

Contrasted land use and development trajectories in the Brazilian Amazon

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Using two case studies in the state of Pará (Brazil), Uruará (Transamazon) and São Félix do Xingú (Southern Pará), the current paper analyzes the landscape dynamics in contrasted frontier areas. It examines how these dynamics are related to infrastructure development, ecological conditions, land tenure and fiscal policies, and to the evolution and organization of the production, consumption and marketing chains of livestock products.



Fragmented landscape along the Transamazon highway.
Photo J.-F. Tourrand.

RÉSUMÉ

DIVERSITÉ D'UTILISATION
ET DE MISE EN VALEUR DES TERRES
EN AMAZONIE BRÉSILIENNE

La forêt amazonienne, plus grand massif forestier tropical sur terre, subit un déboisement rapide depuis quatre décennies. En Amazonie brésilienne, les fronts pionniers se concentrent dans l'Arc de déforestation. Dans cette vaste zone, des processus de changements variés interagissent au travers de plusieurs modes d'utilisation et de mise en valeur des terres. À partir de deux études de cas dans l'État du Pará (Brésil), cet article analyse les dynamiques du paysage dans ces fronts pionniers très contrastés et examine l'influence de facteurs tels que le développement des infrastructures, les conditions écologiques, les régimes fonciers, les politiques fiscales ainsi que l'organisation et l'évolution des filières bovines. Les principaux objectifs sont d'illustrer, d'une part, la variabilité spatiale et temporelle des opportunités ou contraintes à la conversion des forêts à des fins agricoles et, d'autre part, comment des conditions biophysiques et socio-économiques contrastées affectent les dynamiques actuelles et futures de l'utilisation du sol et du développement régional. L'approche repose sur la collecte et l'intégration de variables-clés économiques et biophysiques dans une base de données géoréférencées. Les outils d'analyse de paysage et la construction de modèles économétriques conduisent à l'analyse statistique conjointe des processus de changements d'utilisation du sol et des facteurs observables qui les influencent.

Mots-clés : front pionnier, colonisation, élevage, route, déforestation, Amazonie, Brésil.

ABSTRACT

CONTRASTED LAND USE
AND DEVELOPMENT TRAJECTORIES
IN THE BRAZILIAN AMAZON

The Amazon is the largest tropical forest area on Earth, and is undergoing rapid deforestation since the last four decades. These conversions are mostly located in frontier areas distributed along the so-called "arc of deforestation". Within this large zone, various land use change processes are interacting through several modes of land valorization and organization. From two case studies in the state of Pará (Brazil), the current paper aims at analyzing how these landscape dynamics in contrasted frontier areas are related to infrastructure development, ecological conditions, land tenure and fiscal policies, and to the evolution and the organization of the production, consumption and marketing chains of livestock products. The main objectives are to illustrate the spatial and temporal variability regarding incentives and disincentives to convert tropical forests for other agricultural uses and how do contrasted biophysical and socio-economic conditions (such as accessibility or land tenure) affect current and future land use and development trajectories, with a particular emphasis on the role of roads infrastructure. This study draws on complementary datasets, socio-economic census, key-informants interviews and satellite remote sensing imagery, linked with geo-referenced information on human and biophysical conditions. These data were integrated in a GIS, and the analyses were supported quantitatively by using spatial econometric modelling approaches and landscape ecology tools.

Keywords: Amazon, Brazil, frontier, colonization, livestock, road, deforestation.

RESUMEN

DIVERSIDAD DE USOS
Y APROVECHAMIENTO DE TIERRAS
EN LA AMAZONIA BRASILEÑA

La selva amazónica, el mayor bosque tropical del planeta, sufre una rápida deforestación desde hace cuatro décadas. En la Amazonia brasileña, los frentes pioneros se concentran en el Arco de deforestación. En esta extensa zona, existen diferentes procesos de cambios interactuando mediante distintos métodos de utilización y aprovechamiento de las tierras. A partir de dos estudios de casos en el Estado de Pará (Brasil), este artículo analiza las dinámicas del paisaje en estos frentes pioneros, muy diferentes entre sí, y examina la influencia de factores como el desarrollo de las infraestructuras, las condiciones ecológicas, los sistemas de tenencia de tierras, las políticas fiscales y la organización y evolución del sector bovino. Los principales objetivos consisten en ilustrar, por una parte, la variabilidad espaciotemporal de las oportunidades o limitaciones para la transformación de los bosques en tierras agrícolas y, por otra parte, el cómo las diferentes condiciones biofísicas y socioeconómicas afectan las dinámicas actuales y futuras de la utilización del suelo y del desarrollo regional. El planteamiento se basa en la recogida e integración de variables clave económicas y biofísicas dentro de una base de datos georreferenciada. Las herramientas de análisis del paisaje y la construcción de modelos econométricos conducen al análisis estadístico conjunto de los procesos de cambios de utilización del suelo y de los factores observables que los influyen.

Palabras clave: frente pionero, colonización, ganadería, carretera, deforestación, Amazonia, Brasil.

