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Payments for ecosystem services in Amazonia. The challenge of land use heterogeneity in agricultural frontiers near Cruzeiro do Sul (Acre, Brazil)

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Amazonia became a target area for Payment for Ecosystem Services (PES) initiatives in deforestation. We analysed the implementation of a PES scheme in Acre (Brazil) by taking into account land use heterogeneity in an agricultural frontier. Justified by the modernisation of deforestation control policies, the programme promotes agricultural intensification through fire-free practices. In this way, the PES tends to focus on long-established settlements, where farmers are wealthier and the landscape is dominated by pasture. Agricultural intensification may be adapted to foster reforestation. In order to curb deforestation a specific policy is needed for targeting remote areas where initial stages of deforestation usually take place. By promoting only land sparing, PES programmes in Amazonia may lose sight of their socio-economic and environmental objectives due to limited spatial targeting.

Keywords: deforestation; payments for ecosystem services; agrobiodiversity; REDD; Amazonia

1. Introduction

Payments for Ecosystem Services (PES) have become an increasingly widespread policy tool to address tropical deforestation. Latin America has been receptive to this approach,[1] since direct payments to small landowners to promote reforestation and avoid deforestation may also reduce poverty (Grieg-Gran *et al.* 2005). With the emerging attention on Reducing Emissions from Deforestation and Forest Degradation (REDD), Amazonia became an important PES focus because of its carbon benefits,[2] and agricultural frontiers became target areas for incipient PES initiatives.

In most PES experiences in Amazonia, carbon stocks and biodiversity were considered located in natural forest vegetation. Thus, even if agricultural expansion entails diverse practices and landscapes, land use change is generally analysed by quantifying opportunity costs for not cultivating in forests and

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increasing forest cover (Börner *et al*. 2010). Little attention has been paid to other aspects of deforestation. First, farmers' decisions for land use are driven by many factors and not only by opportunity costs (Walker *et al*. 2002). Second, resource management in agroecosystems is a central issue for ES provision, especially because of the importance of agrobiodiversity and landscape dynamics for ES provision (Posey and Balée 1989, Emperaire and Peroni 2007, Speranza and Sand 2010, Padoch and Pinedo-Vasquez 2010, Narloch *et al*. 2011). Third, the debate on land sparing and biodiversity-friendly agriculture (Green *et al*. 2005, Fischer *et al*. 2008) is clearly absent in PES research, which is focused on economic and institutional arrangements. As a result, more research is necessary to analyse the relationships between PES policy interventions and land use heterogeneity at the local scale.

As with other forest policies, a key aspect in the success of PES is the targeting of beneficiaries of the payments (Hodge *et al*. 1997, Wünscher *et al*. 2008). Some authors call for more flexibility and differentiation of payments so that areas that are particularly important for the provision of environmental services are conserved (Gené 2007). Indeed, targeting has a central spatial component – spatial targeting – i.e. the deliberate focus of particular actions on a particular spatial area (van der Horst 2006). However, forest policies, especially market-based incentives, often fail to take into account the spatial heterogeneity of resource management (McAfee 1999). The main objective of this paper was to identify the spatial targeting of a PES scheme in an Amazonian agricultural frontier and to discuss its social and environmental implications.

We studied the first state-based PES programme launched in 2008 by the government of the Brazilian state of Acre. This state government is one of global leaders in sub-national PES negotiations proceeding in parallel with the national post-Kyoto negotiations. We do not intend to make an evaluation of the results of this PES programme since our data focus on the first phases of the implementation of this policy tool near Cruzeiro do Sul.

The paper has four parts. First, we provide background information on forest policies in the Brazilian Amazon and present our theoretical framework. After the study site and methodology in the following section, we apply a multi-scalar approach to analyse land use heterogeneity and the implementation of the PES programme. We then discuss the implications of the spatial targeting of PES policies in Amazonian agricultural frontiers.

2. Payments for ecosystem services and land use dynamics in the Brazilian Amazon

2.1. Decentralisation of deforestation control and the proliferation of PES projects

In the face of agricultural expansion in Amazonia, protected areas and integrated conservation and development projects are not sufficient to control deforestation (Nepstad *et al*. 2002, Soares-Filho *et al*. 2006). The Brazilian Forest Code (1965) requires colonists in the Amazon to maintain 50–80% of their lands preserved, in the so-called 'Legal Reserve', and it also establishes the protection of forest cover along all water courses and steep hill slopes ('Areas of Permanent Preservation'). The Forest Code has hardly been enforced by Brazilian environmental authorities, especially in agricultural frontiers. Despite the new decree establishing sanctions for illegal activities in 1999, deforestation grew during Cardoso's second presidential term.

Under the Lula administration, in 2004 the Brazilian Government launched a Plan for the Prevention and Control of Illegal Deforestation in Amazonia. This plan called for repression procedures and monitoring of rural properties in order to enforce environmental laws (Fearnside 2005). Remote sensing and geographic information systems (GIS) helped to discover which farmers were engaged in illegal deforestation and to develop Environmental Licensing of Rural Properties. Inspired by local innovative experiences,[3] the government released Decree 7.029/2009, establishing the Federal Farm Land Environmental Compliance Support Programme, known as *Mais Ambiente*. The Environmental Licensing procedure then no longer depended on the Farm Land Registry, managed by the National Institute for Agrarian Reform (INCRA). The federal government, through the Ministry of Environment, could make firm agreements with states, municipalities and public and private institutions to control deforestation. By simplifying procedures and modernising monitoring methodologies, these new policies enhanced the decentralisation of forest policies in Brazilian Amazonia (Toni 2011).

