Conservation and Society 8(3): 157-170, 2010

Article

Deforestation Drivers in Southwest Amazonia: Comparing Smallholder Farmers in Iñapari, Peru, and Assis Brasil, Brazil

Angelica M. Almeyda Zambrano[a,b,#], Eben N. Broadbent[b,c], Marianne Schmink[d], Stephen G. Perz[e] and Gregory P. Asner[b]

[a]Department of Anthropology, Stanford University, Stanford, CA, USA

[b]Department of Global Ecology, Carnegie Institution for Science, Stanford, CA, USA

[c]Department of Biology, Stanford University, Stanford, CA, USA

[d]Center for Latin American Studies, University of Florida, Gainesville, FL, USA

[e]Department of Sociology, University of Florida, Gainesville, FL, USA

[#]Corresponding author. E-mail: aalmeyda@stanford.edu

Abstract

Broad interpretation of land use and forest cover studies has been limited by the biophysical and socio-economic uniqueness of the landscapes in which they are carried out and by the multiple temporal and spatial scales of the underlying processes. We coupled a land cover change approach with a political ecology framework to interpret trends in multi-temporal remote sensing of forest cover change and socio-economic surveys with smallholders in the towns of Iñapari, Peru and Assis Brasil, Brazil in southwest Amazonia. These adjacent towns have similar biogeophysical conditions, but have undergone differing development approaches, and are both presently undergoing infrastructure development for the new Interoceanic highway. Results show that forest cover patterns observed in these two towns cannot be accounted for using single land use drivers. Rather, deforestation patterns result from interactions of national and regional policies affecting financial credit and road infrastructure, along with local processes of market integration and household resources. Based on our results we develop recommendations to minimise deforestation in the study area. Our findings are relevant for the sustainability of land use in the Amazon, in particular for regions undergoing large-scale infrastructure development projects.

Keywords: Amazon, cattle ranching, deforestation, land use, political ecology, slash and burn agriculture

DOI: 10.4103/0972-4923.73805

INTRODUCTION

The Amazon basin contains about 40% of the world's remaining tropical forests (Mayaux *et al.* 1998). Losing up to 25,000 sq. km annually (Achard *et al.* 2002), the region also has the world's highest absolute rate of deforestation (Laurance *et al.* 2001a), even when excluding selective logging and other forest disturbances which in some years double annual estimates of forest disturbance (Asner *et al.* 2005; Oliveira *et al.* 2007) and fragmentation (Broadbent *et al.* 2008). Tropical deforestation and forest degradation are driven by identifiable causes—hereafter referred to as *drivers*. Drivers can be divided into either *proximate* or *underlying* categories (Geist & Lambin 2002b), where proximate drivers are human activities and immediate actions directly impacting forest cover, while underlying drivers are fundamental social processes, such as government policies or subsidies.

Three underlying drivers of deforestation in the tropics have most of the attention in the literature: the development of road infrastructure, markets, and access to financial credit sources for agriculture (e.g., Laurance *et al.* 2001b; Geist & Lambin 2002a). All three are relevant in our research area. Road development in previously remote regions sharply increases deforestation rates (Fearnside 1987). Assessments of the effects of roads on deforestation have shown a 30% forest loss within 10 km of both roads and highways, with the effects of highways causing a further 20% forest loss within 11–25 km, and 15% loss from 26–50 km (Laurance *et al.* 2001b), for areas within the Brazilian Amazon. The paving of the Interoceanic highway is a long postponed, and much anticipated, integration dream of Peru and Brazil. It crosses the bi-national study area, with paving being completed in Brazil in 2002 and presently underway in Peru where it is expected to be completed in 2010. In our research area, the Interoceanic highway has existed since the 1960s as a poorly maintained dirt road, often impassable during the rainy season. However, the paving of this road is expected to result in dramatic changes in land use and -cover throughout the region as most deforestation in the Amazon is concentrated around major roads and pioneer settlements. Three quarters of the deforestation in the Amazon between 1978 and 1994 was within 50 km of a major (usually paved) road (Alves 2002).

Schmink (1994) explains deforestation in the Amazon as an outcome of social processes, and of markets and other dynamic factors that interact in global and national contexts. At the global level, important variables include the demand for Amazon products (e.g., timber, rubber) and foreign investment (e.g., in oil, mining, timber). At the national level, some of the important variables are transportation and export orientation. Research on market impacts has shown mixed impacts. According to Godoy *et al.* (1997), there are three main positions with regard to markets and conservation: the market works to the detriment of conservation; the market increases conservation if land rights are secure; and the market has ambiguous effects on deforestation. Households tend to integrate into markets by selling crop products, labour, or both. If integration is achieved by selling crops, increase in market demand is likely to increase deforestation, unless intensification occurs. If integration is achieved by selling labour, increase in market demand will reduce deforestation since there will be less time to work the land (Godoy *et al.* 1997). Therefore, integration into both markets usually has nonlinear effects. Access to credit, often necessary to engage in free market activities, and especially for agriculture and cattle ranching, has been linked to deforestation. An analysis of the impact of credit on deforestation in a frontier area of the Peruvian Amazon indicated that deforestation rates were higher when credit for agriculture was available, and the highest rates were found within 8 km of the Interoceanic highway (Alvarez & Naughton-Treves 2003).

Roads, markets, and credit do not operate in isolation from other factors. Roads usually lead to more deforestation when there is also access to international and national markets (Schmink 1994). However, the relation is not always direct; in some cases roads are built in previously settled and cleared areas, or settlement and roads may be influenced by other variables such as economic and policy cycles (Kaimowitz & Angelsen 1998). Local social and environmental characteristics have an important effect on the way individual roads influence economic and social changes (Leinbach 2000). Infrastructure development, at the proximate level, normally occurs in parallel to agricultural expansion, wood extraction, and colonisation (Geist & Lambin 2002a). In their review of models of deforestation at the household level, Kaimowitz and Angelsen (1998) include transportation costs which show an inverse relation between market access costs and deforestation. They also find that an increase in off-farm income sources typically decreases the pressure on forests.

Attempting to couple the multiple spatial and temporal scales necessary to address the complex drivers of land use and land cover change has fostered efforts to combine remote sensing and socio-economic data. While proving difficult, this merger has afforded the development of new theoretical approaches and methodologies capable of dealing with these disparate data types and spatial-temporal scales. In the present study we employ a political ecology framework, which builds on concepts of the human-environment interaction from diverse academic fields (Smith 1991; Netting 1993; Rappaport 2000). Political ecology challenges Malthusian (i.e., demographic growth) and technocratic (i.e., inadequate adoption of western economic techniques) explanations for environmental crises (Malthus 1965; Ehrlich & Ehrlich 1990). Political ecologists believe that the cause of environmental change is found in political processes (Bryant & Bailey 1997). Political ecology explanations of environmental crises generally link different spatial and temporal scales of analysis and address the political and cultural factors underlying the use of natural resources and the complex interrelations among people and groups, between and within these different scales (Blaikie & Brookfield 1987; Schmink & Wood 1987).

Several studies of environmental degradation in Latin America have used a political ecology approach. In Central America, two important focal areas of research have been the displacement of small farmers by the expansion of export oriented agriculture (Durham 1979) and cattle ranching (Edelman 1995). This type of natural resource-based development has also been encouraged by governments of Amazonian countries, and many studies have been carried out on the political and economic factors conducive to, or resulting in, environmental degradation in the Amazon (Schmink & Wood 1987). The underlying factors identified usually include, or are related to, policies on infrastructure development, credit, and regional and global markets.

RESEARCH QUESTIONS

Here we use the political ecology framework described above to explain results from multi-temporal remote sensing of land cover change, and then we link these results with an historical analysis of the area, and socio-economic and demographic surveys with 77 small holders in the district of Iñapari, Peru and the municipality of Assis Brasil, Brazil in southwest Amazonia. Iñapari and Assis Brasil are located in similar biogeophysical settings, located directly across the Acre river from one another. However, due to large differences in government development policies, including infrastructure development, they present a unique comparative case study. We use this comparison to understand past and present patterns of land use and land cover in this area, and to identify general trends in proximate and underlying drivers of deforestation and land use in the Amazon.