Introduction

The Amazon, the largest tropical forest area on earth, has undergone rapid deforestation in the last four decades. From the early 1960s the Brazilian government decided to initiate large-scale development programs aimed at integrating the Amazon region into the national economy, which had a significant impact on land use change. The total deforested area in the Brazilian Amazon grew from 152 200 km² in 1978 to 415 200 km² in 1990, and 587 727 km² in 2000 (INPE, 2002). For the period 1978-1989 INPE statistics report a yearly rate of gross deforestation of 0.54 % (21 130 km².y⁻¹). The rate declined somewhat in the early 1990s, remaining below 15 000 km².y⁻¹ for a major part of the 1990s, but rebounding once more to a high level in the late 1990s to reach 0.52 percent or almost 19 000 km².y⁻¹ in 2000 (INPE, 2002). In addition to deforestation, large expanses of forest are being degraded by habitat fragmentation, edge effects, selective logging, surface fires, gold mining, overhunting and other activities (e.g., NEPSTAD *et al.*, 2001).

Land use in the Amazon is strongly shaped by roads and past settlement patterns. Deforestation in the 1990s for the entire Legal Amazon tended to be concentrated in limited regions, growing inertially around areas of previous deforestation and major roads. About 90 percent of Amazon deforestation has taken place within 100 km of major paved highways (ALVES, 2002) and national development plans such as “*Avança Brasil*” would rapidly increase the supply of forest land through the paving of more than 6 000 km of roads in the Amazon (LAURANCE *et al.*, 2001).

In fact, deforestation across the Brazilian Amazon has not proceeded in a random fashion (McCRACKEN *et al.*, 2002): the highest rates were observed in areas along the Bélem-Brasília and the Cuiabá-Porto Velho

highways – the so-called *arc of deforestation* (Figure 1). Lower deforestation rates affected the regions along the Cuiabá-Santarém and the Transamazon highways. The dominant land use following deforestation is pasture for cattle ranching, as a result of the relocation of the Brazilian cattle herd from the southeast area of the country into the southern part of the Amazon Basin (POCCARD-CHAPUIS, 2004).

Using two case studies in the state of Pará (Brazil), the current paper will analyse how landscape dynamics in contrasted frontier areas are related to infrastructure development, ecological conditions, land tenure and fiscal policies, and to the evolution and organization of the production, consumption and marketing chains of livestock products. The aims are to illustrate the spatial and temporal variability regarding incentives and disincentives for converting

tropical forests to other agricultural uses, and to show how contrasted biophysical and socio-economic conditions affect current and future land use and development trajectories, with a particular emphasis on the role of road infrastructure. The first section will provide a brief overview of the existing literature on land use models looking at this issue in the Brazilian Amazon, while the second section will focus on the comparison of deforestation patterns in the two study areas (Figure 2). Complementary datasets were collected, from socio-economic censuses, key-informant interviews and satellite remote sensing imagery, linked with geo-referenced information on human and biophysical conditions. This data was integrated in a GIS and the comparisons were supported quantitatively by using spatial econometric modelling approaches and landscape ecology tools.

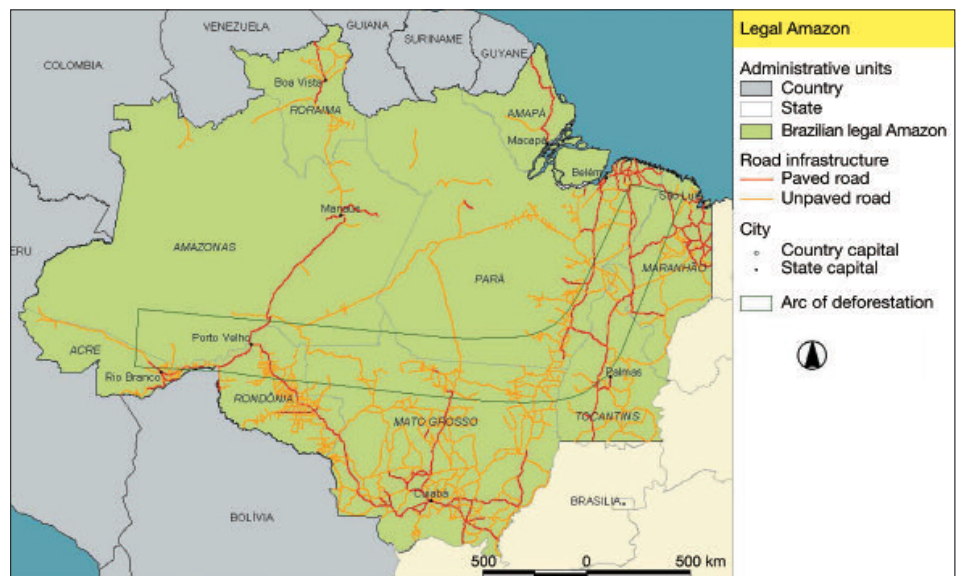


Figure 1.

Legal Amazon, main road infrastructure and Arc of deforestation.

Previous land use change modelling studies in the Brazilian Amazon

There is an increasing literature in the field of land use change modelling applied in the Brazilian Amazon¹. As land use in the Amazon is strongly shaped by roads and past settlement patterns, it is not surprising to see that the impact of roads on deforestation has been considered in most of the studies and that there is a broad consensus regarding the influence of paved highways on increasing deforestation, at least at the national or sub-national scale.

