Geoforum 43 (2012) 864–874

Contents lists available at SciVerse ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Actor and frontier types in the Brazilian Amazon: Assessing interactions and outcomes associated with frontier expansion

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ARTICLE INFO

Article history:
Received 4 July 2009
Received in revised form 26 December 2011
Available online 14 March 2012

Keywords:
Brazil
Amazon
Frontier development
Agrarian change
Deforestation
Cattle ranching

ABSTRACT

This paper analyzes frontier expansion in the Brazilian Amazon as a process that depends on multiple exogenous and endogenous factors operating at diverse scales, but whose trajectory depends on the dominant actor type (smallholders or medium- or large-scale landholders) occupying the frontier landscape. Despite the broad growing trend of pasture expansion for adoption of cattle ranching as the main land use associated with frontier expansion, some differences persist across actor types. In relative terms, medium- and large-scale landholders place most of their cleared forestland under pasture, and in absolute terms, largeholders have deforested more than smallholders because they hold larger tracts of land. Recently, however, deforestation activity has been increasing in frontiers occupied by smallholders who tend to convert a greater proportion of the forestland in their landholdings to agricultural land uses than larger-scale landholders, mainly to expand cattle ranching operations. Furthermore, smallholders tend to maintain higher cattle stocking rates than medium- and large-scale landholders, which tend to adopt extensive systems of cattle production. Both economic and human development indices in each frontier type vary according to actor type. While in absolute terms, higher per capita agricultural income levels are found in frontiers where largeholders predominate, the corresponding incomes are higher in smallholder frontiers when prorated by unit of land under crops and pasture. In addition, the Human Development Index is higher in frontiers with greater presence of large-scale landholdings.

1. Introduction

In the Brazilian Amazon, the debate about economic growth, social development, and forest conservation is closely related to the discussion of the boom-and-bust cycles that characterize the evolution of logging and agricultural frontiers (see Rodrigues et al., 2009; Schneider et al., 2000), the expansion of which occurs to the detriment of extractive and conservation landscapes (Pacheco et al., 2011). Frontier expansion is understood here as the result of a process of progressive occupation of forestland by different actors that often have competing claims over the land (Schmink and Wood, 1992). This process often leads to the appropriation of forestlands, followed by the removal of forest resources for conversion of land to agricultural uses (Andersen et al., 2002). Frontier evolution, in its initial stages, can be interpreted as a process of primitive accumulation; this process, largely motivated by an interest in extracting the existing natural resources (e.g. soil and forests), tends to evolve toward more productive ways of using the land along with frontier consolidation (Kaimowitz, 2002).

The contemporary concept of frontier development involves economic and political aims of integrating into the mainstream national economy territories that are considered unoccupied or idle lands (Dreifuss, 2000). In the Brazilian Amazon, economic goals revolve around establishing and consolidating claims over natural resources, with the aim of generating incomes from exploiting such resources and subsuming their use into broader circuits of capital, labor, and exchange of goods. Yet emerging conservation aims have put into question conventional economic goals, thus highlighting the value of forest ecological services (Nepstad et al., 2011). The political goal of frontier expansion is to include frontier areas within the political domain of the nation-state. Nevertheless, frontier evolution raises challenges in terms of the distribution of benefits derived from natural resources use, creates social conflicts, and tends to deplete such resources in the long term. In some cases, it threatens the livelihoods of the frontier's original inhabitants. Although tenure and land use policies designed to improve the protection of local tenure rights and improve forest conservation have recently been devised, little effort has been invested in enhancing the productivity of already occupied land (Borner et al., 2010).

In this paper, I assess the interplay between frontier and actor types, focusing on the Brazilian Amazon and exploring implications for deforestation, agricultural income, and human development at

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doi:10.1016/j.geoforum.2012.02.003

the municipal level. Various labels have been coined to describe frontier attributes, such as pioneer and consolidated (Schneider, 1995), productive and speculative (Margulis, 2004), contested (Schmink and Wood, 1992), and populist and corporatist (Browder and Godfrey, 1997). I argue that frontier development constitutes a multidimensional process influenced by factors taking place at different scales, and leads to different outcomes depending on both frontier and actor types. This view builds upon emerging explanatory perspectives looking for integrated approaches to understanding nature–society interactions (Batterbury et al., 1997; Roy Chowdhury and Turner, 2006).

At the macro-level, policy shifts and market structures largely define the pattern of capital accumulation taking place in the frontiers. However, a diverse set of decision parameters affects land occupation and use at the micro-level, defining the adopted production systems and resultant land uses (Kaimowitz and Angelsen, 1998). I argue that the interactions between these factors shape frontier configuration, in relation to both frontier and actor types, with impacts on deforestation and local development.

In this light, I adopt a perspective that, on the one side, observes different stages of frontier evolution (i.e., pre-frontier, frontier, post-frontier) and on the other side looks at different actor types (i.e., smallholders, medium- or large-scale landholders) along the different stages of frontier evolution. While smallholders in the initial stages of frontier expansion adopt more diversified production systems with a mix of crops, secondary forest succession, and primary forests, frontiers dominated by large-scale landholders tend to undergo massive forest conversion for extensive cattle ranching. However, whichever way the frontier evolves, landscapes suffer from greater homogenization of land uses due to the growing expansion of pastureland at the expense of forest cover.