The questions driving our study are: 1) How different are forest cover change dynamics between these biophysically identical, but socio-politically distinct, regions? 2) Is infrastructure development the dominant driving force of deforestation? 3) If not, which socio-economic or biophysical variables explain the highly divergent land-use and forest cover visible in these two areas? 4) What can be learned from these areas to minimise deforestation in the future?

The specific objectives of this study are to identify and compare, between Iñapari, Peru and Assis Brasil, Brazil, at both household and landscape scales: 1) The primary drivers of deforestation, 2) Historical changes in land cover using multi-temporal remote sensing, 3) Land use and land cover change dynamics using multivariate explanatory models, and 4) To link the socio-economic data and models with remote sensing results. Due to the difficulty of holding biogeophysical variables constant while varying socio-political ones, these research questions have not commonly been approached using comparative analyses. Our unique study area, including simultaneous infrastructure development in both towns, in contrasting policy environments, makes such a comparison feasible.

STUDY AREA DESCRIPTION

Our study was conducted at the tri-national border between Peru, Bolivia and Brazil, within the district of Iñapari, Peru and the Município of Assis Brasil, Brazil (~625 sq. km; WRS path 3 row 68 and 67). The two towns are bisected by the soon-to-be-completed Interoceanic highway, and separated from each other by the Acre river (Figure 1), which forms the international border. The location of both towns in relation to other cities is also relatively similar: Assis Brasil is located 350 km from Rio Branco, the state capital, and 116 km from Brasiléia; the closest city. Iñapari is located 320 km from Puerto Maldonado, the department capital, and 67 km from Iberia, the closest town (SUDAM & INADE 1998). Both occur under similar biogeophysical conditions. The area consists of lowland moist tropical forests having an annual precipitation of 1800 mm and a distinct dry season between the months of May and October (SUDAM & INADE 1998).

Descriptive demographic statistics of the two towns within their national contexts are provided in Table 1. As recently as the mid 1990s, the number of farms and the total surface area they encompass were similar in Iñapari and Assis Brasil. The most recent Agrarian census (1993 for Iñapari and 1996 for Assis Brasil) shows a similar number of farms in both places, a similar surface area under farmland and a similar distribution of farms across farm size categories (Table 2). Large areas of Iñapari and Assis Brasil are under various forms of protection. Parts of Iñapari belong to the Alto Purus National Park, the state reserve for indigenous groups in voluntary isolation, and the indigenous community of Belgica (Arawak), and parts of Assis Brasil belong to the Acre River Ecological Station or the

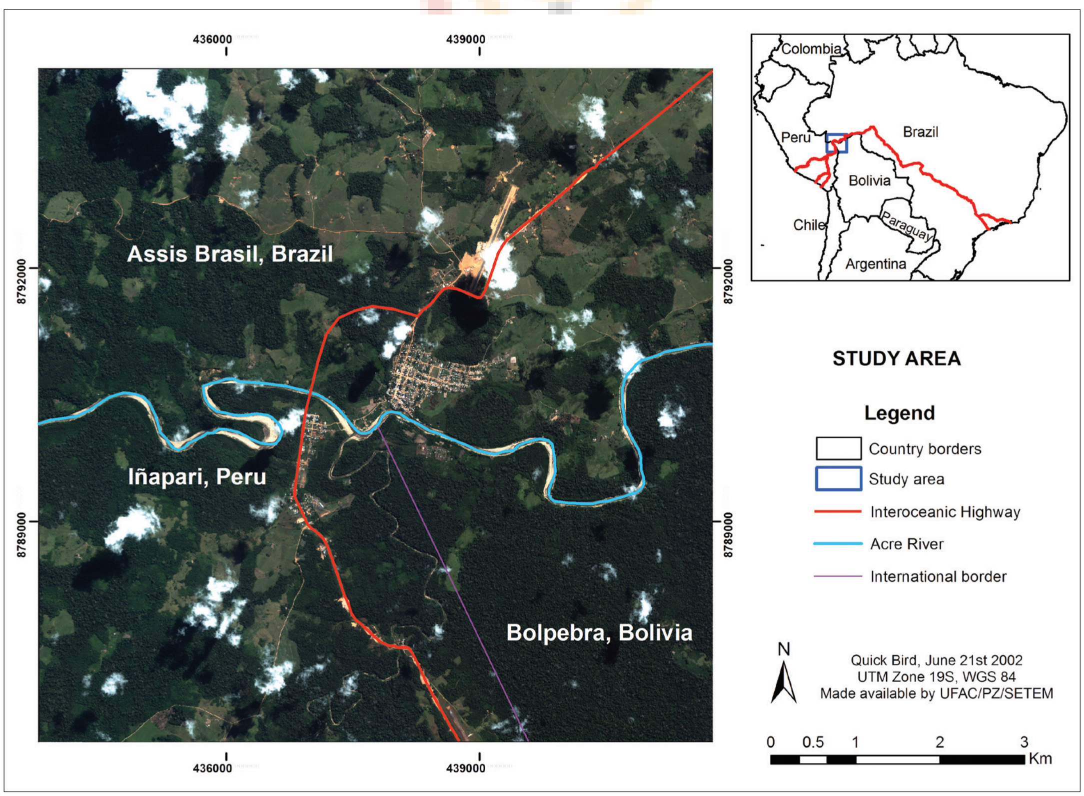

Figure 1
Detailed study area shown on a Quickbird satellite image. The inset shows the Interoceanic highway

Cabeceira do Rio Acre indigenous community (Jaminawa). In addition, areas within Iñapari and Assis Brasil have been zoned for extractive activities. In Iñapari the government has established Permanent Production Forests, providing logging concessions where agricultural activities are not permitted. In Assis Brasil the government has established the Chico Mendes Extractive Reserve, and households within this area are expected to conform to the land use rules of the reserve, mainly by limiting the area available for non-extractive activities such as agriculture and cattle ranching.

Table 3 presents a general timeline for the main development policies that have affected Assis Brasil and Iñapari. The expansion of rubber extraction (1850–1900) marked the beginning of the non-indigenous settlement of Madre de Dios and Acre. Due to concerns about border security with Brazil and Bolivia, the Peruvian government created the city of Puerto Maldonado to stabilise Madre de Dios in 1902 (INRENA 1998). Acre, considered Bolivian territory until 1903, was settled when rubber suppliers spread their network westward, sending migrants from north-eastern Brazil to the area (Schmink & Wood 1992). In 1913, crashing rubber prices

Table 1

Comparisons of land area and population from the country level to the Município of Assis Brasil and the District of Iñapari

Variable	Brazil	Peru
	Federative republic	*Constitutional republic*
	26 states	24 departments
	5 regions	12 regions
Area (sq. km)	8.5 million	1.3 million
Population	172.6 million	26.1 million
	State: Acre	*Department: Madre de Dios*
Area (sq. km)	1,52,581	85,183
Administration	5 development regions	3 provinces
	Município: Assis Brasil	*District: Iñapari*
Area (sq. km)	2,876[a]	14,853[b]
Population		
1993	?	841 (c)[b]
1996	2,918 (c)[a]	1,115 (e)[b]
2000	3,490 (c)[a]	1,160 (e)[b]
2007	5,351 (c)[a]	1,288 (c)[b]

[a]Instituto Brasileiro de Geografia e Estatística-IBGE (2010), [b]Insituto Nacional de Estadística e Informática-INEI (2010), (c) census, (e) estimate

Table 2

Comparison of farms, heads of cattle, area under pasture and agriculture in the Município of Assis Brasil and the District of Iñapari according to the results of the agrarian census of 1996 and 1994, respectively

Farm size class	Assis Brasil, Brazil (1996)[a]		Iñapari, Peru (1994)[b]	
	Number	Area (ha)	Number	Area (ha)
10 < 20 ha	6	109	2	28
20 < 50 ha	29	1,058	72	2,346
50 < 100 ha	112	6,271	73	5,111
100 < 200 ha	55	6,130	45	5,472
200 < 500 ha	9	2,221	8	1,911
500 < 1000 ha	4	2,300	0	0
1000 < 2000 ha	1	1,000	2	2,000
Total	216	19,089	202	16,867
Heads of cattle	5,454		1,228	
Pasture		3,318		2,591
Agriculture		585		520