Two other factors explain why Environmental Licensing is now spreading in forest frontiers of the Brazilian Amazon. First, resolution 3545 of the Brazilian Central Bank in early 2008 prohibited public and private banks from issuing credit to landowners who were not in compliance with legal requirements regarding land tenure and environmental rules. Second, as land tenure security and law enforcement are prerequisites for Environmental Licensing, the broad use of this procedure by state governments may solve the main institutional restrictions that limit the implementation of a large-scale REDD mechanism.

Yet farmers lack economic incentives to change their land use and they disagree with the increasing amount of fines (Börner *et al.* 2007, Hall 2008). In this context, many recent Payment for Environmental Services schemes are targeting the colonisation zones of Amazonia, in order to induce farmers to maintain or restore their Legal Reserve without compromising their welfare. In parallel with the decentralisation of deforestation control policies, such 'pre-REDD' PES programmes are now mostly conceived at the state rather than the federal levels (notably in Acre and Amazonas). They are based on funds from state governments as well as from foundations and international companies positioned on carbon markets, so they can provide alternatives during the crisis in public funding for conservation (Young 2005).

2.2. PES and land use change in agricultural frontiers

Deforestation partly depends on the proximity of roads and markets (Chomitz *et al.* 2007). In agricultural frontiers, swidden cultivation often involves fallow periods of three to eight years, too little time for vegetation regrowth to renew soil nutrients (Perz 2003). The fallow crisis and pasture plantation underlie gradual deforestation (Thiele 1993). Cattle-based systems rely on land concentration and speculative economies that promote migration of small-scale farmers to new forest margins and cities, and thus cause further deforestation (Léna 1992).

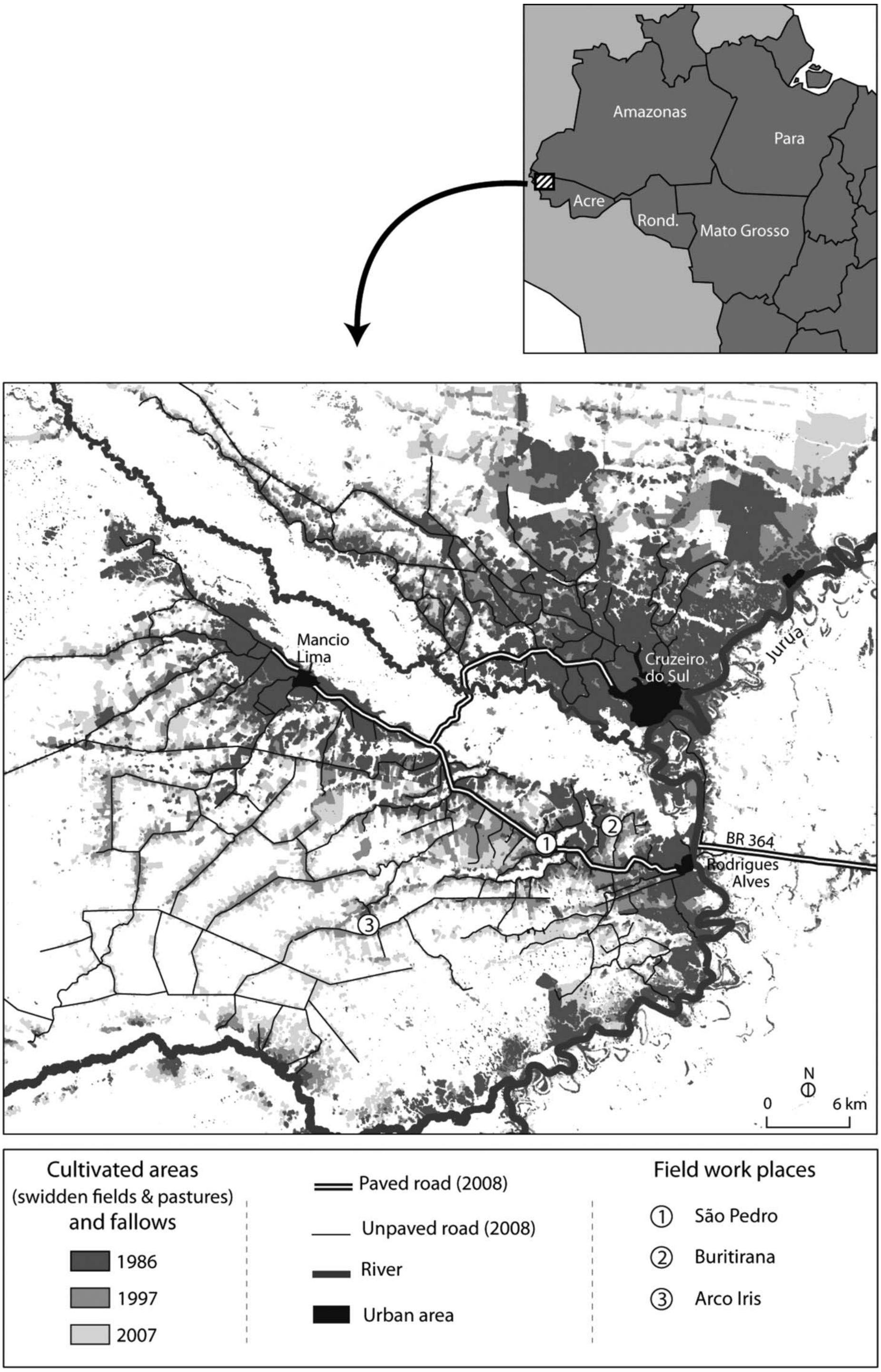
Large-scale cost/benefit analysis for PES targeting in Amazonia (Börner *et al.* 2010) rely on the assumption that the expansion of swidden cultivation and cattle ranching can be contained by compensating their opportunity cost, with little attention paid to the farmers' strategies. However, other studies focusing on the household farm level showed that labour availability, capital and access to markets play major roles in technology adoption and land use changes (De Almeida and Uhl 1995, Brondizio *et al*. 2002, Moran *et al*. 2002, Walker *et al*. 2002, Vosti *et al*. 2003). These factors strongly influence farmers' responses under different policy scenarios, such as PES schemes (Börner *et al*. 2007). However, these models fail to take into account farmers' mobility patterns. Indeed, by focusing either at the macro-scale or at the household farm level, research on PES often overlooked the spatiality of agricultural expansion at the intermediate scales.