In addition, smallholder frontier types tend to distribute income more equitably. Rural economic income measured by the agricultural gross domestic product (GDP) is higher in landscapes with a greater presence of medium- and large-scale landholders when estimated on a per capita basis, but it is higher in smallholder frontiers when prorated by unit of agricultural land. Furthermore, the Human Development Index (HDI) tends to be higher in landscapes dominated by largeholders, although the differences across frontiers when looking at actor types are not significant. Rodrigues et al. (2009), comparing frontiers, argue that boom-and-bust patterns occur in the Brazilian Amazon because the HDI is higher in frontiers with greater deforestation activity and tends to decline in post-frontier situations, in which a larger proportion of the landscape has been deforested. Nonetheless, the latter does not appear to be an overall trend since differences emerge when considering the type of actor using the land in those frontiers.

This paper is organized in six parts including this introduction. In the second part, I discuss the methods and data sources employed for the analysis undertaken in this paper. The third part contains a literature review with regard to the main factors shaping the formation and development of frontiers. In the fourth part, I assess the interactions between actor and frontier types, and their main outcomes in terms of land use and cattle ranching expansion. I then explore the outcomes of frontier development according to the characteristics of the main actors occupying the frontier landscapes, and discuss their impacts on deforestation and agricultural income. In the final part, I present the paper's main conclusion, with some reflections relevant for policy-making.

2. Methods and data sources

The analysis in this paper is based on several methods: literature review, interviews with key informants, and analysis of secondary statistical information. The main data sources are the two most recent agricultural censuses carried out by the Brazilian Institute of Geography and Statistics (IBGE) in 1995/1996 and 2006, and land use change data estimates from remote sensing analysis performed by the National Institute for Space Research (INPE) (Fig. 1). The previous agricultural censuses and land use change data are complemented with secondary information acquired during fieldwork undertaken in the Brazilian Amazon region in two periods, 2003–2004 and 2009–2010.

Despite some shortcomings, the agricultural census data comprise the most comprehensive source of information, disaggregated at the municipal level, for determining socioeconomic trends across the whole Brazilian Amazon. Although in theory the census constitutes a complete count of all agricultural holdings, this is not necessarily true in practice. The main shortcoming of the census relates to its coverage, particularly of remote areas which likely are not included in the census. Nonetheless, it is difficult to quantify the extent of the shortcomings of the two IBGE agricultural censuses employed in this analysis because of the lack of reports assessing the problem.

I classify the various frontiers and actors in order to assess the differentiated implications of different stages of frontier development across actor types. Frontier types are classified based on the extent of converted forests, at the municipal level, as a proxy of frontier evolution. Landscapes are then classified according to the dominant actor type (i.e. small-, medium- and large-scale landholders). In the following, I describe the main criteria used for classifying frontier and actor types in the Brazilian Amazon.

Frontier types are classified following the criteria adopted by Rodrigues et al. (2009), who define frontiers (in a range from inactive to active) according to the extent of deforestation that has occurred in each municipality. Thus, I classify frontier types based on the percentage of the original forest cover that had been lost in each municipality by 2009, according to INPE estimates. Each type corresponds to a quintile of forest cover loss by 2009 (i.e. less than 20%, 20–40%, 40–60%, 60–80%, and more than 80%) (Fig. 2). These ranges correspond to different stages of deforestation. I assume that they are correlated with the timing of frontier occupation, so that they correspond to a transition ranging from pre-frontier to active frontier to post-frontier situations.

To identify the dominant actor type, I use the distribution of landholding sizes reported at the municipal level in the 2006 IBGE Agricultural Census. I adopt the following classification of actor types: (1) smallholders (holding plots smaller than 100 ha); (2) medium-scale landholders (landholdings between 100 and 1000 ha); and (3) large-scale landholders (establishments larger than 1000 ha). To compare data available at the municipal level and actor types, I build a typology of municipalities based on the dominant landholder types located in each municipality (Fig. 3). As the proportions of landholder types differ across municipalities in the region, some thresholds were defined according to the ranges at which these different actors occur at the municipal level. A detailed explanation is provided with the analysis in Section 5 (Table 3).

Finally, I link the census data from IBGE with land use change data from INPE, which is based on remote sensing analysis to 2009, mainly to identify the outcomes in terms of deforestation and local development across different combinations of frontier development according to the dominant actor established at the municipal level.