[a]Instituto Brasileiro de Geografia e Estatística-IBGE (1998), [b]Insituto Nacional de Estadística e Informática-INEI (1999)

Table 3

Main development policies and expected outcome for the area of Assis Brasil and Iñapari since the non-indigenous settlement of the area

Time period	Assis Brasil, Brazil		Iñapari, Peru	
	Policy	Expected outcome	Policy	Expected outcome
Until 1890s	Indigenous territory		Indigenous territory	
1900-1913	Rubber boom until plantations in Asia took over rubber production	Forest to non-forest	Rubber boom until plantations in Asia took over rubber production	Forest to non-forest
1914-1950	Tire industry and World War II maintain rubber tapping in Acre	Forest to non-forest	Migration to Puerto Maldonado and Cuzco	Non-forest to forest
1950s	Seringa and Brazil nut extraction	Stable?	Credit mainly for extractive activities, seringa and Brazil nut extraction	Forest to non-forest
1960s	Unpaved main road is built	Forest to non-forest	Unpaved main road is built	Forest to non-forest
1970s	Operation Amazonia	Forest to non-forest	Agrarian Bank (BAP) National Rice Commercialization Enterprise (ECASA)	Forest to non-forest
1980s	Secondary roads and no credits for agriculture	Forest to non-forest	Directed settlement projects, secondary road, credits for agriculture and cattle, market for produce	Forest to non-forest
1990s	Credits for agriculture	Forest to non-forest	Settlement projects failed Agrarian Bank is closed	Non-forest to forests
2000s	Main dirt road paved (2002)	Forest to non-forest	Main dirt road improved to be used all year round (2001)	Forest to non-forest

due to increased production in Asia stimulated rural migration to the towns of Puerto Maldonado and Cuzco. In Acre the crisis was mitigated to some extent, first by internal demand for rubber from the Brazilian tire industry, and later, by demand from the Allies during World War II (Schmink & Wood 1992).

Following the decline in rubber prices in the 1920s, the dense stands of Brazil nut trees (*Bertholletia excelsa*) in Acre and Madre de Dios increased in value, although they occur in very low densities in both Iñapari and Assis Brasil. Subsistence agriculture became a predominant activity after the rubber crisis, the main annual crops being corn, rice, beans, and manioc, and perennial crops including banana and coffee. The 1960s were marked by the opening of roads and the first incentives for cattle ranching. The Peruvian government provided the first incentives to cattle ranching in Madre de Dios by establishing the Office for Agricultural Research. Its mission was to expand cattle ranching, and encourage the genetic improvement of herds (Varese 1999). This was complemented later with credit programmes and developments in management practices and pasture species that were imported from Brazil. 'Operation Amazonia' began in 1966, and many landlords from the south and southeast of Brazil moved into the region, stimulated by relatively cheap land and by federal incentives for cattle ranching, logging and mining (Wood & Schmink 1993). This marked the beginning of the expansion of cattle ranching in Acre. The roads opened during this period linked Iñapari and Assis Brasil to the rest of their countries via a seasonal dirt road. The 1970s was a period of acute land conflict in Acre due to 'Operation Amazonia' and new road openings. During this decade, the Brazilian government made credit available for agriculture and cattle. The 1980s were marked by an increase in degraded pasture areas, due to both unsustainable intensification and a new pest which thrived in established pastures. In the 1980s, Madre de Dios underwent a government-sponsored effort to settle the area, including settlement projects and road openings. In contrast, in 1989, due to national and international protests, the Brazilian government began to prohibit the use of official credit for development activities that resulted in deforestation in the Amazon.

Iñapari and Assis Brasil were isolated from the rest of their respective countries until recent years. From the 1960s to the late 1990s, they were linked only by a dirt road suitable for walking or tractor during the five months of the rainy season. However, recent infrastructure development in Peru and Brazil has caused dramatic changes over the last decade. In the case of Iñapari, the unpaved road that links it to the town of Iberia and to the city of Puerto Maldonado was significantly improved in many phases by the National Development Institute (INADE). Improvements of the last portion of the dirt road were declared finished on October 21, 2000, making it passable all year round. More recently, work on the Interoceanic highway has brought major changes to infrastructure in the area. The Interoceanic highway is part of the Initiative for the Integration of the Regional Infrastructure of South America, known as IIRSA; once completed, it will link the Atlantic ports of southern Brazil with the Pacific ports of Peru. According to IIRSA this will be a major axis of integration and development, for both countries. However, a recent independent analysis of the project (Babbit 2009) warned that lack of attention and debate, and the absence of a project-wide environmental impact assessment (Dourojeanni 2009) for a highway that crosses the entire southeast Amazon basin, will lead to massive deforestation. In Assis Brasil, the building of the Interoceanic highway meant the paving of its main road (BR-317) from 2000 to 2002, within the framework of Brazil's ambitious Avança Brasil Program. The BR-317 links Assis Brasil to the city of Brasiléia and from there to the rest of Brazil. To connect the BR-317 to the road on the Peruvian side, the 'Puente de Integracion' (Integration Bridge), built over the Acre river, was inaugurated in 2005. Paving began in Iñapari in 2006, and is planned to reach Puerto Maldonado in 2010; most farms in Iñapari are located along this road, and there are only two secondary roads in the district. In contrast, there are many secondary roads that connect to the different farmlands in Assis Brasil although most are impassable during the rainy season.

METHODS

We obtained Landsat satellite imagery from 1986 through 2002 (http://glcf.umiacs.umd.edu/portal/geocover), and co-registered the images using linear regression models (RMSE < 0.3 pixel), then merged and subset the images to the study area. A supervised Maximum Likelihood (ML) method in ENVI software (ITTVIS, Inc., Boulder, CO; 2000–2010) was used to classify imagery as forest or non-forest, while open water, clouds and cloud shadows were excluded from spatial analyses. The minimum mapping unit of our spatial analyses was 0.3 ha (3 pixels), as few land uses are smaller than 0.3 ha, and to remove erroneous classification speckles from clouds and slight georectification differences between the images. Following classification, multi-temporal change trajectory maps of forest/non-forest were created at the pixel scale using custom programmes in the Interactive Data Language (IDL, Version 7.0, Research Systems, Inc., Boulder, CO; 2000–2010). Training samples identifiable in all Landsat images (1986–2002) were identified for our forest class, including secondary and mature forests, and our non-forest class, including bare, built, pasture and agricultural areas, using a 2002 Quickbird image of our study area (see Figure 1), and verified in the field during summer 2003. An accuracy assessment of our final forest/non-forest classification was performed via comparisons with randomly selected forest and non-forest areas using the method described for our training samples. Our accuracy assessment included separate categories for bare soil, pasture, overgrown pasture, agriculture, secondary forests and mature forests. High accuracies (>90% correct classification) were obtained for all classes in all categories except for agriculture, which was classified either as forest or non-forest depending on crop conditions at the time of the Landsat image acquisition. As agricultural areas encompassed a small proportion of total land cover in our study area, we did not deem this a problem.

GIS (geographic information system) data for Iñapari district and Assis Brasil Município borders were available from the National Institute of Natural Resources (INRENA) and the Brazilian Institute of Geography and Statistics (IBGE), respectively. Raster linear distance maps to the Acre river and the Interoceanic highway were created using ArcGIS software (Version 9.3. Redlands, CA: Environmental Systems Research Institute, 2008) and co-located with the remote sensing classifications. For the purposes of spatial analysis the study area was defined by the intersection of a 20 km buffer from the main road and a 20 km buffer from the international border (Figure 2). All of the area 20 km north of the Acre river was considered to be part of Assis Brasil. This criterion includes part of the area that corresponds to the neighbouring Município of Brasiléia whose municipal seat is located 116 km from the study area. For reasons of geographic proximity the farmers in this area of the Município of Brasiléia are more oriented to the Município of Assis Brasil, which provides them with basic municipal services. For this reason these areas were all included within the Assis Brasil study area.

