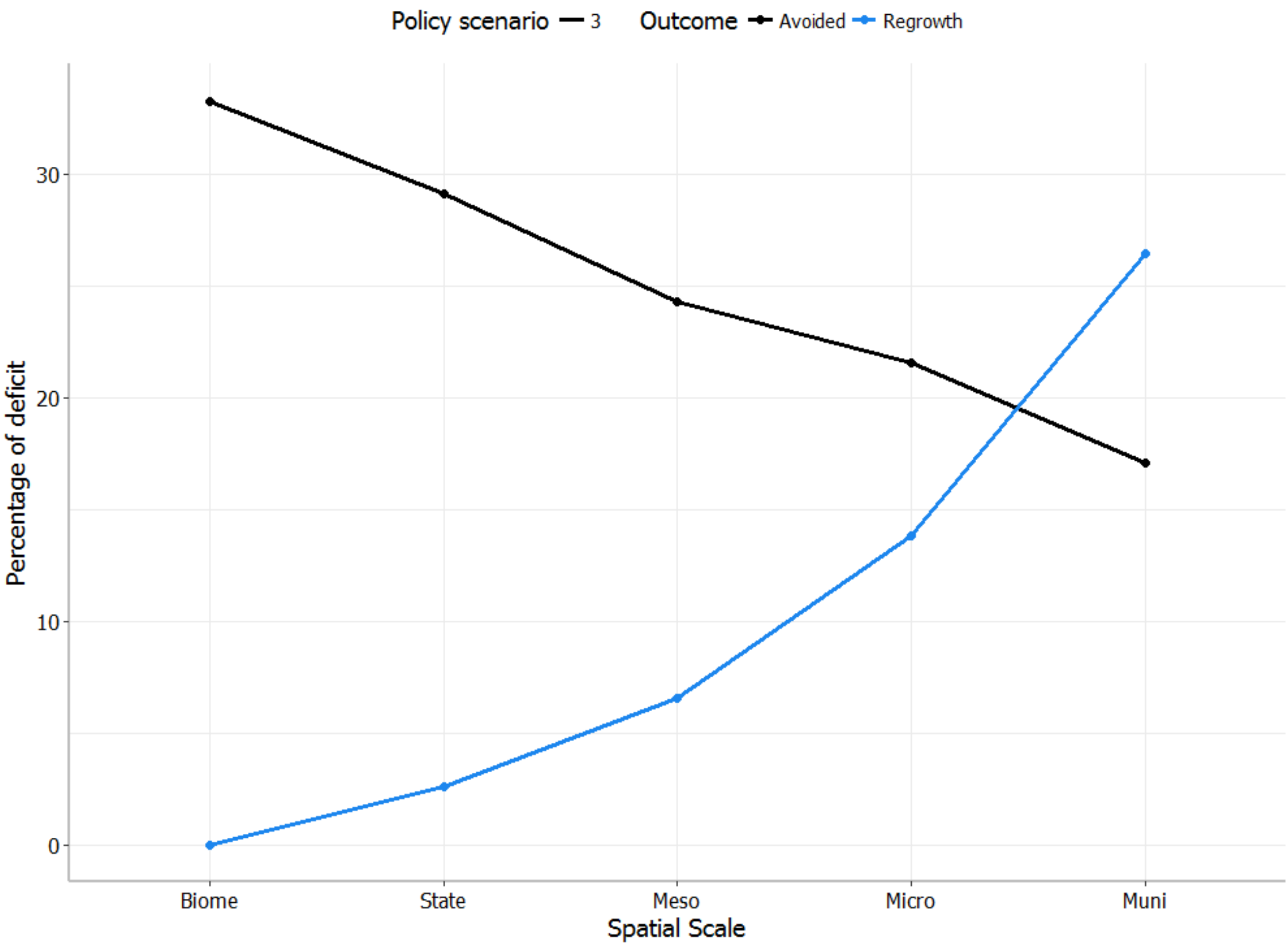


Figure A3.3 Patterns of avoided deforestation and regrowth after increasing sellers' contracts to ten and keeping buyers' at three, at the five different administrative boundaries. Only policy scenario 3 was used to test increase in contract number.