The method adopted for the analysis undertaken in this paper has some limitations, in that it includes some fuzzy classifications of both frontier and actor types, with no clear boundaries between groups. Nevertheless, due to the availability of existing data, it provides an indication about the interactions established between frontier evolution, deforestation, and economic and human

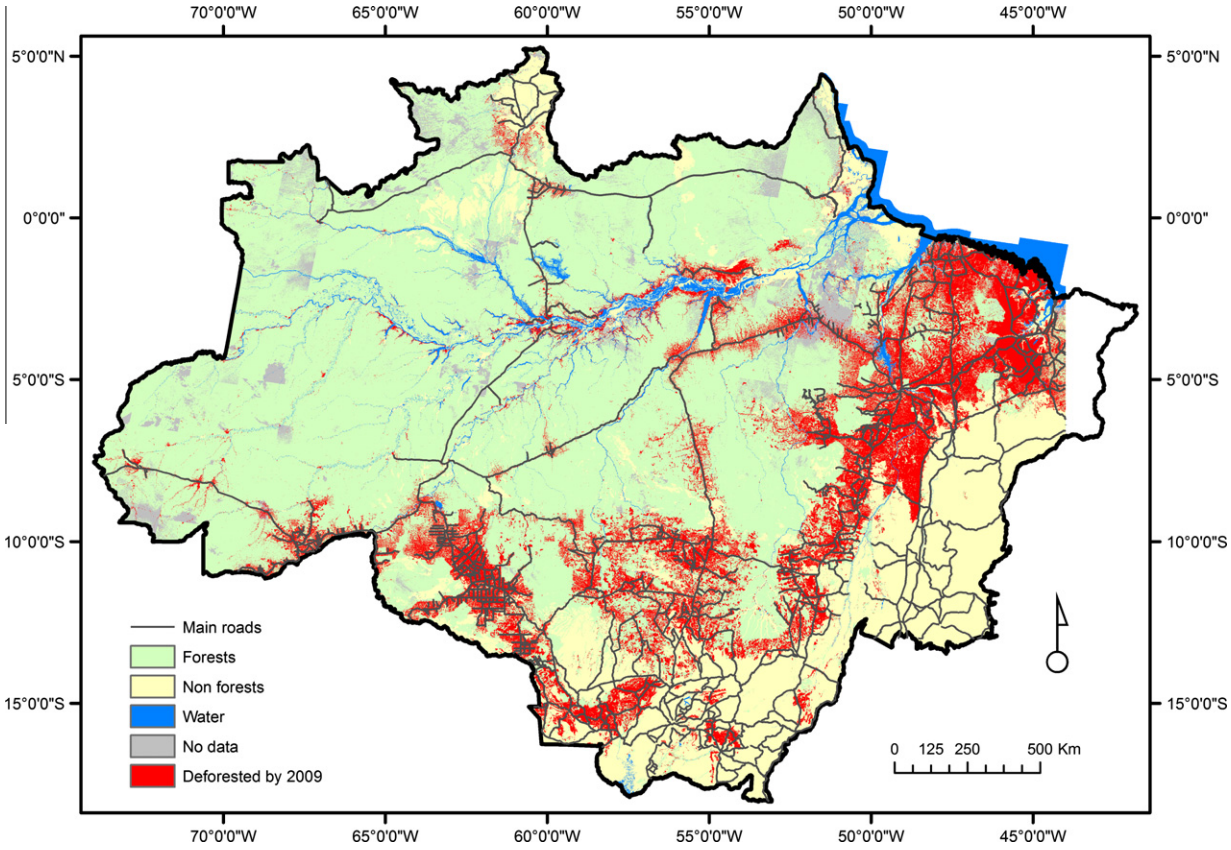

Fig. 1. Land use in the Brazilian Legal Amazon in 2009. Author's elaboration based on deforestation estimates from INPE.

development taking place region-wide, mediated by actor type, which otherwise would not be possible to assess.

3. Review of the factors shaping frontier expansion

It has been argued elsewhere that the nature–society interactions that induce landscape change are complex, and that the interactions taking place at one scale (e.g. national or regional) are not necessarily those operating at other scales (e.g. individual or community levels) (Rindfuss et al., 2004). This geographic "truth" has paramount importance in the Amazon's development and conservation debate because issues and viewpoints have often been evaluated at one spatial scale and then extrapolated to other scales. In this study, I propose that the development trajectories of frontiers—framing this discussion for the case of the Brazilian Amazon—and their implications for people and landscape change constitute both a multiscale and a multidimensional phenomenon, approaches that are central to land-change science (Gutman et al., 2004).

Frontier development is assessed here as a multidimensional process that results from political, institutional, and market forces operating at the macro-level, and agency decision-making operating at the micro-level. At the macro-level, policy decisions affect the allocation of public investment, incentive structures, and exchange and interest rates. Furthermore, institutional conditions such as those that define landownership and governance systems for natural resources management also operate at this scale, along with market conditions linked to demand and supply of goods and financial resources (Wunder, 2004). A different set of factors defining resources use and allocation operate at the micro-level. These factors include household life cycles, access to resources and markets, adoption of available technology, and biophysical setting and constraints (e.g. precipitation, soil quality) (Browder et al., 2004; Moran et al., 2000; Perz and Walker, 2002; Pichón et al., 2003; Kaimowitz and Angelsen, 1998).