To identify and gauge the importance of the diverse possible socio-economic and biophysical variables driving land use and land cover change (LULCC), we conducted a total of 77 semi-structured household interviews with smallholder farmers from June to September 2003, representing 17.8% (N=36) and 20.3% (N=41) of all smallholder farmers in the district of Iñapari and the Município of Assis Brasil, respectively (INEI 1999; IBGE 1998). It is important to note that although there are indigenous populations in both Iñapari and Assis Brasil, as well as extractivist reserves in Assis Brasil, this research is focused on farmers outside these areas, since other theoretical approaches would be required to adequately address natural resource use under common property arrangements. This interview encompassed diverse topics, including demographic, socio-economic, and human-environment interactions.

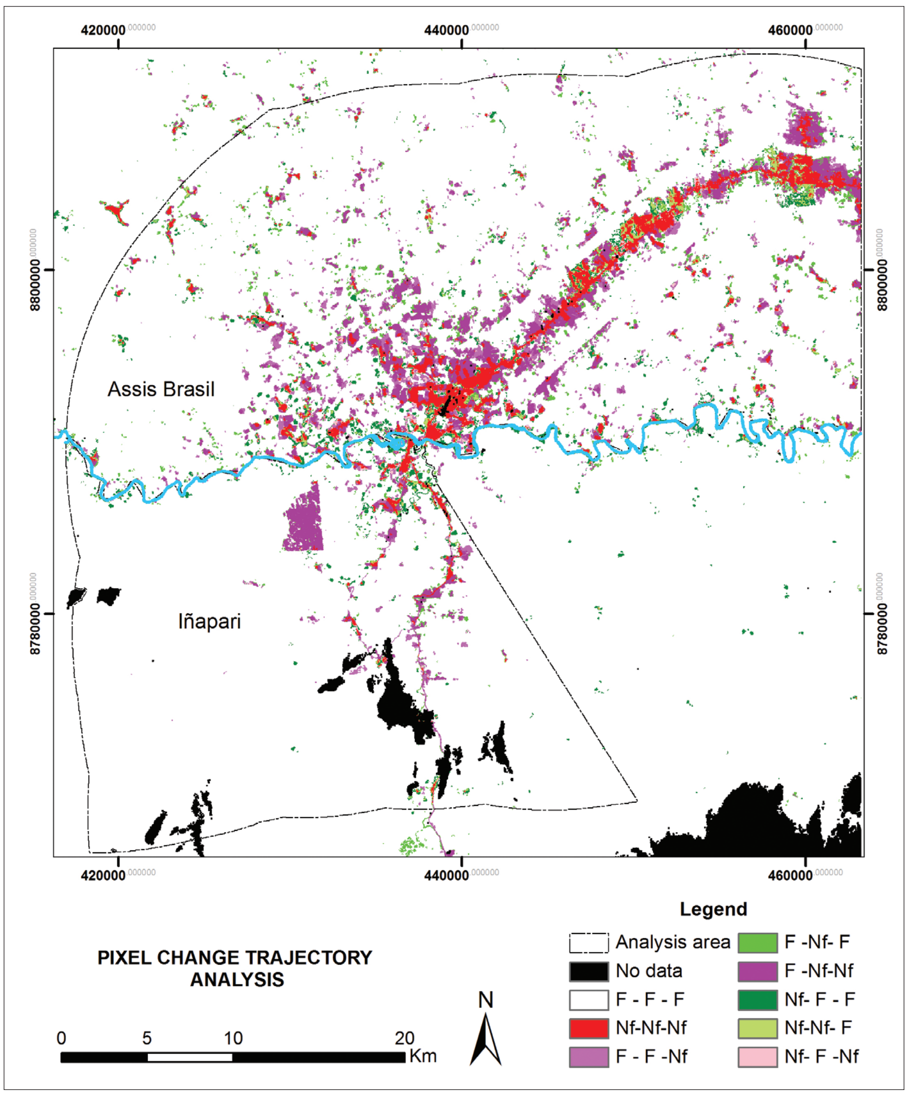

Figure 2

Map of forest (F) and non-forest (Nf) change trajectories for the years 1986–1996 and 1996–2002 respectively

Results from the questionnaires were coded for multivariate statistical analyses. We grouped all variables into five primary classes: 1) Land use outcomes, defined as indicators of household land use activities, 2) Land cover outcomes, defined as indicators of deforestation since arrival to the farm, 3) Background information, defined as control variables, 4) Land use drivers, divided into sub-sections of markets and credit and road infrastructure variables, and 5) Household life cycle variables, used to normalise for household level variance. We also included a place variable to distinguish differences in model outcomes between Iñapari and Assis Brasil. Within the Assis Brasil and Iñapari context, market variables are at the local and regional level, credit variables are at the national level, and road infrastructure variables are at the local regional and national level. Household life cycle variables are at the household level, the same as land use, land cover and background information variables. To address the research questions, five data analysis steps were followed. First, descriptive statistics were created for all variables for both towns. Data for variables with skewness over 1 were transformed by converting to the natural logarithm and adding 1 unit to avoid '0' values. This procedure reduced overall skewness and improved normality for statistical analyses. Second, independent t-tests were used to compare mean values for all variables between Iñapari and Assis Brasil to reveal differences and similarities between both towns. Third, bivariate correlations were run between each land use and land cover outcome as well as against all other variables, in order to test the relationship between dependent variables and between dependent (outcome) and independent variables. Fourth, multivariate models were run using the Ordinary Least Square regression (OLS) method between each outcome variable and each group of independent variables to gain insights into variable interactions and their effects on specific outcome variables. Fifth, multivariate models were run using the OLS method for each outcome variable using the independent variables found to be significant in the previous steps. All statistical tests were run using SPSS software (SPSS Inc., Chicago, IL; 2000–2010).

RESULTS AND DISCUSSION

We start by addressing the first research question: How different is forest cover between these biophysically identical, but socio-politically distinct, areas? Percentages of non-forest area, area deforested and area reforested are all higher for Assis Brasil for all study years (1986, 1996, 2002) and time periods (1986–1996 and 1996–2002) (Table 4). Still larger differences exist for total non-forest area and deforestation, showing both greater non-forest area existing at the beginning of the initial study year and greater deforestation occurring thereafter. The pixel change trajectory analysis (Table 5) shows that the two most dominant trends are the same for both towns. Areas of permanent forests (Table 5, CT 1) are dominant in both sites but with a higher percentage for Iñapari (94.7%) than for Assis Brasil (83.3%). Previously limited access to this area is a likely explanation for the relatively high abundance of permanent forest pixels as compared to other pixels. The second most dominant pixel change trajectory is conversion from areas classified as forests in 1986 to areas detected as non-forest in 1996 and 2002 (Table 5, CT 5), with a higher percentage for Assis Brasil (4.8%) than for Iñapari (1.9%). The third dominant pixel change trajectory for Assis Brasil is permanent non-forest areas (Table 5, CT 2, 3.6%), indicating that this may be due to events previous to 1986 such as the incentives provided by the Brazilian government for land clearing during the 1970s. For Iñapari the third dominant pixel change trajectory is the conversion of areas detected as forest in 1986 and 1996 to non-forest in 2002 (Table 5, CT 3, 1%). These results demonstrate that forest cover is significantly different between our study towns: Iñapari has a higher percentage of forest cover for all years, and lower deforestation for all time periods, although the main deforestation trends are still similar in both towns.