Spatial heterogeneity of resource management and mobility patterns may have strong implications for forest policy outcomes. Farmers take actions that impact ecosystem services far away from their farmlands, and landscape dynamics may reflect these impacts (Tscharntke *et al*. 2005, Morse *et al*. 2009). The distribution of farm types tends to follow the biophysical characteristics of the land and to reflect diverging trajectories with regard to farming traditions, landownership patterns, market integration etc. (Moran *et al*. 2002, van der Horst 2006). In Amazonia, this distribution implies different production strategies and responses regarding rural development projects (Coomes *et al*. 2004, Arnaud de Sartre 2006). For example, as many farmers migrate and combine intensive and extensive activities within multi-lot farming systems (Ludewigs and Brondizio 2009), projects intended to avoid deforestation in one area may lead to further deforestation in other places of the same agricultural frontier.

3. Study area and methods

The study was undertaken near Cruzeiro do Sul, in the Rodrigues Alves municipality,[4] Juruá river valley. We chose three rural settlements in the area of São Pedro village, along the BR 364 highway (Figure 1). This is an interfluvial zone where the mature ecosystem is formed by a dense ombrophile forest (Governo do Acre 2000). Most farmers in this region are descendents of migrants from Northeastern Brazil who settled in Acre in the early twentieth century to work in rubber tapping (Salisbury and Schmink 2007). The decline of *Hevea* rubber prices in the 1960s and the massive eviction of rubber tappers within the Agrarian Reform programme contributed to the influx of new landless migrants in the 1970s. The federal government reacted by setting up additional rural settlements and building the state's main roads (BR 317 and BR 364). Former rubber tappers who practised subsistence agriculture settled along the roadside and turned to commercial production of cassava flour (Emperaire *et al*., in press). Most farmers practise swidden cultivation and have small lots (<50 ha), almost no access to capital, and low profits relative to ranchers (Table 1). They used to plant rice and corn in the first year after forest clearing, followed by a second crop of beans and cassava in the second year. The food crops are often supplemented by raising chickens, pigs and a few head of cattle. Land tenure is reasonably secure among smallholders, once they live in INCRA lots.

The combination of socio-economic data obtained at the farmland scale and land cover data obtained from satellite images was used to investigate farmers' production strategies and their impacts on land use (Caviglia-Harris and Harris 2008). Land use assessment also included mobility patterns that reveal farmers' socio-spatial strategies, i.e. relations of competition and complementarity within and between groups exploiting resources (Cortes 1998).



Ludivine Eloy and Regis Darques@ARTDEV CNRS 2009. Supervised classification on Landsat TM scenes 26/07/1986, 22/06/1997, and 21/08/2007, delivered by INPE et GLCF, projection UTM WGS 1984 Z18S.

Figure 1. Land use dynamics in the study area.

Table 1. Land distribution in Acre.

	Number of land holdings	%	Area (ha)	%
Family agriculture (up to 400 ha)*	23,037	84.6	1,486,202	42.8
Non-family agriculture	4202	15.4	1,983,103	57.2
Total	27,239	100	3,469,305	100

Note: *According to Law 11.326, land holdings up to four *Módulos Fiscais* (standard lot measure) may be classified under 'family agriculture'. In the State of Acre, one *Módulo Fiscal* corresponds to 100 hectares.
Source: IBGE 2006 Agricultural Census (2006).

The field survey was undertaken in 2008. We considered two key dimensions that explain land use heterogeneity: duration of land use and degree of market integration. Thus, sample stratification was based on distance to markets. We used this criterion for all interviews. Three rural settlements were chosen – São Pedro, Buritirana and Arco Iris – which were founded in 1963, 1982 and 2001, respectively (Figure 1). The unpaved roads linking Arco Iris to São Pedro are often only passable during the dry season. This area was colonised recently and has relatively higher proportions of farms still forested. The community sizes were estimated as follows: 359 families in Sao Pedro, approximately 100 families in Buritirana, and approximately 70 families in Arco Iris.[5] Given that the main research question is related to land use heterogeneity, we decided to use similar sampling sizes for each community.

The first survey aimed at characterising production systems, spatial allocation of land uses within properties by GPS tracking, and mobility patterns of the household head (migration trajectory, location of houses and production sites, displacements). We interviewed 38 farmers (12, 11 and 15 in each settlement, respectively). For the second survey, we selected 11 families (4, 4 and 3 families in each settlement, respectively) to make a detailed ethnobotanical assessment on agrobiodiversity management, including names of all cultivated plants, uses, origins and locations. Botanical plant identification was provided through a photography registry (Eloy and Emperaire 2011).

For regional land use analysis, we conducted vegetation classification analyses with Landsat TM images covering the Cruzeiro do Sul region in the years 1986, 1997 and 2007.[6] A mixed supervised/unsupervised classification strategy was carried out, which provided a more ample classification schema, even in years in which training sample data were lacking. An unsupervised classification was carried out on each image by using a clustering algorithm to define land-cover classes based on spectral statistics with a standard number of 100 classes, 12 maximum iterations and a convergence threshold of 0.95. Our 100 classes were gradually collapsed into six vegetation classes: mature forest (i.e. natural or old-growth forest), secondary forest, cultivated areas (pastures and fields), bare soil, water and urban areas. Class assignment involved three assessments: (1) visual interpretation using expert knowledge and participant mapping/land-use histories collected in the field; (2) comparative analysis by the signature mean plot module of the spectral behaviour of the signatures for each of the 100 classes as well as groups of similar classes; and (3) interpretation of unsupervised classes based on their spectral separability statistics generated using a transformed divergence module. The final signature files representing six land-use/land-cover classes for each image constituted the input for a supervised classification using a probability-based maximum likelihood algorithm. The total area for each land use type was then calculated for each date.