At the macro-level, the main motivation for occupying the frontier is the economic interest in transforming natural resources into commodities (e.g. land, timber resources, minerals, genetic resources, carbon) and articulating these to broader circuits of exchange in the markets (Kaimowitz, 2002). Other factors driving this expansion include lack of land, poverty, and violence in other regions, which motivate the displacement of people to frontier areas in search of new opportunities, as well as geopolitical interests in sovereignty (Hecht and Cockburn, 1989). However, the way in which natural resources are appropriated and commoditized, and the determination of which actor captures the benefits in frontier areas, is a process mediated by policy decisions and power relationships (Schmink and Wood, 1992).

Public policies influence institutional decisions about how public land is allocated, either by inaction allowing squatting, or through the allocation of land for conservation, forest reserves, colonization, and agribusiness. Policies also define the amount of resources that are transferred to frontier areas through public investment (e.g., roads, electricity, and other services), fiscal incentives, and credit. In this regard, access to or ownership of land makes it possible for landholders to benefit from institutional rents provided by the state such as access to incentives, credit flows, and road infrastructure that facilitates access to markets. The appropriation of institutional rents tends to stimulate land speculation driven by expectations of benefits not only from resources use but also from state subsidies (Hecht, 1985). Indeed, it is difficult to

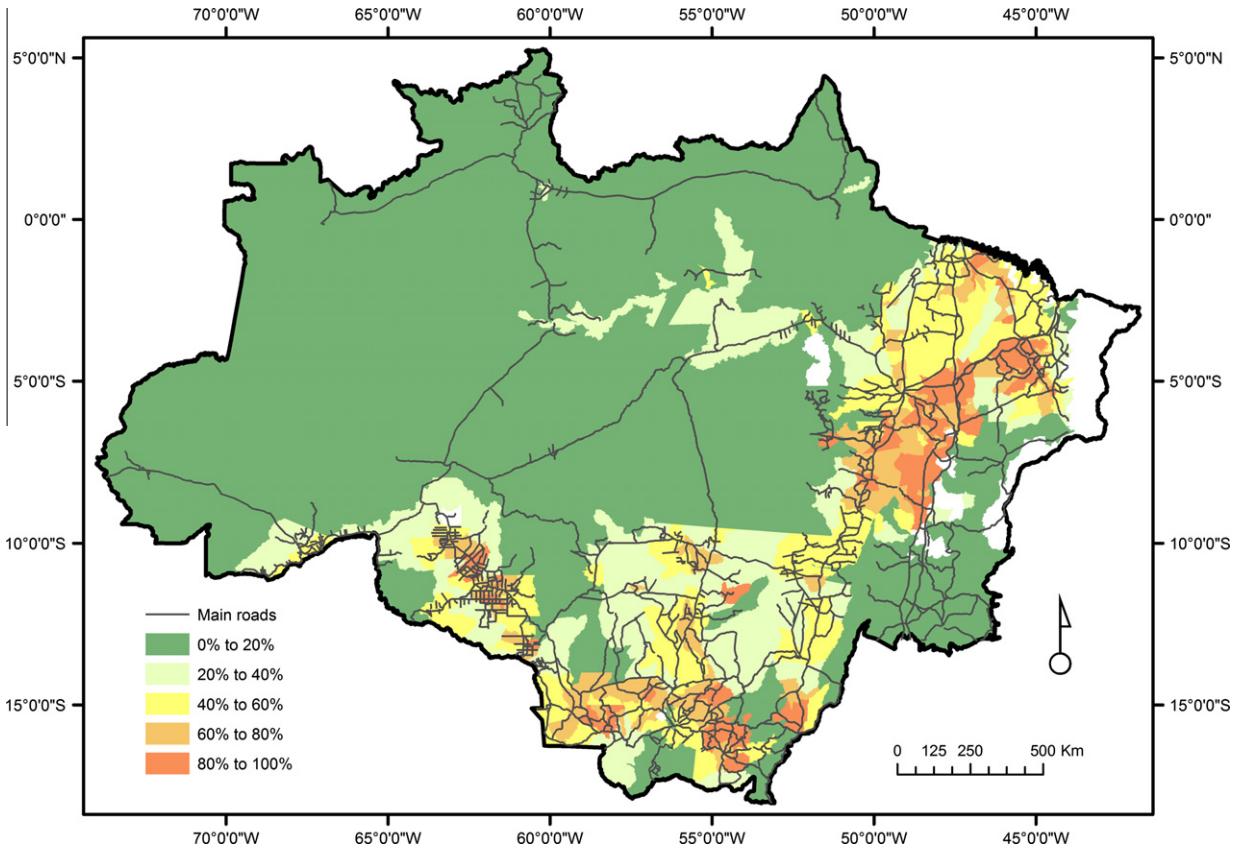

Fig. 2. Proportion of deforested area in 2009 by municipality in the Brazilian Legal Amazon. Author's elaboration based on deforestation estimates from the National Institute for Space Research (INPE).

imagine a frontier without rent-seeking behaviors and speculation because these constitute an easy way of obtaining economic rent without significant investment (Kaimowitz, 2002).