ANDERSEN, REIS (1997) looked at the relationships between deforestation and development policies for the period 1970 to 1985 and concluded that while subsidized credit implied a relatively good trade-off between economic growth and deforestation, large road building projects had a much less favourable trade-off. Intensive transport infrastructure development inside the agricultural frontier seems to have a less harmful impact on deforestation than extensive development because it may favour land use intensification (PFAFF, 1997; BERARDO *et al.*, 1998). Moreover, if paving projects within existing frontiers were accompanied by investments in education and health services, as well as marketing facilities, they might foster socially equitable rural development and long-term prosperity (NEPSTAD *et al.*, 2001).

Therefore, it is still difficult to predict, without large error margins, the location and intensity of deforestation that would be associated with road building or improvement. For instance, NEPSTAD *et al.* (2001) underline the different potential impact of road building according to the specific environment of the sub-regions. MERTENS *et al.* (2002) show that the impact of the roads depends on the type of road, the stage of development of the frontier area and the type of producers. CATTANEO

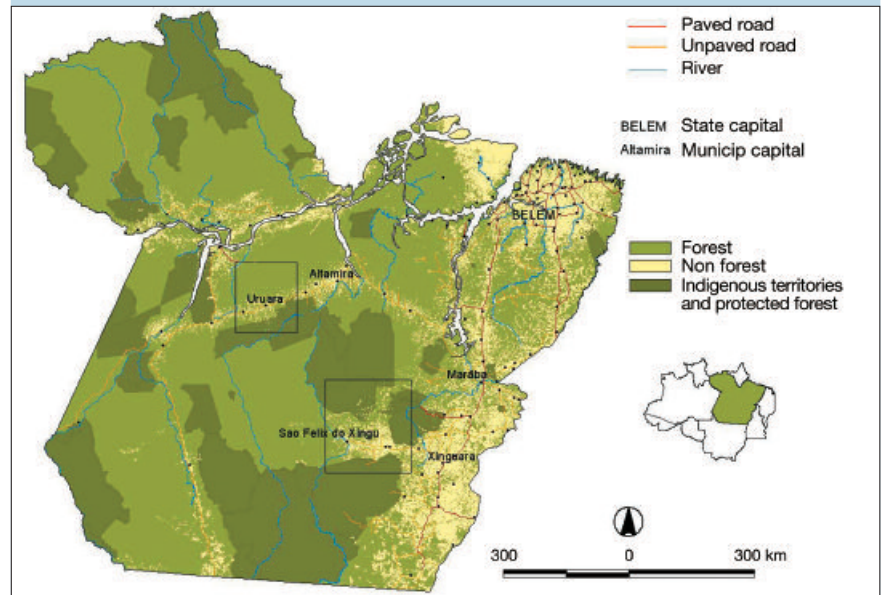


Figure 2.
State of Pará and study areas.

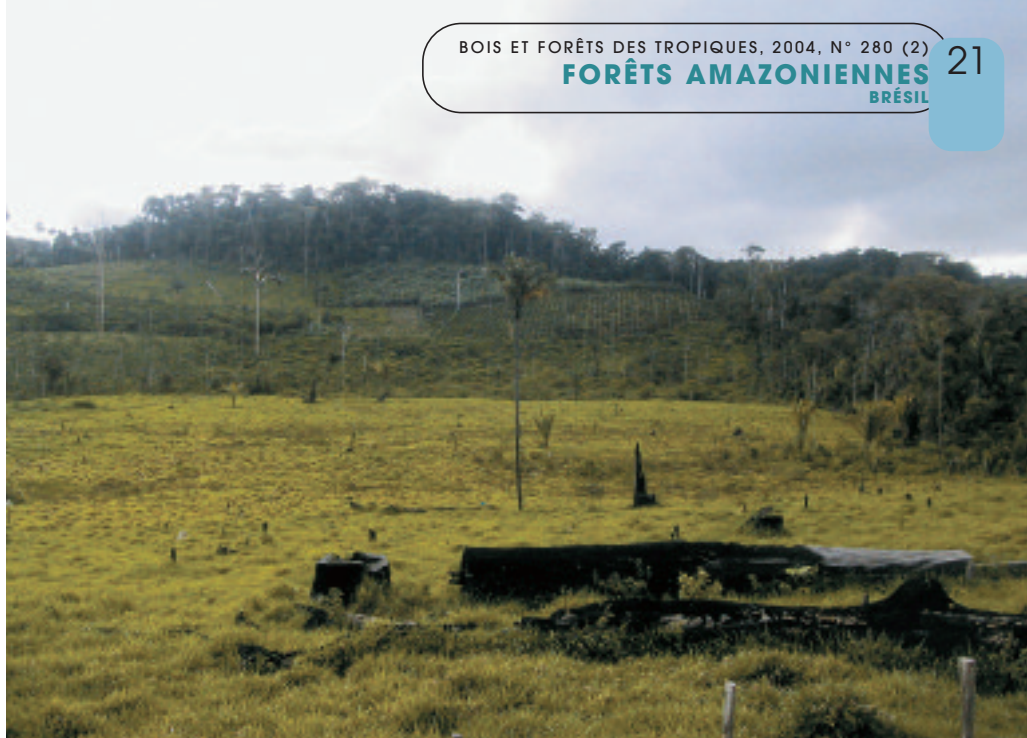


Large-scale cattle ranching in São Félix do Xingú.
Photo B. Mertens.