To study the implementation of Acre's PES policy in the municipality of Rodrigues Alves, we analysed official texts from international and national institutions, and carried out participant observation during information meetings about the PES. These data were completed with three semi-directive interviews with representatives of the government: the first with those who conceived the programme at the State Secretariat for the Environment (SEMA) of Acre's government in Rio Branco, the second with the chief of the State Secretariat of Agricultural Production (SEAPROF), and the third with a regional deforestation inspector at IBAMA (the Brazilian Institute for the Environment and Renewable Resources) in Cruzeiro do Sul.

4. Results

4.1. Land use heterogeneity: from municipality to the farmland scale

Figure 1 illustrates the progression of deforestation in the municipality of Rodrigues Alves, near Cruzeiro do Sul. Roads and agricultural settlements are gradually progressing towards the southwest from urban centres on the BR highway, in the direction of dense forest reserves. The total deforested area rose from 5933 ha to 23,680 ha (nearly 400%) between 1986 and 2007 (Figure 2), but the annual rate of deforestation has been decreasing since 2003 (Figure 3). Figure 2 indicates that, since 2001, farmers have tended to use more fallows for crop cultivation and pasture than dense forest. Indeed, the ratio of secondary forest areas to cultivated area decreased. This may be a consequence of the strengthening of command-and-control measures that ban fires in dense forests.

Long-established settlements are located closer to the BR 364 Highway. In this area, the large geometric plots (over 100 ha) have a greater prevalence of pastures, and reveal a process of deforestation and land concentration. Table 2 shows that family farmers in Arco Iris are younger, with less off-farm income and land than

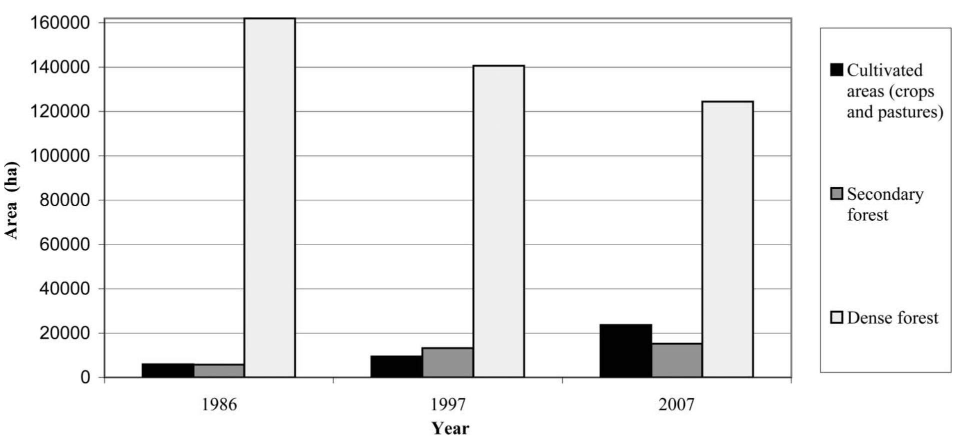


Figure 2. Evolution of cultivated areas, secondary forest areas, and dense forest areas in Rodrigues Alves municipality.

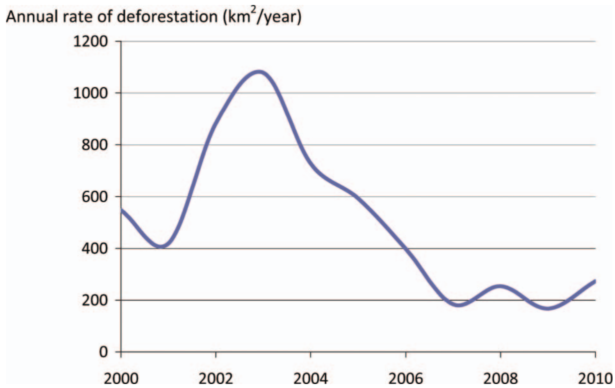


Figure 3. Evolution of the annual deforestation rate in Acre since 2000, INPE (2010).

farmers in older settlements. However, the settlements are intensively interconnected. Young farmers in young settlements are used to visiting and working (on foot or by motor-cycle) with their parents, who generally live in older settlements. Parents also frequently go to recent settlements where they cultivate a plot with their offspring, because their own lot is covered by pasture. Indeed, in our survey, 53% of households developed a multi-lot system, which is associated with multi-sited households, i.e. families that maintain houses and economic activities in rural areas (including young and old settlements) as in urban areas (Padoch *et al*. 2008, Eloy and Emperaire 2011).

Table 2 details the changes in landscape structure in household lots along the agricultural frontier. The Arco Iris settlement still displays large reserves of dense forest and diversified tree fallows. In long-established settlements (São Pedro and Buritirana), household lots are largely covered in pasture, herbaceous fallows (grass savannahs dominated by *capim-de-burro* [*Poaceae*] and *Pruma* [*Pteridium aquilinum (L.) Kuhn*]). Most farmers have a field ploughed by tractor. The narrow strips of dense forest and old fallows generally correspond to riparian forest whose clearance was banned with the forest code (1964), but enforced after the late 1990s.