Next, is infrastructure development the dominant driving force of deforestation? Surprisingly, results from the remote sensing analyses suggest that primary road development does not provide the dominant explanation for the different patterns of forest cover change in these areas, although it does play an important role. The opening of secondary roads

Table 4
Total area of non-forest cover per year and area deforested and reforested within each period

Year	Assis Brasil, Brazil			Iñapari, Peru		
	Pixels	sq. km	% **	Pixels	sq. km	% **
*A. Total Non-Forest Area**						
1986	69,486	62.5	6.9	12,649	11.4	2.2
1996	1,15,208	103.7	11.5	19,571	17.6	3.3
2002	1,21,319	109.2	12.1	22,384	20.1	3.8
B. Deforestation						
1986-1996	69,493	62.5	6.9	13,798	12.4	2.4
1996-2002	35,539	32.0	3.5	6,569	5.9	1.1
C. Reforestation						
1986-1996	23,967	21.6	2.4	6,392	5.8	1.1
1996-2002	29,072	26.2	2.9	3,815	3.4	0.7

*The difference in total non-forest areas for a time period should equal the difference between deforestation and reforestation for the same time period

**Percentage of Assis Bazil and Iñapari study areas respectively. The study area is defined by the intersection of a 20 km buffer from the main road and a 20 km buffer form the international border in the 1980s, combined with the availability of credit, is likely to explain a large part of the dominant trend of forest conversion between 1986 and 1996 (Table 5, CT 4 and 5). Figure 3 shows our analysis of forest cover, deforestation and reforestation by distance to the main road. The area within the first 10 km is where areas with higher percentages of non-forest, deforestation and reforestation are found. In most cases, Assis Brasil shows higher percentages for all years and all distances from the road. For non-forest areas the most important differences between the two towns occur within 1 km of the road, with Assis Brasil showing strikingly higher percentages of non-forest areas than Iñapari (e.g., 56.5% vs. 16.6% in 2002). For Assis Brasil, there is a marked difference between the 1986 curve and the later curves: a marked increase in the 1980s in non-forest percentages within the first km, and also between 2 and 5 km from the road, suggest that this was the consequence of secondary road building. This secondary road penetration does not exist in Iñapari where marked differences exist between the first two km from the primary road, except for a bulge in 1996 between 6 and 7 km, mostly due to a single large forest clearing for cattle ranching.

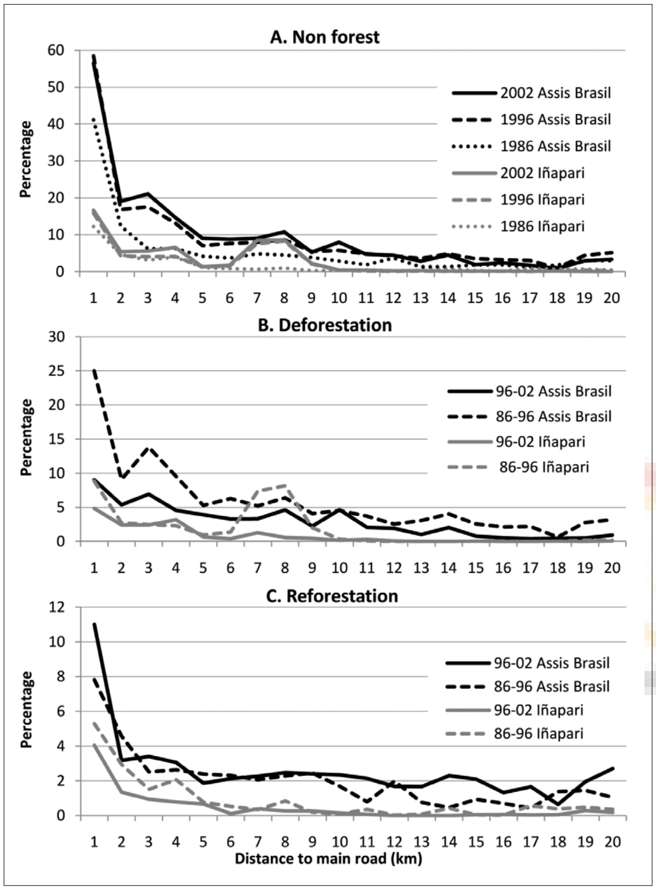

Figure 3

Percentage of non-forest cover per year by distance to road, percentage of area deforested and reforested within each period by distance to the road

Considering that the paving of the Interoceanic highway was finished on the Brazilian side in 2002, and that the road in Peru was made passable all year round in 2001, we expected to see a marked increase in deforestation for the period 1996–2002, but that was not the case (Table 4B). The conversion of forest during 1996–2002 is the fourth dominant trend for Assis Brasil and the third dominant trend for Iñapari (Table 5, CT 3). Our explanation for the decrease in deforestation for the period 1996–2002 is threefold. First, the main road for both Assis Brasil and Iñapari has existed since the 1960s, although in very poor conditions, and since then both towns have maintained relatively stable populations. For this reason the paving and improvement of the respective main roads did not have the anticipated effect as it did not necessarily open new forest areas for use. Second, farmers had already cleared as much forest as they could during the 1986–1996 period when new forest areas became accessible by the opening of secondary roads, and forest clearing was easily funded by credit for agriculture and cattle ranching. Third, the full effect of the road will not be appreciated until after the completion of the paving of the Interoceanic highway sometime during 2011.

If infrastructure development is not the driving force of deforestation, which socioeconomic variables can explain the differences we found in forest cover? We address this question at the household level using data on land use, land cover, road infrastructure, background information, market, credit and household life cycle variables (Table 6). Assis Brasil and Iñapari are small rural towns, and work on local farms is the principal economic activity (SUDAM & INADE 1998). In

Table 5

Pixel change trajectories for forest (F) and non-forest (Nf) classes between the years 1986, 1996 and 2002 for the study area

Change trajectory				Assis Brasil, Brazil			Iñapari, Peru		
CT*	86	96	02	Pixels	sq. km	%	Pixels	sq. km	%
1.	F	F	F	832,840	749.6	83.3	5,51,817	496.6	94.7
2.	Nf	Nf	Nf	36,437	32.8	3.6	4,073	3.7	0.7
3.	F	F	Nf	30,139	27.1	3.0	5,576	5.0	1.0
4.	F	Nf	F	21,670	19.5	2.2	2,759	2.5	0.5
5.	F	Nf	Nf	47,823	43.0	4.8	11,039	9.9	1.9
6.	Nf	F	F	18,567	16.7	1.9	5,399	4.9	0.9
7.	Nf	Nf	F	7,402	6.7	0.7	1,056	1.0	0.2
8.	Nf	F	Nf	5,400	4.9	0.5	993	0.9	0.2
Total				10,00,278	900.3	100.0	5,82,712	524.4	100.0

*F for pixels identified as forest, Nf for pixels identified as non-forest

Table 6

T-tests of means for land use outcomes, land cover outcomes, background information, markets and credit, road infrastructure and household life cycle variables between Iñapari, Peru and Assis Brasil, Brazil

Variables	Unit	Means		T-value
		Assis Brasil (N=41)	Iñapari (N=36)	
Land use outcomes				
Annual crops	Ha	3.27	2.38	-2.12* t
Perennial crops	Ha	0.85	0.65	-2.12* t
Pasture	Ha	21.29	11.79	-2.20* t
Head of cattle	Count	42.37	13.31	-3.79** t
Land cover outcomes				
Old growth forest	Ha	63.54	45.69	0.11 (a) t
Secondary forest	Ha	9.09	8.57	-0.57 t
Deforested area[a]	Ha	19.88	20.46	1.19 t
% deforested of forest[b]	%	24.05	28.07	1.82 (a) + t
Road infrastructure				
Lives in main road	0=No, 1=Yes	0.02	0.22	2.66 (a)*
Lives in secondary road	0=No, 1=Yes	0.44	0.22	-2.06 (a)*
Lives in tertiary road	0=No, 1=Yes	0.54	0.00	-6.81 (a)**
Lives in walking path	0=No, 1=Yes	0.00	0.56	6.61 (a)**
Distance from main road	Km	7.65	3.24	-4.74**
Transportation time	Hours	0.46	0.76	3.24 (a)** t
Background information				
Farm size	Ha	96.78	68.40	-1.60 (a) t
Initial old growth forest	Ha	83.42	66.15	0.48 (a) t
Initial secondary forest	Ha	9.26	2.18	-3.77 (a)** t
Regular monthly income	0=No, 1=Yes	0.49	0.31	-1.64 (a) t
Daily wage	0=No, 1=Yes	0.15	0.42	2.69 (a)** t
Born in the study area	0=No, 1=Yes	0.80	0.50	-2.90 (a)** t
Education	Years	3.39	7.75	4.91 ** t
Market and credit				
Distance from nearest market	Km	10.5	14.59	2.89 (a)**
Sells annual crops	0=No, 1=Yes	0.76	0.64	-1.11 (a)
Sells perennial crops	0=No, 1=Yes	0.12	0.14	0.22
Sells small animals	0=No, 1=Yes	0.54	0.28	-2.37 (a)*
Sells cattle	0=No, 1=Yes	0.76	0.33	-4.064**
Farm product commoditisation[c]	Index	7.95	5.08	-2.732**
Times credit was received[d]		0.76	1.42	1.69 + t
Household life cycle				
Years on farm	Years	13.73	14.08	-0.48 t
Age of household head	Years	44.83	44.72	-0.03
Family members on lot	Count	4.56	4.53	-0.08
Family members working on farm	Count	2.76	2.17	-2.16* t
Number of children	Count	1.83	1.56	-0.76
Number of adults	Count	4.46	3.86	-0.96 t
Labor hired[e]	Index	3.10	2.00	-3.60**
Labor exchanged[f]	Index	2.00	2.14	0.49