¹ Most land use change models applied in the Brazilian Amazon are categorized as non-spatial models since they do not provide any information about the specific location of forest clearing or take into account the spatial distribution of landscape elements and adjacency effects.

(2002) highlights the fact that the magnitude of the impact of road building depends on the regional level of production factor flows following road building. Existing studies do not always agree on the impact of unpaved roads. PFAFF (1997) does not find a positive impact of unpaved road on deforestation whereas FERRAZ (2001) and MERTENS *et al.* (2002) do. Surprisingly, few studies have been carried out at a finer scale to examine these relationships.

The main puzzling aspect on the issue of road building is the fact that most deforestation is linked to extensive cattle ranching, which is structurally less sensitive to transport costs than any other agricultural activity. Most of the models have not addressed the potential impact of road building on the establishment of associated local agro-processing factories. Following recent theoretical works in the field of regional economics (FUJITA *et al.*, 1999), it may be assumed that improving road infrastructure toward agricultural frontier areas has a negative local impact in the first instance (i.e. the agro-processing factories remain in their regions of origin but stock up with products from the frontier areas at lower cost), and a positive local impact in the second instance (i.e. new factories tend to be built within the frontier area). The dynamic effects depend particularly on the type of product, the level of economies of scale, local infrastructure and forwards and backwards linkages. Most of the actors surveyed in several agricultural frontiers in the Brazilian Amazon pointed out that access to markets for livestock products was a main determinant of the expansion of cattle ranching in the Amazon (VEIGA *et al.*, 2001). On the other hand, credit policies tried to promote the development of agro-forestry systems, but met with failure due to the fact that access to markets for these products was not secured. It is therefore necessary to achieve a better understanding of the determinants of the location of agro-processing factories inside or outside of the Amazon Basin, in order to fully understand possible future land use change trajectories.



Diversified production systems in Uruará: recent clearing, annual and perennial crops and pasture.
Photo J.-F. Tourrand.

Two contrasted patterns of land use change dynamics

The region of São Félix do Xingú

The region of São Félix do Xingú is located in the southern region of Pará, in the Eastern Brazilian Amazon (Figure 2). It is one of the largest counties (84 000 km²) and has a very low population density (<0.5 inhabitants per km²), with 77 percent of the population living in rural areas. In 1982, after successive cycles of forest resource extraction activities, São Félix do Xingú was linked by road to the expanding frontiers areas of Xinguára (SCHMINK, WOOD, 1992). From that time on, mining activities, wood extraction, small farmer settlement projects and livestock activities stand out as the four successive and complementary drivers of regional development. The statistics of the *Instituto Brasileiro de Geografia e Estatísticas* (IBGE) show a rapid immigration in São Félix do Xingú county: the population grew from 4 954 in 1980 to 24 834 in 1991, and

to 40 983 in 1996 (IBGE Census and inter-census data). This process seems to have been underestimated as observed in the field, and by MATURANA (2001).

The interpretation of the time series of satellite remote sensing Landsat images (1986-1992-1999) allows the characterization of the land cover change dynamics that affected the region (Figure 3). In 1986 the intensive gold mining activities gave the first impetus to colonization with the arrival of thousands of gold-diggers, creating camps that then became towns. Small plots (50-100 ha) can be distinguished along tracks built in the forest and along well organized secondary roads in the Tucumã sector. On the other hand, some large-scale properties (thousands of ha) or *fazendas* are already in place, discernable by the enormity of their size and their geometric form. Contrary to small-scale farming systems, these *fazendas* are isolated from the transport infrastructure. The dense network of logging tracks also reveals the intensive extraction of valuable woods, in particular Mahogany (*Swietenia macrophylla*).

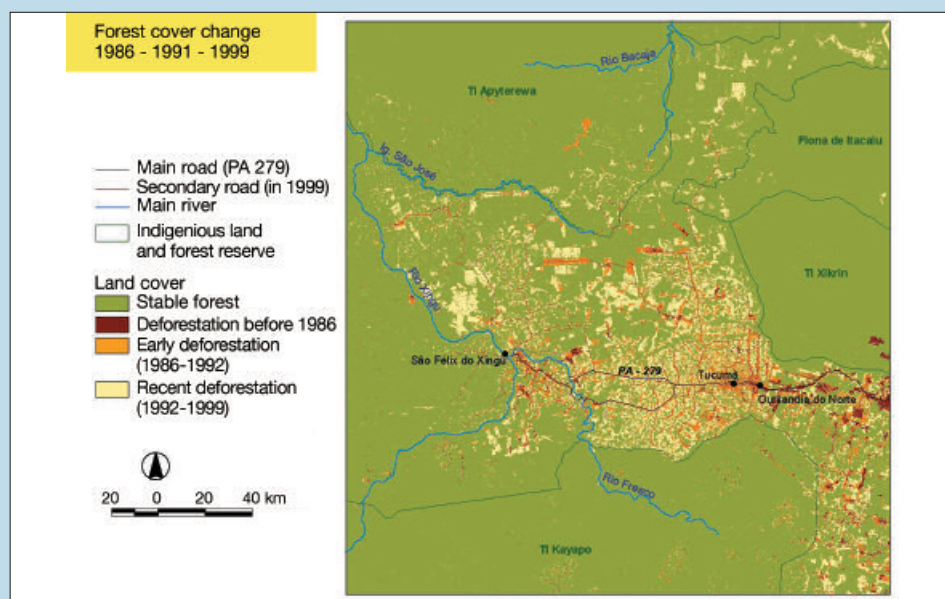


Figure 3.
Forest cover change in São Félix do Xingú.