A nutrient depletion process underlies land-use patterns. After cultivating the first swidden plot, farmers gradually move towards the 'back' of the lot where the remaining dense forest is found. Cultivation periods last from one to three years. With short fallow periods (two to four years) and no use of fertiliser, yields decline[7] in a few years and pasture occurs gradually. This is why farmers' offspring often have to look for a new plot of land to work on once they are married.

Very short fallow periods and no tree planting reveal the lack of fallow management, which leads to suppression of forest cover. This land use pattern coincides with a loss of agrobiodiversity (Figure 4). In the oldest settlement (São Pedro), 83% of cultivated plants are in home gardens. Small lots near BR 304 are gradually transformed into diversified urban home gardens, for example, the smallest lot in São Pedro in Figure 4. In the younger settlement (Arco Iris), the total number of cultivated plants is higher, and 45% of this diversity is observed in fields. Buritirana settlement has an intermediate situation.

The findings presented above indicate that the land use patterns of farmers living in recent settlements differ from those in older settlements. They produce more

Table 2. Characteristics of sample households (n = 38).

	São Pedro (created in 1963) (n = 12)			Buritirana (created in 1982) (n = 11)			Arco Iris (created in 2001) (n = 15)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Household characteristics									
Age of household's head	52	7.4	45–61	43.3	13.6	35–59	39.2	11.4	22–51
Years on lot	24.0	5.3	19–31	12.3	4.6	7–15	5.8	1.9	4–9
Off-farm income (R$/year)	6600.0	692.8	6000-7200	2880.0	2704.7	1200-6000	1968.0	935.7	1440-3600
Landholding									
Surface of lot (ha)	45.0	40.3	8–95	17.0	7.2	11–25	15.0	6.1	10–25
Dense forest area in lot (%)	17.3	16.7	5–41	17.0	6.2	12–24	41.0	7.6	32–51
Diversified tree fallow (%)	8.7	5.6	3–14.7	15.0	3.0	12–18	20.8	5.0	14–27
Herbaceous fallow (%)	31.5	15.7	16–45	39.0	6.9	35–47	14.0	5.1	8–19
Pasture (%)	29.3	22.9	15–63	2.3	4.0	0–7	3.8	2.9	0–7
Crops fields (%)	7.8	3.6	5–13	22.7	10.7	16–35	16.8	1.6	15–19
including ploughed crop fields (%)	1.5	2.4	0–5	3.0	5.2	0–9	0.0	0.0	0–0
Home garden (%)	5.6	2.8	2.3–9	4.0	2.6	2–7	3.6	1.8	1–6

Source: Field survey in the municipality of Rodrigues Alves (2008).

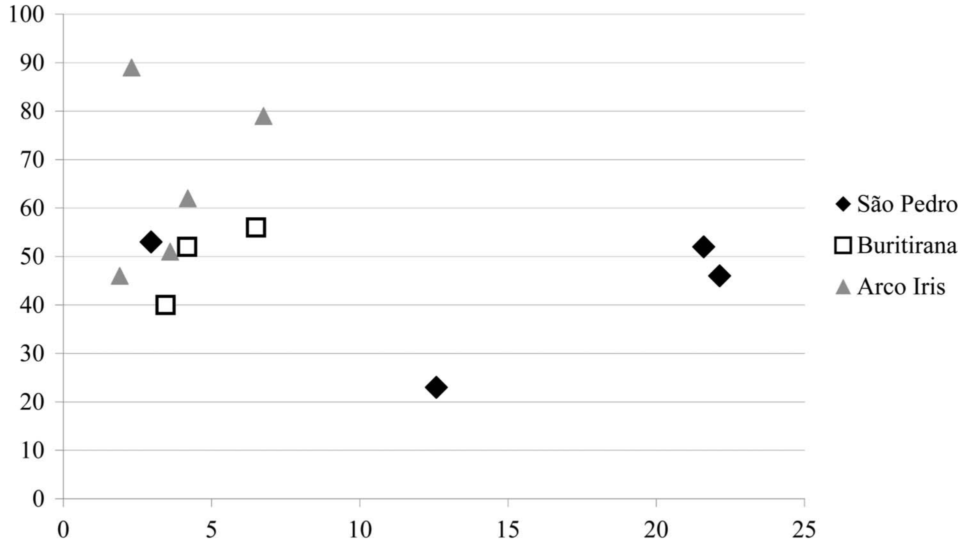


Figure 4. Number of cultivated plants per 11 households in the three rural settlements. Source: Field survey in the municipality of Rodrigues Alves (2008).

crops, maintain greater agrobiodiversity and retain larger amounts of fallows and dense forest. Long-established settlements are mainly covered by pasture, but farmers are wealthier and better connected with markets and technical assistance.

4.2. The drivers of spatial targeting of PES

In Acre, annual deforestation rates increased in the 1970s, 1980s and 1990s, with a peak in 1995 at 0.86% (INPE 2010). Agricultural expansion in Acre takes place in rural settlements along the roads and is mainly driven by cattle-based systems and annual cash-crop family agriculture (Ludewigs *et al.* 2009). In 1999, the new government in Acre, known as the 'Government of the Forest' (*Governo da Floresta*), ushered in an era of new agricultural policies, notably by placing greater emphasis on environmental issues. The state stopped economic incentives for cattle ranching, invested in research and environmental education, and launched a large-scale ecological and economic zoning programme. The state strengthened its capacity to enforce forest laws through the use of data collected from aerial photography and satellite imagery.

Acre's environmental institutions set up a system that delivers annual deforestation permits. Fines are given based on the identification of non-authorised forest clearings, primarily through remote sensing. Between 2001 and 2004, the number of permits and sizes of deforestation areas fell significantly and they have continued to drop to this day, while new technologies improved law enforcement (Souza *et al.* 2006). Deforestation rates have been significantly reduced since 2003 (Figure 3).