+ $p < 0.1$, *$p < 0.05$, **$p < 0.01$, (a) Significant differences in variance identified (F test; $p<0.05$); for T test equal variance is not assumed. Data for variables with skewness over 1 were transformed by converting to the natural logarithm and adding 1 unit to avoid 0 values to further reduce skewness. (t) Transformed t-values (ln (1+var)[1]) and significance are provided. [a]Initial old growth forest minus current old growth forest. [b]Ha deforested x 100 / ha initial old growth forest. [c]A value was assigned to each one of the different combinations of products sold, 1 to 13, lower values for households that sell annuals and higher to households that sell cattle. [d]Since arrival to the property. [e,f]Values range from 1 to 5; 1 when no labor was hired or exchanged during the last 12 months, and 5 when labor was hired all year round.

2003 the market for agricultural products in both towns was still very limited, and farmers produced mainly for subsistence. On both sides, complaints from producers were the same: the local market demand was not sufficient to consume all that was produced in the area, and high transportation costs were the main barrier to marketing in nearby larger towns, Iberia in the case of Iñapari, and Brasiléia in the case of Assis Brasil. For small animals the market was usually Puerto Maldonado. The most successful market was for beef: buyers from Puerto Maldonado and from Rio Branco would drive all the way to the farmlands in Iñapari and Assis Brasil respectively, with trucks that might carry up to eight or twelve animals, depending on

Table 7

Final models for land use outcomes showing all the independent variables that were significant in final multivariate land use and land cover models

Independent Variables	Land use (Dependent variables)			
	Annuals	Perennials	Pasture	Cattle
Background information				
Ln ha of farm size			0.632**	
Number of years of education	0.042**	0.019**		
Market and credit				
Distance in km from nearest market				-0.048*
Sells annual crops	0.335**	0.182**		
Sells cattle	1.109**	0.597**		
Farm product commoditisation (index)[a]	-0.088**	-0.052**	0.115**	0.200**
Road infrastructure				
Lives in secondary road				0.693**
Lives in walking path	-0.463**	-0.261**		
Ln transportation time (index)	0.648*	0.448**		
Household life cycle				
Ln years on farm			0.538**	0.305*
Number of children				-0.236**
Labor hired index[b]			0.136*	
Labor exchanged index[c]	0.101*	0.044*		
Place				0.482+
R2	0.538	0.549	0.632	0.712
F	11.483**	11.983**	30.948**	28.800**
Constant	0.324+	0.306**	-2.896**	0.13

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, (a) All models use OLS estimation, and coefficients are unstandardised slopes, N=77. [a]A value was assigned to each one of the different combinations of products sold, 1 to 13, lower values for households that sold annuals and higher to households that sold cattle. [b,c]Values range from 1 to 5; 1 when no labor was hired or exchanged during the last 12 months, and 5 when labor was hired all year round.

Table 8

Final models for land cover outcomes showing all the independent variables that were significant in final multivariate land use and land cover models

Independent variables	Land cover (Dependent variables)			
	Old growth forest	Secondary forest	Area deforested	% deforested
Background information				
Ln ha of farm size		1.012**		-1.144**
Ln initial ha old growth forest	0.977**	-0.962**	0.577**	0.905**
Ln initial ha secondary forest	0.167**		-0.390**	-0.413**
Market and credit				
Sells annual crops	0.240+	0.669**		
Sells cattle				0.687**
Road infrastructure				
Ln transportation time (index)	0.707*			
Household life cycle				
Ln years on farm		0.367*	0.693**	0.640**
Place				
R^2	0.724	0.309	0.667	0.634
F	47.110**	8.042**	48.789**	24.619**
Constant	-0.968*	-0.011	-1.220*	2.382**

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, (a) All models use OLS estimation, and coefficients are unstandardised slopes, N=77.

their size. They bought cattle at the farm gate, and paid cash, usually for young bulls that were taken to fields near the cities to be fed, processed and have their meat sold. Before the road was built, the only way to get cattle to the town was by walking them for four days, which was usually done by the cattle owners. Now cattle owners no longer walk their cattle to cities, as a 'cattle mafia' of monopoly buyers consolidated itself with the paving and improvement of the roads, and farmers find it difficult to sell their cattle directly to the feeding centres or to the slaughterhouse rather than to the 'mafia' buyers.

All land use outcomes are larger in Assis Brasil than in Iñapari, likely because of a combination of the market and road variables. Households in Assis Brasil are closer to the market, sell more small animals (which eat part of the crop production, therefore requiring larger crop fields) and sell more cattle. They have a shorter transportation time because they have a better road network. In Iñapari, many farmers can only get to their farms using walking paths. For this same reason farmers in Iñapari tend to live closer to the main road and to spend more time on transportation. The differences in market and road variables are explained by the fact that Assis Brasil is a relatively older frontier compared to Iñapari, and this is in turn explained by the events presented in Table 3. Old frontiers are regions that were heavily settled during the last three decades. New frontiers are regions that were not settled, or that were initially settled and abandoned later, usually due to severe transportation problems and lack of health and education services, which is partly the case for Iñapari, except that it was not totally abandoned. The frontier ageing effect is confirmed by the fact that although most household life cycle variables, such as the age of the household head, are not different, background information variables are: More heads of households in Assis Brasil were born in the study area, and their farms had larger areas under initial secondary forest than in Iñapari, indicating previous occupation and use of the land.

We suggest an explanation for the similarities in area deforested per household between farmers of Assis Brasil and Iñapari. The historical character of the variable deforestation, defined as total area of old growth forest cleared since arrival to the property, reflects both past and present conditions. It is likely that when the Agrarian Bank was providing credit and the National Rice Commercialization Enterprise (Empresa de Comercializacion del Arroz, S.A., ECASA) was buying rice and corn, farmers in Iñapari had larger areas under crops. Results from the remote sensing analysis support this explanation: Table 4 indicates higher deforestation rates for the 1986–1996 period. Considering that both ECASA and the Agrarian Bank were closed in 1991, it is highly likely that agriculture fields abandoned in 1991 would be classified as forests (secondary forests) in the 1996 satellite image, therefore also showing a high reforestation rate for the same period. Since the total area deforested at the household level is not significantly different between the two towns, the higher deforestation observed in Assis Brasil in the remote sensing analysis can be explained in part by the larger number of households (study area also includes farms in the neighbouring Município) and in part by the larger area deforested for pasture in Assis Brasil. These areas would have been maintained as pasture for the whole study period, as opposed to Iñapari where areas were deforested mostly for annual crops, and the fields were abandoned after two to three years due to poor initial soil fertility and/or soil degradation, and eventually because of the lack of credit and markets.

To better understand the role of these variables in determining land use and land cover outcomes, we developed multivariate models. Tables 7 and 8 provide the significant independent variables from the multivariate modelling analyses. The lack of significance of the variable 'place' in the multivariate models indicates that differences between Assis Brasil and Iñapari are well explained by the significant variables. All land cover outcomes are best explained by background information and household life cycle variables. Market, credit and road infrastructure variables seem to play a limited role. These results imply a historical nature of land cover outcomes: households with more years on the farm and with larger initial areas of old growth forest have deforested larger areas. These results suggest that for the study period deforestation did not occur at once; instead it took place gradually over the years.