The image taken in 1992 reveals drastic changes in the landscape. This period corresponds to the end of gold mining activities and most of the forest tracks are no longer visible, except in some areas in indigenous reserves. Larger pasture areas have replaced the small patches of clearings observed in 1986, tending to form a thin continuum along the secondary roads, which have been extended. A larger still unpaved road (PA-279) now serves São Félix do Xingú. The image analysis confirms the predominance of pasture. For this first period, from 1986 to 1992, the area of deforestation was 2 449 km² (Table I), which is 408 km².y⁻¹, or a yearly rate of deforestation of 0.74 percent.

A higher deforestation rate is measured for the period 1992-1999, when the yearly rate of deforestation reached 1.33 percent or nearly 700 km².y⁻¹. The area deforested from 1992 to 1999 was 4 899 km². Globally, from 1986 to 1999, the forested area converted to agriculture, mainly for pasture, totals 7 348 km² (Table I). In the core area, a continuum of pasture monoculture can be observed, with some remaining forest galleries along the rivers and small forest blocks as land or fertility reserves for producers (Figure 4). Producers now have little room to increase their property size. The number and size of the *fazendas* continued to increase and the 1992 isolated properties are now forming larger groups. Some land use patterns reveal the emerging conflicts or pressure over land, such as forest reserves surrounded by pasture in large exploitations (to protect them from invasion) and forest clearings in very isolated areas (more than 250 km from the PA-279) or in marginal mountainous areas. In response to the decreasing land availability in the core area, former logging and mining tracks have been rehabilitated, giving access to new forest land which colonists and *fazendeiros* can acquire through *grileiros*, who falsify the land titles. An extensive hierarchic secondary road

Table I.
Land cover and land cover change from 1986 to 1999 in São Félix do Xingú.

Land cover		1986	1992	1999
Forest	(km ²)	55 156,70	52 207,50	47 809,10
	(%)	98,10	93,70	85,10
Pasture/agriculture	(km ²)	491,40	2 940,60	7 839,10
	(%)	0,80	5,20	13,90
Deforestation ^a	(km ²)	2 449,10	4 898,40	
	(km ² .year ⁻¹)	408,20	699,70	
	(%.year ⁻¹)	0,74	1,33	
	(%.year ⁻¹) ^a	1,48	2,66	

^a For this adapted yearly rate of deforestation, the reference forest area corresponds to the forests that are likely to be affected by clearing, i.e. forest areas located outside indigenous and protected areas.

Table II.
Land cover and land cover change from 1986 to 1999 in Uruará.

Land cover		1986	1991	1999
Forest	(km ²)	9 577,50	9 342,90	8 705,50
	(%)	94,90	92,60	86,30
Pasture/agriculture	(km ²)	507,00	741,70	1 379,10
	(%)	5,00	7,30	13,70
Deforestation	(km ²)	234,70	637,30	
	(km ² .year ⁻¹)	46,90	79,60	
	(%.year ⁻¹)	0,490	0,85	

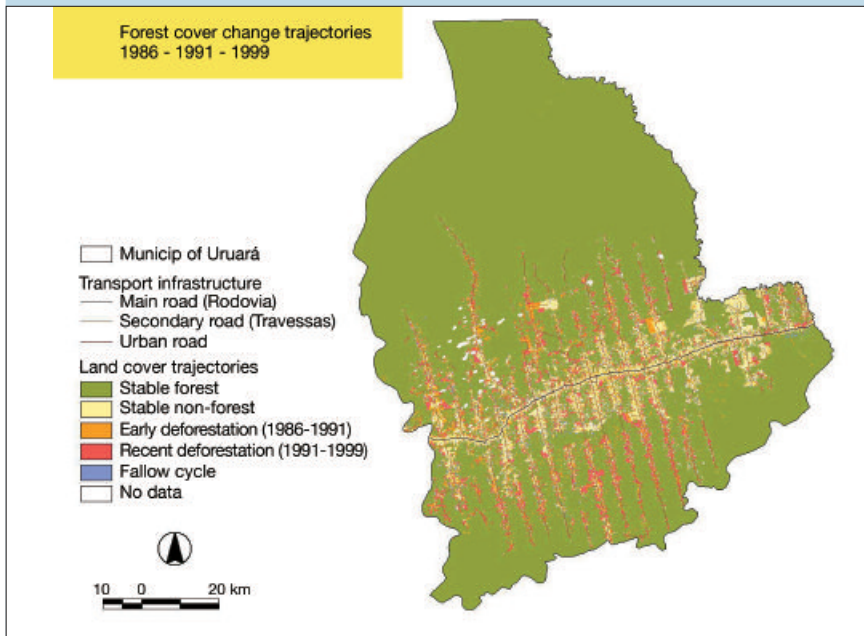


Figure 4.
Forest cover change in Uruará.