Furthermore, public policies affect macro-variables such as currency rates and interest rates, which in turn influence investment decisions. Private investment in processing facilities, such as in slaughterhouses and dairy plants, plays an important role in stimulating production in frontier areas (Poccard-Chapuis, 2004). Market conditions and prices also influence demand by affecting access to international markets. In turn, investment decisions are largely influenced by both domestic and foreign market demand—which in turn depends on population growth and income—which makes investment in either beef or crop production more attractive (Nepstad et al., 2006; Poccard-Chapuis et al., 2001). The increased market integration of the Amazon region means that global and domestic markets have a greater influence on fueling investments, not only in production of soybean and beef, but also in processing and transportation facilities (Walker et al., 2009).

Other factors working at this level that influence frontier expansion are primarily linked to public policy decisions about road construction, land distribution in the frontiers, and economic incentives. The location, extent, and shape of the road network are important features determining the spatial pattern of land occupation (Perz et al., 2007; Pfaff, 1999). Land distribution policies in turn tend to influence the balance between smallholders and largeholders, because allocation of land through colonization encourages smallholders and landless people to settle, whereas sale of public land tends to benefit only firms or individuals that have sufficient resources to buy large tracts of land (Binswanger, 1991). Finally, as noted above, economic incentives play a significant role in influencing households' decision-making regarding land use portfolios because such incentives tend to affect the relative profitability of certain land uses, and thus the economic benefits obtained (Andersen et al., 2002; Vosti et al., 2003).

At the micro-level, agents have different objectives. Their final decisions on production and land use are mediated by several parameters linked to land availability, output prices, labor costs, available technology, traditional knowledge and information, and environmental factors such as climate and rainfall. Household demographics, such as available family labor and dependency rates, also influence the allocation of land and other productive factors (Perz and Walker, 2002; Walker et al., 2002). It is important to stress that no actor type—neither smallholders nor medium- or large-scale cattle ranchers—is an internally homogeneous groups that displays uniform responses to policy and market incentives (Aldrich et al., 2006; Walker et al., 2000).

Differences in smallholders' land use behavior are mainly explained by the quality and quantity of land available, family labor and capital, and location variables that determine access to markets. By contrast, characteristics that differentiate medium- and large-scale cattle ranchers include the scale of their operations, their management systems, and the availability of capital. Furthermore, for medium- and large-scale ranchers, land speculation, as well as production, is a common motivator of land use decisions. In the early years of frontier occupation, land speculation driven by potential fiscal incentives (subsidy-seeking speculation) was important (Almeida and Campari, 1995). Although this type of speculation persists today, it has increasingly given way to speculation based on anticipated increases in the marketable value of land.

It is noteworthy that processes operating at macro- and micro-levels also change over time. At the macro-level, the increase in the