Recently, the government of Acre investigated alternatives to solve the problem of over-deforested properties because many small landowners could not pay fines. The government implemented the Programme to Promote Reforestation in Acre as part of the Law of 5 June 2007. This programme was inspired by previous PES experiences (ProAmbiente), and was supported by the decentralisation and modernisation of deforestation control policies (see section 1). According to our interviews, the broad spatial targeting of this policy relies on the results of the ecological and economic zoning programme. The strategy of the government is to focus on rural settlements near roads, where the rates of deforestation are the highest. The programme was implemented at the end of 2008 and has been financed by public funds, with approximately R$180 million per year in 2008/2009.[8] Since 2010, the state government has been negotiating for private and international funds via REDD opportunities.

The Programme to Promote Reforestation includes a PES project, known as the 'certification project', which aims at achieving Environmental Licensing of rural properties. In exchange for an annual payment (R$500 a year for three years, then R$600 a year for six years), farmers commit themselves to stopping swidden cultivation in natural forest, and restoring or protecting their legal reserve by the end of the contract, with priority given to permanent protection areas. By November 2010, 2100 families had joined the certification programme (Chaves 2010).

According to our interviews at the Acre government, the PES project targets smallholders. In fact, the Forest Government, which is run by the PT, has strong affiliations with rural workers and smallholders' movements and extractivists. The decision to target smallholders is based on a study by the NGO Imazon showing that INCRA settlement caused 38% of the deforestation between 1998 and 2004 in Acre. Small class sizes of deforestation plots (< 10ha) caused 55% of the overall deforestation, especially plots under 3ha (30%) (Souza *et al*. 2006).

Moreover, the small payment that is available for each farmer may not be attractive for most large-landholders, who practise cattle-based systems and can comply with the environmental law through compensation or exemption, according to the Federal law on environmental crimes.[9] However, this situation may change in the future with a new Acre law on PES (N° 2308, 22/10/2010) that fosters market-based incentives for avoided deforestation and reforestation in rural properties.

To avoid deforestation, the PES programme aims at containing agriculture and cattle breeding within deforested areas, in order to reduce cultivation within natural forests; this is also called the land sparing strategy (Green *et al*. 2005). Led by the public extension system (EMBRAPA at federal level and SEAPROF at state level), alternative land use entails three types of fire-free farming systems: permanent crop cultivation using rotation with leguminous fertilisers ('*roça sustentável*'), agroforestry systems and silvopastoral systems. The fire-free crop cultivation model requires inputs of lime and seeds, and often requires pesticides and mechanical soil ploughing to remove weeds. Moreover, agroforestry systems based on perennials are labour-intensive relative to swidden cultivation (Eloy 2008a). Silvopastoral systems require higher investment per hectare (tree planting, cut and carry system, fencing) than extensive cattle-based systems (Pagiola *et al*. 2004). Fire-free farming through intensification is to be monitored by IBAMA (federal level) and IMAC (state level), which focuses on the mapping of fires and new cleared areas every year. The technical assistance network is intended to support farmers engaged in agricultural transition.

However, technical assistance, tractors, chemical inputs, hired labour and access to outlet markets are far beyond the reach of labour and/or cash-constrained farmers living in remote settlements. Therefore, agricultural intensification is mainly directed to farmers who have more capital and are connected with urban markets and technical assistance.

Qualitative observations in information meetings confirmed that the PES programme was mainly directed to long-established settlements. In November 2008, the environmental and agricultural extension agencies (IMAC, IBAMA, SEAPROF) presented the PES programme to farmers in the region of Cruzeiro do Sul by organising meetings in the main villages along the BR 304. These villages are former rural settlements, mainly covered by pasture, where extension agencies had already tested alternatives to slash-and-burn for many years and were familiar with farmers.[10] During these meetings, we observed that farmers belonged only to old settlements of the neighbourhood. When we visited the young settlement (Arco Iris), no farmer was aware of the PES programme.

The following section discusses the implications of such targeting and presents how the PES programme could be improved to address the overall deforestation process and development issues.

5. Discussion: perspectives for PES with environmental planning at the local scale

Many scholars and politicians argue that PES can help to avoid deforestation while alleviating poverty (Grieg-Gran *et al.* 2005). Our study on the PES programme implemented near Cruzeiro do Sul (Acre) reveals limited spatial targeting, mainly driven by political and technical choices. The programme was designed in a context of expansion of international REDD opportunities, and its implementation was justified by previous decentralisation and modernisation of Brazilian deforestation control policies. The programme supports a classical agricultural extension system that promotes intensification (inputs, labour and capital), in line with a monitoring system that focuses on mapping of fires and newly cleared areas.

As a result, the PES scheme tends to target farmers living near the main roads, who have more capital and are connected with urban markets and technical assistance, and whose properties are mainly covered by pasture. Fire-free crop cultivation systems are promising for capitalised landholders, who are compelled to comply with environmental legislation. These alternative land uses may be adapted to foster reforestation in pasture land. However, to curb deforestation and alleviate poverty in the long term, a specific policy should target remote areas, where the initial stage of deforestation usually takes place, where the agroecosystem fertility and agrobiodiversity are already high, and where farmers are younger and poorer.

For many years, agricultural intensification via technology adoption has been proposed as a solution to the deforestation in the Amazon basin. It is widely used in environmental policies in Amazonia in order to promote a land sparing strategy (Green *et al.* 2005), i.e. setting aside natural forests through agricultural intensification. This model is highly controversial because where land is abundant and labour and capital are scarce, farmers might be interested in saving or shifting their capital and workforce to other tasks, including clearing forests in more recently colonised areas (Fearnside 1987, Angelsen and Kaimowitz 2001, Perz 2003).