Appendix 4: Supplementary Information Chapter 4

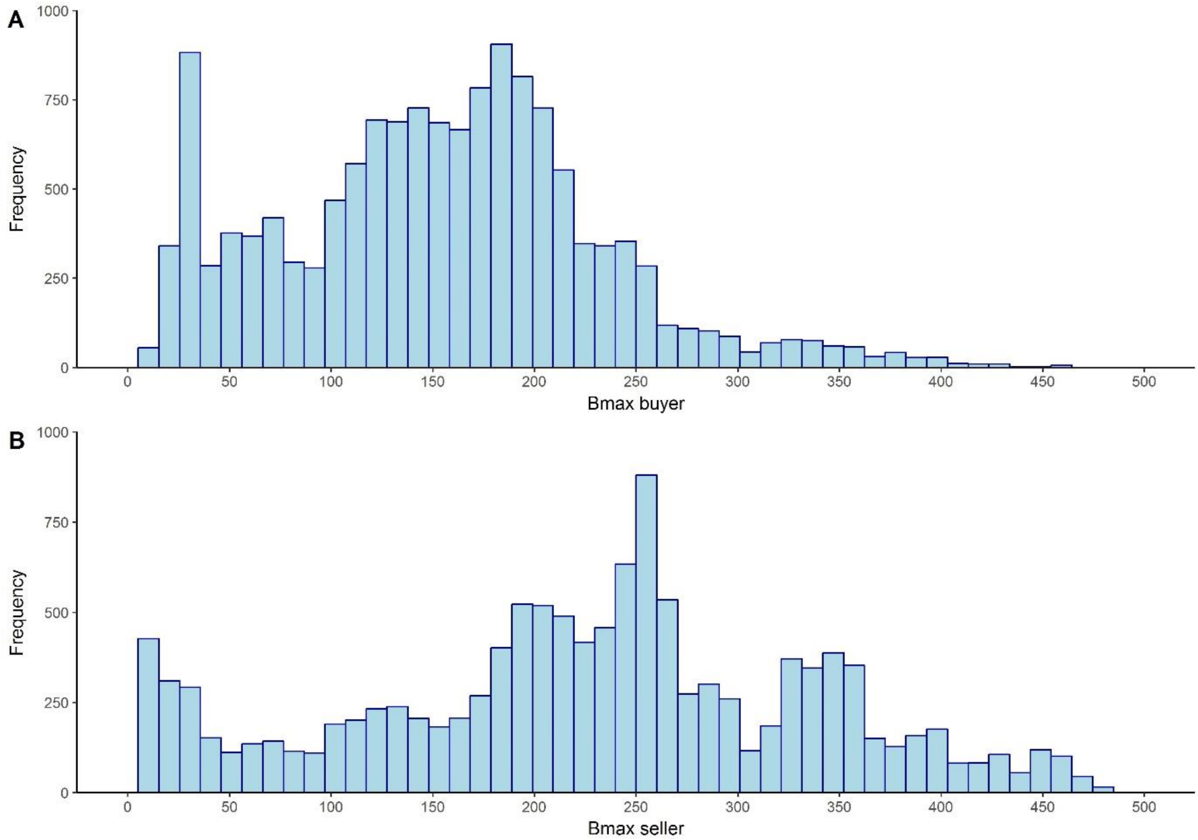


Figure A4.1 Distribution of maximum biomass values within buyers (A) and sellers' (B) properties.