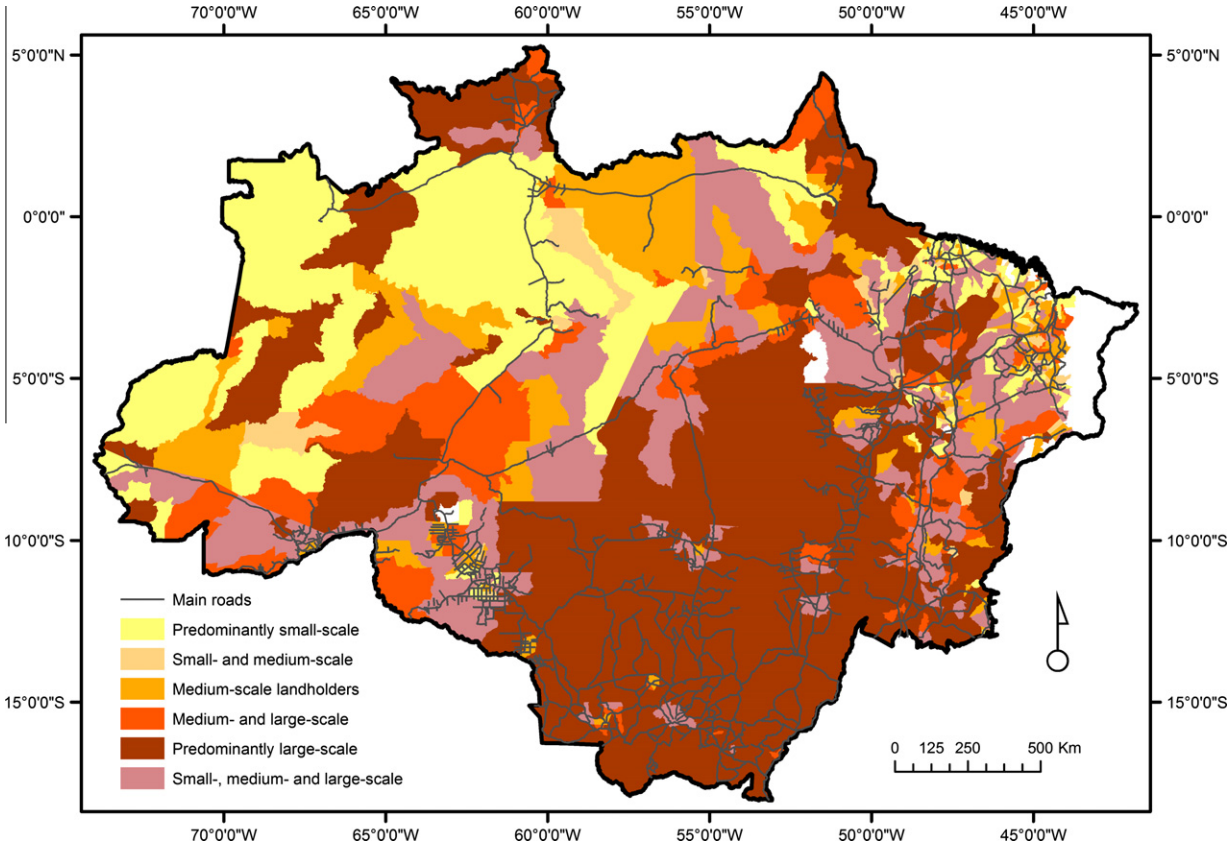

Fig. 3. Predominant type of landholdings by municipality in the Brazilian Legal Amazon based on total landholding size according to the IBGE 2006 Agricultural Census. Author's elaboration.

number of cattle has been driven by urban demand for meat and dairy products, in turn shaped by the restructuring of supply channels, including the increasing role of supermarkets (Poccard-Chapuis, 2004). Monetary policies affecting currency rates have influenced the competitiveness of the cattle industry in foreign markets (Kaimowitz et al., 2004). This dynamic interacts with others factors such as the expansion of the road network and the construction of slaughterhouses and meat-packing plants in production zones (da Veiga et al., 2004); these stimulate the already growing demand, thus creating incentives for farmers to expand beef production. Furthermore, improved access to international grain markets has stimulated soybean production in frontier areas, creating another powerful incentive for land use substitution (Vera et al., 2008). At the micro-level, wealthier farmers often take greater advantage of market incentives for cattle and soybean production designed for smallholders (Pacheco, 2009a). These various factors and interactions are further characterized by complex causal relationships, which are difficult to determine.

4. Actor types across the Amazon deforestation frontier

Different types of economic frontier can be identified, particularly based on the natural resources present, that is, mining, timber, and agricultural frontiers. This paper focuses on agricultural frontiers, which differ from other frontiers in that they tend to demand more substantial alterations of natural habitats and involve larger population flows. In addition, the global significance of the cumulative effects of deforestation for biodiversity conservation, and associated impacts on local and global environmental change means that tropical agricultural frontiers are attracting considerable attention (Lambin et al., 2001; Nepstad et al., 2011). Given the wide range of economic activities, social groups, and levels of wealth involved, making generalizations about frontier types might seem a fruitless exercise. However, defining frontier types may prove a useful explanatory process that could guide formulation of policy designed to influence future land use trajectories, with impacts on livelihoods and economic growth. Several approaches to describing frontiers have been tested, and some typologies provided.

Conventional approaches identify two types of frontiers according to their stage of development: pioneer and consolidated (Schneider, 1995). Pioneer frontiers are dominated by high discount rates, relatively high land turnover rates, extended land speculation, and deforestation in order to claim land rights rather than for production purposes. Margulis (2004) stresses that pioneer frontiers involve speculative land grabbing based on expectations of profit from resale. By contrast, consolidated frontiers, which constitute older frontier settings, are characterized by enlargement of profits through investment of capital in productive agricultural activities. Others consider that a direct correspondence exists between frontier development and governance, with greater levels of governance to the extent that frontier evolves (Nepstad et al., 2002).

An alternative approach to differentiating Amazonian frontiers is offered by Browder and Godfrey (1997), who distinguish between populist and corporatist frontiers. In their view, populist frontiers are characterized by colonization from smallholders, independent miners, petty merchants, and others engaged in various forms of labor-intensive activity. The corporatist frontier, by contrast, is dominated by capitalized enterprises pursuing activities such as cattle ranching, agribusiness, and large-scale

Table 1
Establishments, land use, and cattle herds in the Brazilian Legal Amazon by actor type, 1995/1996 and 2006. *Source:* Author's elaboration based on IBGE 1995/1996 and 2006 Agricultural Censuses.

Selected indicators	Main actor types according to landholding size			
	Small-scale (Less than 100 ha)	Medium-scale (100–1000 ha)	Large-scale (More than 1000 ha)	Total
In 1995/1996				
No. of establishments (thousand)	643	127	18	788
Average size (ha)	21	240	4190	150
Total land (thousand ha)	13,232	30,346	74,684	118,262
Total pastureland (thousand ha)	4147	14,526	31,796	50,469
Total cleared forestland (thousand ha)	6988	13,680	26,572	47,240
Cattle herd (thousand head)	5811	12,319	16,986	35,117
Stocking rate (head/ha)	1.4	0.8	0.5	0.7
In 2006				
No. of establishments (thousand)	573	124	18	715
Average size (ha)	26	247	3373	149
Total land (thousand ha)	14,654	30,645	61,373	106,672
Total pastureland (thousand ha)	7554	16,873	29,016	53,443
Total cleared forestland (thousand ha)	8786	16,761	28,873	54,420
Cattle herd (thousand head)	12,121	20,044	23,277	55,443
Stocking rate (head/ha)	1.6	1.2	0.8	1.0

extraction of timber or minerals. Each frontier type has its own logic of spatial organization. The reality, however, may more resemble a continuum in which intermediate frontiers comprise a mix of corporatist cattle ranching and medium-scale traditional and modernized cattle ranching. The admixture of types often tends to generate contested claims over property rights and access to natural resources as documented for some frontiers in southern Pará (Schmink and Wood, 1992).