The region of Uruará

The county of Uruará is located in the central region of Pará (Figure 2), along the Transamazon Highway. The region covers about 10 080 km² and has a higher population density (4.2 inhabitants per km²), with around 30 percent of the population living in urban areas. From 1991 to 2000 the population almost doubled from 25 339 to 45 201 inhabitants (IBGE census data). Uruará is an older settlement frontier originally established in the 1970s as a farming colony along the Transamazon Highway. The population grew rapidly during the 1970s due to the state-directed initial colonization efforts. In the days of land distribution the INCRA provided 100 ha lots to individual households or migrants, who began clearing the forest for annual and perennial crops. Since then some land concentration has occurred.

network is developing. The main obstacles for clearing expansion are large rivers, which form obstacles to road construction and mobility, and conservation and indigenous reserves, which are increasingly surrounded by pasture but are still crossed by tracks for wood extraction.

São Félix do Xingú can be considered a recent agricultural frontier which is the focus of land speculation, cattle expansion and deforestation. Road construction, investments in electrical energy, rapid increases in credit for cattle since 1981 and the land reform policies of the *Instituto Nacional de Colonização e Reforma Agraria* (INCRA) have all fuelled this process. All these factors make this region one of the most dynamic agricultural frontiers in the Brazilian Amazon. Cattle ranching is by far the dominant land use in the region, which recorded one of the highest growths in cattle herds. A high proportion of the cattle production is exported to other states since the region has access to important national consumption markets for beef and dairy products.



Recent clearing in São Félix do Xingú.
Photo B. Mertens.

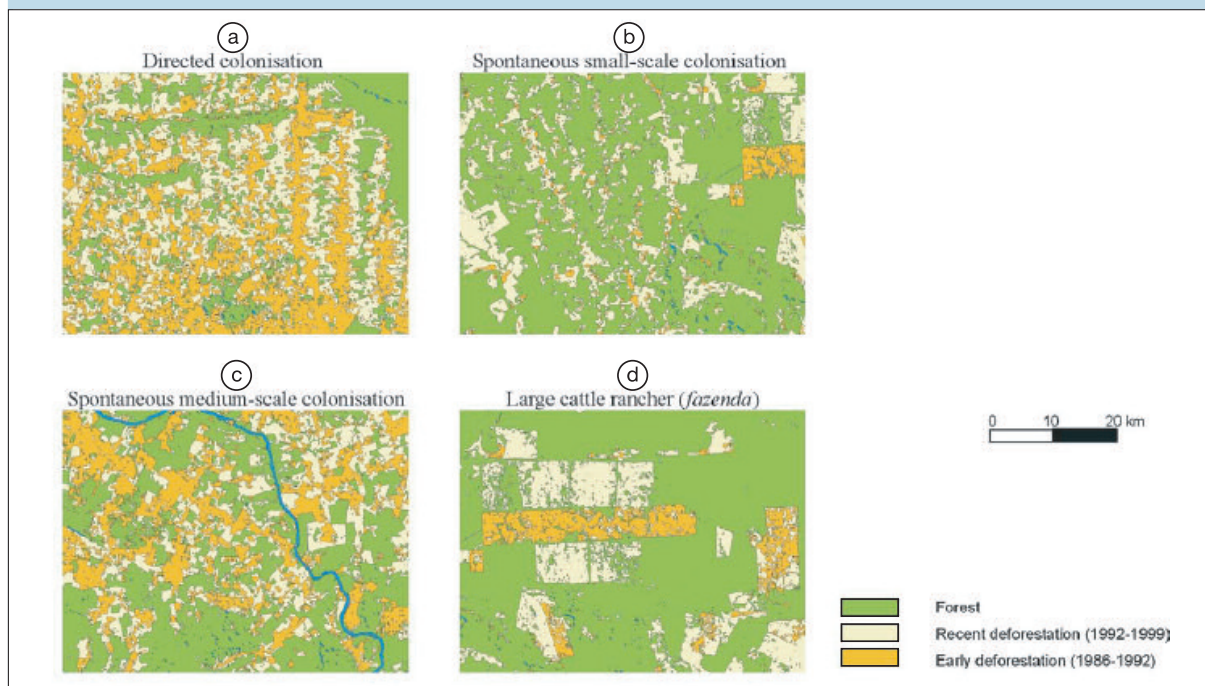


Figure 5.
Dominant patterns of forest cover change in São Félix do Xingú.

In the 1980s the economy boomed as a result of the high prices for cocoa, pepper and coffee, which attracted even more migrants. Again, time series of satellite images allow the characterization of the land use dynamics that took place in the region (Figure 5). In 1986, the fish-bone pattern of the secondary road network is already well established, as it was originally initiated by the government policies. Secondary roads, or *travessões*, are crossroads running north and south off the main road to distances of about 30 km. About 500 km² of pasture and crops were established along the main road and these secondary roads. Annual and perennial crops accounted respectively for 3.5 and 15.7 percent of the total non-forest area. Some large *fazendas* were established, mostly in the eastern part of the county, accounting for about 20 percent of non-forest areas.