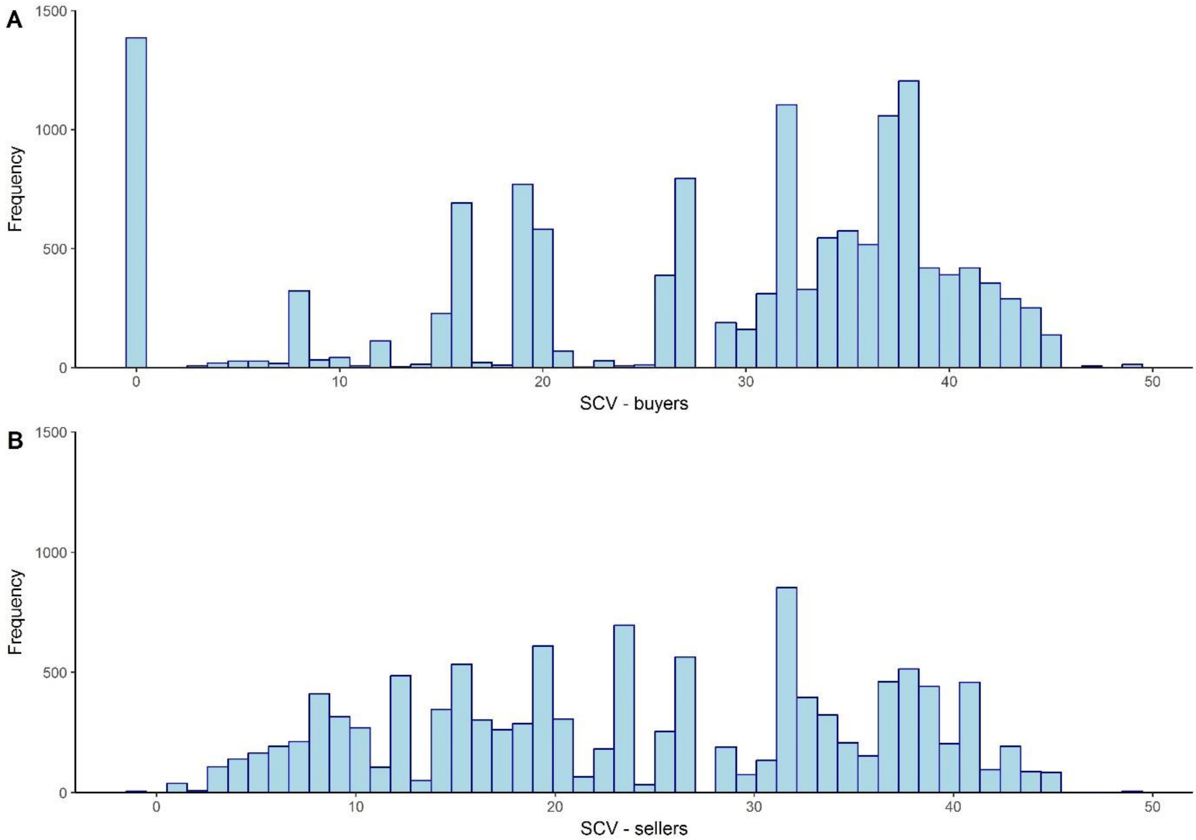


Figure A4.2. Distribution the predominant species composition value within buyers (A) and sellers' (B) properties. Panel A shows the distribution prior to the moving window procedure.

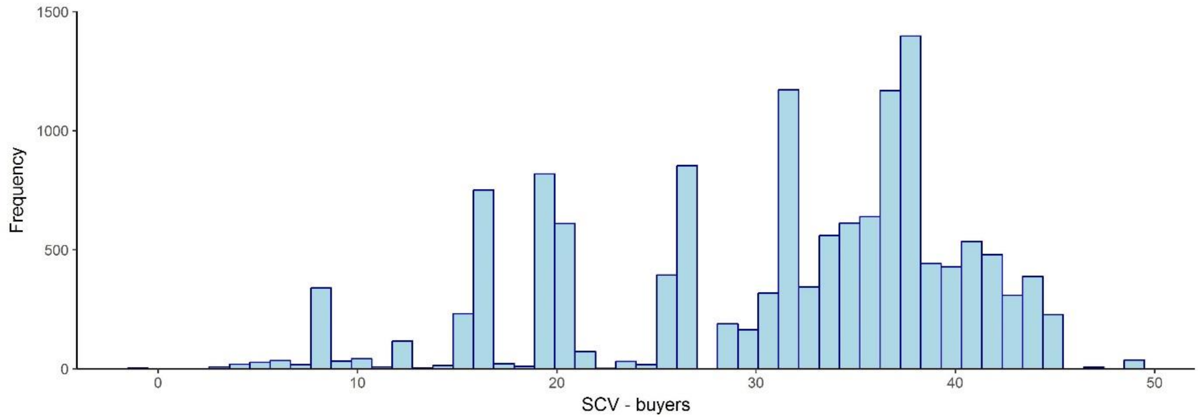


Figure A4.3. Distribution of species composition values of buyers after the moving window procedure.