I argue that in order to gain better understanding of frontier expansion, it is important to assess its different stages of development along with the different actor types that occupy and use the forestland. The frontier types discussed here, however, should not be interpreted rigidly. To paraphrase Browder and Godfrey (1997), the history of the Amazon is the story of competing fronts put into motion at specific locations by different social groups. Although each frontier type defines a set of opportunities and constraints for the decisions made by different actors, each allows for the emergence of a heterogeneous array of decisions about production and land use.

This section focuses on assessing the characteristics of actor types across different stages of frontier expansion, as explained in Section 2 on methods and data sources. Distinguishing frontiers according to the level of forest conversion—which is a proxy for timing of occupation—and dominant actor type is important because what happens to the natural resources depends both on the length of the process of frontier development and on who is the actor that appropriates the available land and forest resources.

Smallholders often use their land differently from medium- and large-scale landholders. Smallholders tend to access small plots to develop labor-intensive activities that then form the main source of their livelihoods. Smallholders' asset levels vary, but the disparities are not great. Smallholders often adopt diversified agricultural systems to reduce risks and spread the demand for their labor over the year (Netting, 1993). They rely on labor-intensive activities because of their lack of access to capital and the relatively low opportunity cost of labor (Castellanet et al., 1998). In the initial stages of frontier development in the Brazilian Amazon, smallholders maintain mixed land use mosaics with cropland and pasture interspersed with fallows and patches of primary forests; during the latter stages of frontier transitions, however, pasture tends almost invariably to dominate over other land uses (Perz and Walker, 2002; Tourrand et al., 1995).

Largeholders in the Amazon tend to develop cattle ranching operations, although intensive production of soybean has expanded in Mato Grosso (Vera et al., 2008). Largeholders have often relied on traditional extensive production systems inherited from other regions, but have also adapted their pasture/herd management techniques (Faminow, 1998; Pacheco, 2009b). Extensive livestock and/or agriculture ventures occupy large tracts of land, and specialization tends to simplify the management of field operations and supervision of labor. Such landholders tend to operate at large scales because they often have access to sufficient capital to support initial developments (Kaimowitz, 1995). Their operations have led to significant conversion of forests to large tracts of pasture, and forest regrowth is unlikely (Margulis, 2004).

Chomitz and Thomas (2001), drawing on IBGE data from the 1995/1996 Agricultural Census, suggest that there is a marked differentiation according to size of establishment in the Amazon, in the sense that small farmers with smaller plots of land tend to be more subsistence-oriented, and rely more on cash products such as milk, manioc, and banana. According to the same authors, large and very large establishments (in the range of 100–100,000 ha) tend to orient their economic activities toward cattle and soybean production. Finally, the "ultra-large" establishments (those larger than 100,000 ha) dedicate a proportion of their forestland to silviculture or nonproductive uses. However, the situation is changing, due to the slow intensification of cattle ranching, the gradual expansion of soybean production in forestland, and the rapid fragmentation of the "ultra-large" establishments.

The IBGE agricultural censuses show that the number of establishments, excluding landless people, was 715,000 in 2006, compared with 788,000 in 1995/1996, in the nine states of the Brazilian Legal Amazon (Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Maranhao, Tocantins, Mato Grosso). As Table 1 shows, in 2006, smallholders (with plots less than 100 ha) number 573,000 units, but occupy only 14.6 million hectares, with the size of landholdings averaging 26 ha. By contrast, there are about 18,000 largeholders (with landholdings larger than 1000 ha) with a total of 61.3 million hectares and an average landholding of 3373 ha. Although the proportion of land held by large-scale establishments fell from 63% to 58% from 1995/1996 to 2006, land tenure distribution in the Brazilian Legal Amazon is still highly skewed.

The IBGE Agricultural Census data provide evidence that cattle herds have continued to expand in the Brazilian Amazon, thus

Table 2
Land use across frontier and actor types in the Brazilian Legal Amazon in 2006. *Source:* Author's elaboration based on IBGE 2006 Agricultural Census.