From 1986 to 1991 the area of deforestation was 235 km², which is 47 km².y⁻¹, or a yearly rate of deforestation of 0.49 percent. The image analyses reveal that most of the land use changes concerned perennial crops. Annual and perennial crops

accounted respectively for 1.9 and 31.2 percent of total non-forest area. The price of pepper still remained high and provided good returns per hectare even on poor soils. Few new large-scale properties were created, and a small extension of the existing *fazendas* can be observed. Most of the deforestation areas are located close to the main road and to a lesser extent along the secondary roads.

In the 1990s decreasing market prices for key crops, as well as crop-specific diseases such as *Crinipellis pernicioso* in cocoa and *Fusarium s. piperi* in black pepper, resulted in bankruptcies among more specialized farmers, and led many landholders to reorient their farming systems toward pasture for cattle. This period showed the emergence of medium-size landholders who took advantage of these events to acquire cheap land and constitute small *fazendas* (hundreds of hectares).

The last period, from 1991 to 1999, is characterized by drastic landscape and land use changes. The area of deforestation was 637 km², which is about 80 km².y⁻¹, or a yearly rate of deforestation of 0.85 percent. Most of the forest clearings are located along

the secondary roads, affecting areas located far from the Transamazon Highway. Land use change analyses reveal a small increase in the annual crops (4 percent of the non-forest area), but a sharp decrease of the perennial crop area, falling to 0.6 percent of the non-forest area. However, the agricultural census of 1996 indicates a higher proportion of temporary and permanent crops, which still accounted for about 17 percent of all deforested areas (IBGE, 1996). These results seem to confirm the major shift of the farming systems toward pasture for cattle, or at least a higher integration of pasture within diversified production systems.

The county of Uruará can be considered an older agricultural frontier mostly characterized by the state-directed colonization scheme and a high proportion of small-scale subsistence farmers with imperfect market access (WALKER *et al.*, 2002). Farming systems tend to be more diversified, typically including annuals (such as rice and beans), perennials (cocoa, pepper and coffee) and pasture. Livestock activities, for meat and dairy products, became the dominant land use in the region.



Cocoa field.
Photo A.-E. Lacques.

Spatial and temporal variability: evidence from econometric land use change models

Spatial statistical models are useful tools for identifying and evaluating the relationship between deforestation and spatially explicit explanatory variables such as accessibility, biophysical conditions, land tenure and zoning restrictions. These models are well suited for understanding where deforestation is more likely to occur in the future and therefore where policies aimed at reducing deforestation should be applied.

Binary and multinomial logistic regression models were run for each period and study area. This method is used to model how the value of a set of independent variables affects the presence or absence of deforestation. The independent variables considered aim to capture the main biophysical and socio-economic explanatory factors that are likely to influence the patterns and/or the intensity of deforestation². The overall fits of the models are significant for all periods, with *pseudo-R*² ranging from 0.29 to 0.48. It should be remembered that such models do not claim to explain all the causes of land

use changes but only those related to spatially referenced variables. The parameter estimates and associated statistics provide information on the impact and relative importance of the selected variables in explaining the deforestation patterns observed.

In the case of São Félix do Xingú, spatial and statistical results indicate that prior to 1986 there was little deforestation in the forest reserves and mountainous areas. Forest clearings, mostly for pasture, tend to be located close to the main road, and far from the villages. Note that most of the villages existing before 1986 were remote mining centres, located far from the towns and the main road, which did not lead to further forest conversions after the gold rush. The 1980s correspond to the beginning of the colonization of the counties of São Félix do Xingú and Tucumã.

Over the second period (1986-1992), deforestation still tends to be located outside the reserve areas and the mountainous areas, far from the villages and close to the main road. But the agricultural frontier is progressively moving to more western and remote forested areas. Most deforestation tends to be located near existing cleared areas, illustra-

ting the spread effect of deforestation. Similarly, the occurrence of deforestation is increasingly associated with the proximity to the emerging networks of dairy industries and secondary roads.

Finally, over the third period (1992-1999), agricultural and pasture areas are spreading around previously deforested areas, and along the network of secondary roads and near dairy industries (related to the improved marketing networks). The reserve areas continue to show little deforestation, while the mountainous areas, still constraints for forest conversion to other land use, are becoming increasingly affected by deforestation as the pressure on land increased (TOURRAND *et al.*, 2004).

In the case of Uruará, forest clearings before 1986 tended to be concentrated along the recently constructed secondary road network, along the main road and near the city of Uruará. Areas characterized by soils that have a higher aptitude for agriculture (*terra roxa*) are more affected by forest clearing. The importance of perennial crops continued to increase during the second period (1986-1991). Most of the large *fazendas* were created in the early 1980s. The occurrence of deforestation is less associated with the proximity to the city and the main road. The proximity to secondary roads remains the main explanatory factor for deforestation, which corresponds to the extension of previously deforested areas and new clearings farther away from the main road. The presence of good soils no longer appears as a significant factor.

During the last period, deforestation is even more closely associated with the proximity to secondary roads and previously deforested areas. As land scarcity increased near the main road, most of the clearing took place in more remote areas at the end of the secondary roads. The distance from the main road and the city is no longer significant. This pattern is also due to the sharp decrease of the perennial crops as compared to pasture areas in the 1990s.

² A full description of the statistical analyses, modelling framework and specifications can be found in MERTENS *et al.* (2002).