Moreover, for most poor landholders in Latin America, the agricultural models based on technological inputs and labour intensification entail prohibitive costs and risks (Milleville 1999, Coomes *et al.* 2004). In a context of economic and climatic uncertainties, swidden cultivation allows these farmers to cope with the risks and variability of the family labour force. If deforestation control policies continue to ban forest clearing, most small-scale farmers without a viable alternative may accelerate their rotations in fallow areas, as observed in Figure 2. Moreover, as farmer families develop multi-lot systems and mobility patterns that link long-established and recent settlements, the ban on forest clearing might lead to leakage in deforestation at the scale of the municipality (Figure 5).

By promoting only land sparing, PES programmes in Amazonia may lose sight of their socio-economic and environmental objectives due to limited spatial targeting. In a tree-abundant and labour-scarce region with low access to public services, a specific PES scheme should go beyond the land-sparing model and promote a wildlife-friendly agriculture strategy, based on low-input management (Green *et al.* 2005). Indeed, poor smallholders may be able to change their land use in order to slow deforestation by enhancing the interrelations between the components of their agroecosystem, rather than by technology-dependent modernisation and use restriction (Altieri 2002, Tonneau *et al.* 2005).

The effects of slash-and-burn on ecosystem services depend on the diversity and the temporary nature of cultivation after clearing the forest (Angelsen 1995). Forest fallows are generally the primary source of carbon storage, soil fertility restoration and biodiversity conservation for Amazonian smallholders (Coomes *et al.* 2000). Fallow management contributes to heterogeneous landscape mosaics and diversified sources of food (Posey and Balée 1989, Eloy 2008b).

Specific fallow set-aside payments may help retain more carbon than in pasture lands while also increasing farm income (Morse *et al.* 2009). They should target communities or small-landowners who already have large areas of land under secondary growth (Perz and Walker 2002). This PES scheme may reward fallow management practices and agrobiodiversity conservation, such as the enrichment planting in fallows. Forest clearings should not be banned except in permanent protection areas. Such PES schemes may be designed and monitored with better participation of farmers and the incorporation of Amazonian traditional knowledge about fallow management (Selman 2004). Some of these proposals are underway with the passing of recent legislation in Acre (L2308, 22/10/2010), which encourages bio-friendly schemes such as enriched fallows as set-aside fallow payments.

The implementation of such differentiated PES scheme may have some limitations. First, according to Coomes *et al.* (2000), policies that encourage larger and longer fallows for environmental benefits would increase inequality by benefiting wealthier households. However, Coomes' study was carried out in land-scarce communities. In younger frontier colonies where land is relatively abundant and agriculture continues to expand, household land abundance does not foster greater regrowth (Perz and Walker 2002).

Second, the lack of land tenure security in younger frontier settlements would hinder the development of PES schemes in these areas (Wunder 2006). However, if local governments continue to use the Environmental Licensing tool independently from the federal Farm Land Registry system operated by the INCRA, they will be able to control land use changes at the household level, even in the most remote forest areas. Third, as policies encouraging more fallowing can hinder conversion to pasture in Amazonian agricultural frontiers, they may compete with the speculative logic of cattle-ranching expansion (Hecht 1985). Lessons learned from the Arboreto project and other similar initiatives throughout the Amazon that are associated with the Academy, local associations and NGOs must be used as the basis of a new Rural