Market, credit and road infrastructure variables have an important role in explaining land use outcomes such as the area under crops, and the number of heads of cattle. However, the area under pasture is better explained by background information and household life cycle variables. Results suggest that farmers can quickly respond to changes in market and road infrastructure variables by changing the area under crops but increasing the area under pasture seems to be a slower process. A household with limited resources will prioritise annual crops over cattle ranching, due to lower costs and the fact that annual crops may provide both food and income. Farmers with limited resources who are interested in cattle ranching tend to initially clear land for annual crops, and after a year or two, plant pasture rather than abandon the field to regrow as secondary forest. Only once the household has accumulated enough resources will it be able to afford converting forest areas directly to pasture.

The role of market, credit and road infrastructure variables is limited in explaining land cover outcomes in the multivariate models, but it is worth giving attention to three variables that were found to be significant. Selling annual crops is positively associated with larger areas of secondary forests, and selling cattle is positively associated with larger percentages of deforestation, while longer transportation times are positively associated with larger areas of old growth forest. The market variables highlight the different effects of selling annual crops versus selling cattle. Because soils are poor and farmers do not have access to fertilisers and/or herbicides, annual crop fields are abandoned after two to three years, leading to forest regrowth. On the other hand, pastures are used for many years, and even if they were to be abandoned they take a longer time to regrow into secondary forests. Considering the mean number of heads of cattle and the significantly larger areas under pasture than under crops (Table 6) it appears that most farmers in Assis Brasil have reached the point at which they are able to convert forest directly into pasture, but fewer farmers in Iñapari seem to have reached that point. Most farmers practicing cattle ranching expressed a desire to increase their herd size and/or pasture areas. Many of the farmers who did not own cattle were expecting to be able to acquire them in the near future. Our findings suggest that the study area will continue to experience a steady growth in cattle ranching.

The only significant road infrastructure variable indicates that higher transportation times are positively associated with larger areas of old growth forest. Our remote sensing analysis shows higher deforestation levels for the 1986–1996 period, which coincides with when credits were available and secondary roads were opened. We attribute at least part of the higher deforestation in Assis Brasil than that in Iñapari to the more extensive secondary road network in Assis Brasil. This is supported by findings presented in Figure 3; deforestation in Assis Brasil is not only higher, but it also reaches farther from the main road than it does in Iñapari. Research by Arima *et al.* (2005) underscored the importance of interacting social actors in shaping the emergence of road networks and local deforestation patterns in Amazonia.

What can be learned from these areas to minimise deforestation in the future? Our findings suggest that cattle ranching will continue to experience a steady growth. With the rapidly developing Interoceanic highway, the cattle ranching cycle will be reinforced by better roads that translate into lower costs, and in a stronger demand from quickly growing regional markets, thereby leading to increased deforestation in the area in the near future. So far, planting of annual crops have led to deforestation but also to forest regrowth following cropland abandonment due to poor soils. If the Interoceanic highway makes it easier for farmers to access fertilisers and/or herbicides, deforestation could decrease due to the ability to farm the same land for a longer time period, but depending on the quality of the products and training in their use and application, it could also bring chemical misuse and contamination issues to the area.

The Interoceanic highway will also fuel migration to the area which is likely to increase deforestation. This is not a new frontier, and virtually every piece of land has been claimed already. Those who migrate to the area will either have to encroach upon existing private or government land claims (i.e., national parks, indigenous reserves, and logging concessions) or buy land from sellers. Those who encroach upon land are more likely to have to clear forest to grow their own food, (i.e., slash and burn agriculture), potentially increasing risks for wild fires in previously intact forested areas. Those who are able to buy land usually come from bigger cities and are likely to have the necessary resources to clear larger areas of forests more quickly than the previous landowners. In the worst case, buyers could be companies with strong interests in cattle ranching or in crops that are known to require deforestation of large areas, such as soybean or palm plantations. Either way, migration to the area will certainly result in increased deforestation.

In the Brazilian Amazon, assessments of the effects of roads on deforestation have shown a 30% forest loss within 10 km of both roads and highways, with the effects of highways causing an additional 20% forest loss within 11–25 km, and 15% loss from 26–50 km (Laurance *el al.* 2001b). The main road in the study area was built in the 1960s, and our 2002 assessment of deforestation in the area within 20 km from the road shows only 12% non-forest area for Assis Brasil and 3.8% for Iñapari. These lower than expected figures are explained by the relative isolation of the area. The Interoceanic highway will put the study area in the middle of an important trade route, and although the area is not a new frontier, the potential for rapid and significant increases in deforestation does exist.

The Interoceanic highway will reinforce previously existing deforestation trends and will create new ones, but its effect will be not be the same on both sides of the border. Iñapari and Assis Brasil represent different frontier ages and are expected to be impacted differently by infrastructure development. In economic terms, the paving of roads in new frontiers increases land supply, reducing land value in the older frontiers as it encourages colonisation and forest clearing (Laurance *et al.* 2001b). Increased governance, on the other hand, might conserve up to 70–80% of forest cover (Nepstad *et al.* 2002). Although Assis Brasil and Iñapari are not new frontiers, Iñapari is a relatively younger one and the effects of the Interoceanic highway are more likely to be stronger here. Our explanation for this prediction is threefold. First, the relatively younger frontier of Iñapari has a larger percentage of forest cover and therefore there is a higher potential for deforestation here. Second, a stronger presence of both state and federal government in Assis Brasil ensures greater control over natural resources and regulation of their use than in Iñapari. Third, legislation limiting the percentage of deforestation within farms to 20% of the area already exists in Brazil, although the regulation remains poorly enforced.

To minimise deforestation in the face of the Interoceanic highway in Iñapari we consider it vital to develop a system that will establish and enforce limitations on the area of forest a landowner can clear. For Assis Brasil, reducing deforestation would require, first of all, the enforcement of current regulations. For both towns, existing pressures require additional regulations to: 1) quickly and effectively enable the removal of land encroachers, 2) place restrictions on the opening of both public and private secondary roads, 3) limit credit only to activities that will not result in the clearing of more forests, and 4) develop programmes that provide basic services such as education, electricity and water to encourage current farmers to remain on their lands, rather than sell them. Equally important will be the elaboration of a project-wide impact assessment of the Interoceanic highway, although this would have been more useful before the decision was made to build it. It is of extreme importance to have a clear idea of the future project-wide impacts if both the exemplary biodiversity and forest cover of this area, and its diverse residents, are to coexist in a sustainable manner.

CONCLUSION

We use remote sensing and socio-economic approaches to address questions that require incorporation of different spatial-temporal scales and land cover classes. Our findings suggest that the patterns of land cover change observed in Iñapari and Assis Brasil since the 1980s cannot be explained using models of single land use drivers such as demographic growth, road development, or market integration. To do so, it is necessary to understand the interaction of national and regional policies regarding credit availability and road infrastructure, along with local processes of market integration and household resources (Arima *et al.* 2005).

Specifically, the expected land cover patterns predicted from policy changes were only partially found. Other household- or farm-level variables may operate in an opposing fashion. This study demonstrates the importance of local and regional variables and transient factors (e.g., secondary and tertiary roads, regional market prices) in determining LULCCs at very fine scales, in spite of larger-scale drivers acting at national or international scales, and emphasises the necessity of considering multiple scales when developing conservation/development policies. The practical implication of our findings is that the Interoceanic highway will not have a homogenous effect through its path in the Brazilian and Peruvian Amazon. Deforestation is likely to be higher in areas: 1) that until now have remained relatively isolated and therefore have high forest cover, 2) where farmers have already accumulated necessary resources to convert forest directly into pasture, 3) where new secondary roads are being opened and 4) that can be easily encroached upon, such as those lacking immediate occupants or in areas having poor law enforcement capabilities. Special attention must be given to areas where farmers are more likely to sell their land to richer farmers or companies that are interested in activities that require the deforestation of large areas, such as has been seen for soybean and sugar cane plantations and industrial cattle ranching. Deforestation in these most susceptible areas could be minimised through the development of a system to establish and enforce limitations on the area of forest a landowner can clear. To be effective, such a policy would need to simultaneously aid effective removal of land encroachers, restrict the opening of both public and private secondary roads, and encourage current farmers to remain on their lands.