Forest landscape between São Félix do Xingú and Uruará.
Photo A.-E. Lacques.

Conclusion

The land use change analysis in the two regions shows quite distinct results with regards to colonization history, deforestation patterns and associated factors. The spatial statistical models have highlighted the fact that explanatory variables such as the access to markets or the proximity to the roads, and the presence of soils of different aptitude, influence deforestation in different ways depending on the stage of development of the frontier area (or the time period) and the type of producers considered. In both regions pasture expansion remains the major driver of deforestation, although the region of Uruará experienced more complex land use trajectories compared to São Félix do Xingú.

Road construction in these remote forested areas unambiguously increased the incentives to convert them to other uses by offering improved marketing opportunities and lowering the cost of migration, access and land clearing (either for productive or speculative purposes). Some similar results are found in both regions with regards to the impact of roads on land use change. The main road seems to influence the first step of the colonization process, principally providing access to the increasing demand from remote markets, while more recent clearings tend to be associated with the emerging secondary road network. In both regions the secondary roads are still unpaved and not always passable during the rainy season. However,

while maintenance and improvement of the main road depends mainly on public policies, the secondary road network is mostly linked with local or regional strategies and private decisions such as mining, logging and commercialisation. Therefore, the “robust forecasts” on the future rate and pattern of deforestation that would follow road development, such as the estimated impacts of the *Avança Brasil* program (e.g., LAURANCE *et al.*, 2001), should be treated with caution. These predictions ignore the spatial and temporal variability of the road impact on land use change and probably overestimate the impact of public investment.

Road development appears to be important in explaining deforestation processes due to small-scale colonization, but less significant for large-scale deforestation (*fazendas*). This in fact highlights once again a specificity of the livestock sector in comparison with other agricultural sectors, which is that transport is not a significant constraint for large-scale cattle ranching. So why is large-scale deforestation so important in São Félix do Xingú but less important (and to some extent “negligible” during the last period) in Uruará? Part of the answer can be found in the patterns and evolution of livestock production and marketing chains. Land tenure, systems of fiscal and credit incentives and infrastructure, different in the two regions, have to a large extent shaped the characteristics of the agricultural frontier evolution.

São Félix do Xingú belongs to the Southern Pará region where the livestock sector is very dynamic and competitive, resulting in the establishment of large slaughterhouses oriented toward the growing consumption markets in the northeast, and more recently in the southern markets. This may stimulate both intensification of cattle production, particularly close to the slaughterhouses and the main road, as well as extensive production systems through new forest clearings. This process particularly affects remote areas such as São Félix do Xingú where cheap forest land is still available.

In contrast, small-farmers in Uruará do not place their trust exclusively in cattle as a way to improve their livelihoods. Few slaughterhouses have been established along the Transamazon Highway and cattle are still exported by river to northern and northeastern markets through Altamira and Santarém. Demand remains low, although this could change rapidly as there are already plans to build a slaughterhouse in Altamira. In the near future these changes could lead to a major increase of large-scale pasture expansion and result in a complete reorganization of the landscape, as found in Southern Pará (POCCARD-CHAPUIS, 2003). However, land markets in Uruará and São Félix do Xingú are completely different. Small- or medium-scale landholders are already well established in the region of Uruará and may be more reluctant to sell their land to new investors. This means that the extension of large-scale cattle ranching may only affect remote and marginal land.

Land tenure policies are often mentioned as a tool for preventing deforestation when farmers are clearing land in order to secure property rights, although several studies on the determinants of the rate of deforestation by smallholders at the property levels tend to find that those with secure land tenure do not deforest less (e.g., WALKER *et al.*, 2002). This study tends to confirm this result. In Uruará, where most of the smallholders have secure property rights, defor-

References

estation has tended to increase over time. In São Félix do Xingú, farmers with secure land tenure seem to be protected from land concentration but do not deforest less (MERTENS *et al.*, 2002). The issue is more complex for large-scale properties, as large landholders consider that forest clearing often prevents potential expropriation or invasion from landless people (e.g., VEIGA *et al.*, 2001; FEARNside, 2001). For this particular segment of landholders, it is clear that the impact on deforestation of obtaining secure land tenure requires further examination, particularly in such dynamic frontier areas as São Félix do Xingú.

We have examined the influence of soil quality only in Uruará. Results indicate that the impact of soil quality has varied over time. This is probably related to the cocoa cycle, which is strongly influenced by price fluctuations. Periods of booming prices are followed by the extension of cocoa production, while decreasing prices coincide with a decrease in the area planted and the expansion of pasture, which is itself influenced by other variables. Therefore, soil aptitude is likely to influence the rate and location of deforestation for perennial farming systems (specifically cocoa) but does not limit deforestation for pasture expansion. This is due to the increasing flexibility of pasture management and its greater adaptability to different soil quality.

Overall, the increasing population and livestock activities, the development of a secondary road network, the creation of new colonization zones and the resulting pressure on land make remote and marginalized areas more attractive for migrants. Even though improved accessibility has resulted in increased pressure on forest reserves, it seems that the conservation areas are reasonably well preserved from deforestation, as shown in the region of São Félix do Xingú. This does not seem to be true in relation to forest degradation, as logging exploitation has affected all the forests in the study area, both inside and outside the forest reserves.

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