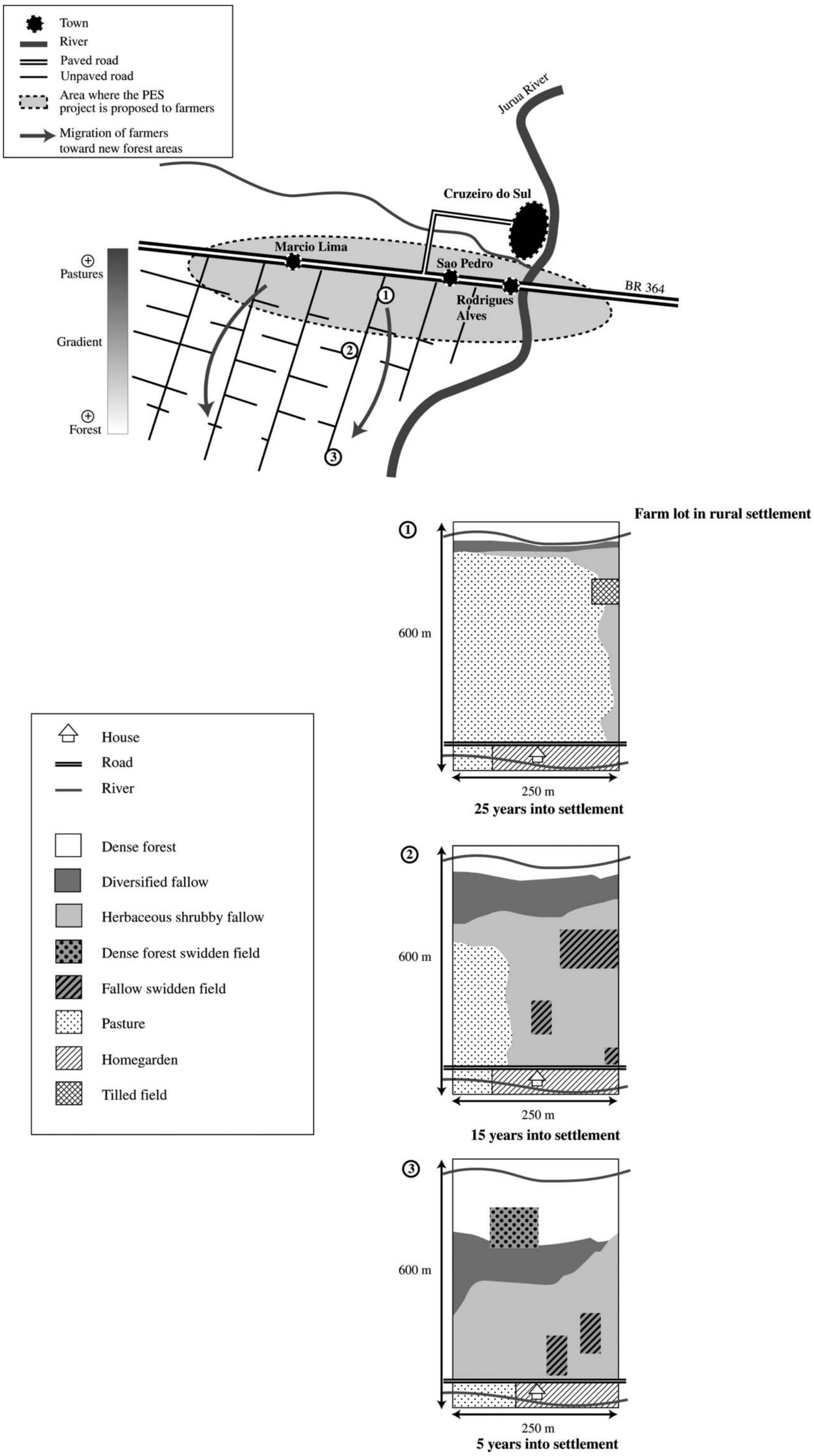


Figure 5. Representative scheme of the spatial targeting of the PES and land use in the study area.

Extension system based on different conceptions of agricultural development in forest frontiers. As such, PES costs will go well beyond the opportunity costs. They must be associated with investments in rural development (education, infrastructures, land rights enforcement etc.) (Gregersen *et al.* 2010).

The final limitation is the monitoring method. The present method used by environmental agencies relies on mapping fire and new cleared areas by remote sensing. An area under secondary fallow is easily 'visible' using remote sensing, but the age and structure of fallow vegetation is more difficult to detect. Nevertheless, improvements in remote sensing techniques have made estimations possible (Puig 2005). Finally, progress in monitoring methods should address the gap between global assessments and atomised action (i.e. designed at the scale of individual property) in order to take into consideration land use heterogeneity and landscape dynamics at intermediate scales (Zimmerer 2009).

6. Conclusion

Our findings suggest that the implementation of PES schemes for forest conservation in the Amazon do not depend only on solving institutional and economic limitations (Borner *et al.* 2010, Muradian *et al.* 2010). PES policies must also address the spatial heterogeneity of land use in agricultural frontiers in order to encompass landscape-level ecosystem services provision, and to promote alternative options that are adapted to smallholder strategies. PES policy tools that only promote land sparing may lose sight of their socio-economic and environmental objectives due to limited spatial targeting.

We argue that specific policies should focus on cash-poor farmers who live in remote settlements, in order to foster wildlife-friendly agriculture, enhance local knowledge and alleviate poverty. As the negotiations around REDD mechanisms advance, co-construction of land use alternatives and monitoring methods with family farmers should be developed to improve environmental planning and management at the local scale. The state of Acre, like other Amazonian states, will need to find a compromise between the visibility and efficiency of new environmental policies based on the concept of environmental services.

Additional research is necessary to determine in which conditions and places different types of PES schemes would be the most cost-effective to simultaneously maintain ecosystems services, address rural poverty and enhance landscape connectivity. Since future policy tools will determine the types of development that shape the landscape in the Amazon (Fearnside 2003), it is necessary to pay greater attention to the geographical dimensions of PES programmes.

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Notes

1. Although Boliviaran countries (mainly Venezuela, Bolivia and Ecuador) reject PES on the assumption that nature cannot be marketed (COP 16, Cancun 2010).
2. Apart from the national PES programme in Costa Rica and the federal ProAmbiente experience in Brazil, most PES programmes in Latin America have been designed in small-scale areas. Most initiatives for water management and forest conservation are implemented at the watershed scale (Pagiola *et al*. 2005, Southgate and Wunder 2009). Among the PES that have been implemented, two of the most studied cases are the REDD projects Noel Kempff in Bolivia and Bolsa Floresta in Amazonas state (Robertson and Wunder 2005, Cenamo *et al*. 2009).
3. Namely the ProAmbiente programme (Mattos 2010) and the experience developed since 2005 by Lucas do Rio Verde municipality (Mato Grosso) and The Nature Conservancy (TNC), which aimed at social and environmental compliance by rural properties (Toni 2011).
4. The municipality had 12,428 inhabitants in 2007 according to census by the Brazilian Institute of Geography and Statistics (IBGE).
5. The INCRA database reveals average property sizes are 74 hectares in São Pedro and 23 hectares in Arco Iris
6. Landsat images 26/07/1986 (TM, source INPE), 22/06/1997 (TM, source GLCF), 21/08/2007 (TM, source INPE) were used. Geometric rectification was carried out on the 2007 image based on ground control points collected in the region using a GPS, using roads and intersections, as well as rivers and waterways. The resampling was done using a nearest neighbour resampling algorithm. The 2007 image was then used as a base to which the remaining scenes were resampled.
7. According our interviews in Arco Iris, settlement yields in new swidden fields range from 5000 to 8250 kg of cassava flour per hectare, while after herbaceous fallow in São Pedro and Buritirana, yields range from 2000 kg to 3500 kg.
8. ANC (2008). R$1 = US$ 0.6, February 2011.
9. Compensation is defined as carrying out reforestation or acquiring and protecting other dense forest areas, even those outside their property, in the same watershed. Exemption means payment of a fee that is proportional to the lack of legal reserve (*passivo ambiental*).
10. Our results are consistent with the study of Daniels *et al*. (2010), who showed that the spatial correlation between PES and pre-PES projects is due to existing social networks and institutional path dependency.

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