ACKNOWLEDGEMENTS

This research was made possible with a graduate fellowship from the Organization of American States, field research funds from the Tropical Conservation and Development programme at the University of Florida, the Tinker Foundation and the Setor de Estudos do Uso da Terra e Mudanças Globais at the Federal University of Acre. We thank the people of Assis Brasil and Iñapari, especially the families that allowed Angelica M. Almeyda Zambrano to interview them for this project. We also would like to thank Manuel Batista de Araujo, Prefeito of the Município of Assis Brasil, and Mario Enrique Montes León, Alcalde of the Province of Iñapari. We would like to thank Michael Binford for his help and support throughout the research process and for useful comments on preliminary versions of this manuscript. We would like to thank William Durham, Joanna Mountain, and Dominique Irvine for their valuable insights into the theoretical and statistical approaches used in this paper. Finally, we would like to thank Foster Brown for providing the Quickbird satellite imagery used in this study and for invaluable insights and help throughout the entire project.

REFERENCES

Achard, F., H. Eva, H. Stibig, P. Mayaux, J. Gallego, T. Richards and J. Malingreau. 2002. Determination of deforestation rates of the world's humid tropical forests. *Science* 297: 999–1002.

Alvarez, N.L. and L. Naughton-Treves. 2003. Linking national agrarian policy to deforestation in the Peruvian Amazon: A case study of Tambopata, 1986-1997. *Ambio* 32(4): 269–274.

Alves, D.S. 2002. An analysis of the geographical patterns of deforestation in the Brazilian Amazon in the period 1991-1996. In: *Deforestation and land use in the Amazon* (eds. Wood, C.H. and R. Porro). Pp. 95–106. Gainesville: University Press of Florida

Arima, E.Y., R.T. Walker, S.G. Perz and M. Caldas. 2005. Loggers and forest fragmentation: Behavioral models of road building in the Amazon basin. *Annals of the Association of American Geographers* 95(3): 525–541.

Asner, G.P., D.E. Knapp, E.N. Broadbent, P.J.C. Oliveira, M. Keller and J.N. Silva. 2005. Selective logging in the Brazilian Amazon. *Science* 310: 480–482.

Baabbit, B. 2009. Manifest destiny in the Amazon Basin. *Americas Quarterly Summer* 2009: 28–34.

Blaikie, P.M. and H.C. Brookfield. 1987. *Land degradation and society*. London: Methuen.

Broadbent, E.N., G.P. Asner, M. Keller, D.E. Knapp, P.J.C. Oliveira and J.N. Silva. 2008. Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biological Conservation* 141: 1745–1757.

Bryant, R.L. and S. Bailey. 1997. *Third world political ecology*. London: Routledge.

Dourojeanni, M., A. Barandiarán and D. Dourojeanni. 2009. *Amazonía Peruana en 2021: Explotación de recursos naturales e infraestructura*. Lima: ProNatureleza.

Durham, W.H. 1979. *Scarcity and survival in Central America: The ecological origins of the soccer war*. Stanford: Stanford University Press.

Edelman, M. 1995. Rethinking the hamburger thesis: Deforestation and the crisis of central America's beef exports. In: *The social causes of environmental destruction in Latin America* (eds. Painter, M. and W.H. Durham). Pp. 25–62. Ann Arbor: The University of Michigan Press.

Ehrlich, P.R. and A. Ehrlich. 1990. *The population explosion*. New York: Simon and Schuster.

Fearnside, P.M. 1987. Deforestation and international economic development projects in Brazilian Amazonia. *Conservation Biology* 1: 214–221.

Geist, H.J. and E.F. Lambin. 2002a. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52: 143–150.

Godoy, R., D. Wilkie and J. Franks. 1997. The effects of markets on Neotropical deforestation: A comparative study of four Amerindian societies. *Current Anthropology* 38 (5): 875–878.

IBGE. 1998. *Censo Agropecuário 1995/1996*. Instituto Brasileiro de Geografia e Estatística. Brasilia, Brasil.

IBGE. 2010. Cidades: Assis Brasil. Instituto Brasileiro de Geografia e Estatística [accessed February 23, 2010]. Available at http://www.ibge.gov.br/cidadesat/topwindow.htm?1.

INEI. 1999. *III Censo Nacional Agropecuario 1994*. Instituto Nacional de Estadística e Informática. Lima, Peru.

INEI. 2010. Banco de Información Distrital: Distrito Iñapari. Instituto Nacional de Estadística e Informática [accessed February 23, 2010]. Available at http://desa.inei.gob.pe/mapas/bid/

INRENA. 1998. *Zonificación Ecológica-Económica Yaco-Iñapari e Iberia-Iñapari, Madre de Dios*. Instituto Nacional de Recursos Naturales, Lima, Peru.

Kaimowitz, D. and A. Angelsen 1998. *Economic models of tropical deforestation: A review*. Centre for International Forestry Research, Bogor, Indonesia.

Laurance, W.F., A.K.M. Albernaz and C. Da Costa. 2001a. Is deforestation accelerating in the Brazilian Amazon? *Environmental Conservation* 28: 305–311.

Laurance, W.F., M.A. Cochrane, S. Bergen, P.M. Fearnside, P. Delamonica, C. Barber, S. D'Angelo and T. Fernandes. 2001b. The future of the Brazilian Amazon: Development trends and deforestation. *Science* 291: 438–439.

Leinbach, T.R. 2000. Mobility in development context: changing perspectives, new interpretations, and the real issues. *Journal of Transport Geography* 8: 1–9.

Malthus, T.R. 1965. *First essay on population*. New York: Augustus M. Kelley.

Mayaux, P., F. Achard and J. Malingreau. 1998. Global tropical forest area measurements derived from coarse resolution satellite imagery: a comparison with other approaches. *Environmental Conservation* 25: 37–52.

Nepstad, D., D. McGrath, A. Alencar, A.C. Barros, G. Carvalho, M. Santilli and M. del C. Vera Diaz. 2002. Frontier governance in Amazonia. *Science* 295: 629–631.

Netting, R.M. 1993. *Small holders, householders: Farm families and the ecology of intensive sustainable agriculture*. Stanford: Stanford University Press.

Oliveira, P.J.C., G.P. Asner, D.E. Knapp, A. Almeyda, R. Galvan-Gildemeister, S. Keene, R.F. Raybin and R.C. Smith. 2007. Land use allocation protects the Peruvian Amazon. *Science* 317: 1233–1236.

Rappaport, R.A. 2000. *Pigs for the ancestors: Ritual in the ecology of a New Guinea people*. Long Grove: Waveland.

Schmink, M. 1994. The socioeconomic matrix of deforestation. In: *Population and environment: Rethinking the debate* (eds. Arizpe, L., P. Stone and D. Major). Pp. 253–275. Boulder: Westview Press.

Schmink, M. and C.H. Wood. 1987. The 'political ecology' of Amazonia. In: *Lands at risk in the Third World: Local level perspectives* (eds. Little, P.D. and M.M. Horowitz). Pp. 38–57. Boulder: Westview.

Schmink, M., and C.H. Wood. 1992. *Contested frontiers in Amazonia*. New York: Columbia University Press.

Smith, E.A. 1991. *Inujjuamiut foraging strategies*. New York: Aldine de Gruyter.

SUDAM and INADE. 1998. *Plan de desarrollo de las comunidades fronterizas Peruano-Brasileñas Iñapari - Assis Brasil*. Superinendencia de Desenvolvimento da Amazonia (SUDAM) and Instituto Nacional de Desarrollo (INADE), Lima, Peru.

Varese, M. 1999. Drivers of investment in cattle among landholders in the southern Peruvian Amazon. viii+116 pp. M.Sc. Thesis. University of Florida, Gainesville, USA.

Wood, C.H. and M. Schmink. 1993. The military and the environment in the Brazilian Amazon. *Journal of Political & Military Sociology* 21: 81–105.