Actor type[b]	Frontier type based on deforestation extent[a]				
	Pre-frontier		Frontier	Post-frontier	
	Less than 20%	20–40%	40–60%	60–80%	More than 80%
Small-scale landholders (less than 100 ha)					
Stocking rate (head/ha)	1.9	1.6	1.5	1.6	1.6
Cleared land in landholding (%)	48.5	58.9	68.8	76.2	75.5
Contribution to total cleared (%)	2.5	2.8	3.7	3.2	3.3
Planted pasture/total cleared (%)	63.7	82.7	75.7	87.9	81.6
Medium-scale landholders (100–1000 ha)					
Stocking rate (head/ha)	1.2	1.3	1.2	1.3	1.3
Cleared land in landholding (%)	53.2	54.0	68.3	75.1	79.5
Contribution to total cleared (%)	6.1	5.3	7.1	5.4	5.8
Planted pasture/total cleared (%)	77.8	84.0	84.0	90.4	89.9
Large-scale landholders (more than 1000 ha)					
Stocking rate (head/ha)	0.7	0.9	0.9	0.9	1.0
Cleared land in landholding (%)	54.2	45.4	60.9	65.4	77.0
Contribution to total cleared (%)	14.5	11.2	14.2	8.3	6.6
Planted pasture/total cleared (%)	78.4	80.3	83.7	82.3	89.5

[a] Deforestation extent refers to the total deforested area by municipality as of 2009 relative to the total original forest cover during 2000–2009, based on INPE estimates.
[b] Based on total landholding size in municipalities in the Brazilian Legal Amazon according to IBGE Agricultural Census 2006.

increasing pressure for conversion of forest to pastureland, which is the main land use derived from forest conversion. Cattle herds grew by 20 million head in the 10-year period from 1995/1996 to 2006, reaching a total of 55.4 million head in 2006. Although there has been a notable growth of cattle herds on smallholdings—increasing their contribution from 17% to 22% respect to the total during the same period—cattle herds continue to be largely concentrated in large- and medium-scale landholdings, which accounted for about 42% and 36% of total cattle herds in 2006, respectively (Table 1).

The expansion in the size of cattle herds has been accompanied by a slight increase in stocking rates in the period from 1995/1996 to 2006, suggesting that each unit of pasture area is supporting a relatively larger number of cattle. In 2006, the stocking densities are higher in smallholdings (1.6 head of cattle per each hectare of pastureland) and they tend to decrease as landholdings get larger. In this vein, stocking rates are 1.2 and 0.8 head/hectare of pastureland in medium- and large-scale landholdings, respectively. This fact suggests that land use tends to be more intensive in smallholdings when compared with more extensive systems adopted in large-scale landholdings.

Three main trends emerge when looking at land use, cattle ranching expansion, and deforestation across frontier types (Table 2). The first is that, overall, compared with medium- and large-scale landholders, smallholders tend to deforest a greater proportion of their land to put it to agricultural or pasture uses, and that landholders with greater access to land tend to keep a larger proportion of it as forest. This trend occurs largely because smallholders have access to less land. The second trend is that, compared with smallholders, medium- and large-scale landholders tend to use a greater proportion of cleared forests as pastureland, as these landholders hold the largest cattle herds. The third main trend is that, when examining the absolute accumulated values of cleared forestland, the actor's contribution to total deforestation is related to landholding size. That is, when looking at the landholdings counted at the time of the last census, largeholders' contribution to total cleared forests amounted to about 54.8%. The corresponding figures for medium- and small-scale landholders are 29.8% and 15.5%, respectively.

The land use trends from 1995/1996 to 2006 are more clearly observable in Fig. 4, which shows the relative presence of the main land use categories across different frontier types for each of the three actor types identified. These data reveal a clear trend for pasture to occupy a greater proportion of total landholdings with frontier evolution, a trend that, interestingly, is similar across all three types of actor. However, it is noteworthy that the proportion of annual crops reported in small-scale landholdings fell from 1995/1996 to 2006. By contrast, large-scale landholdings reported a higher proportion of their landholdings under annual crops in 2006 than in 1995/1996. The latter is likely linked to expansion of soybean production on large-scale plantations.

5. Implications for forest conversion and rural incomes

According to the INPE, the deforested area in the Brazilian Legal Amazon increased from 15.2 million hectares in 1978 to 41.5 million hectares in 1990, and covered about 58.7 million hectares in 2000 and 74.8 million hectares in 2009 (INPE, 2010). Most of the deforestation is concentrated in an area labeled the "arc of deforestation" (Alves, 2001). INPE estimates include only areas with complete removal of natural forest and do not account for forest regeneration, which is significant.

Skole and Chomentowski (1994) reported that 30% of the deforested area in the Amazon is regenerating forest. Lucas and colleagues (2000) support this figure, arguing that one-third of the deforested area supports forest regrowth, with more than half of this forest estimated to be less than 5 years old. Much of the secondary succession, however, may be temporary fallows, and is not properly forest. Furthermore, it has been argued that secondary forest succession differs throughout the region (Moran et al., 1994). EMBRAPA/INPE (2011) estimates that out of the total area deforested by 2008, 62% is pasture, 5% agriculture, and 21% forest regrowth (EMBRAPA/INPE, 2011). There is not enough empirical evidence to make a firm assessment about the conditions under which forest regeneration occurs. Nonetheless, it is likely that a portion of forest regrowth takes place in lands under control of smallholders who, as part of their production systems, leave some lands as fallows after cultivation. Forest regrowth could also be associated with land abandonment in larger-scale landholdings.

It is largely assumed that smallholder frontiers tend to have more complex land use trajectories because of their combinations of temporal and perennial crops and fallows, with less forestland being converted to pasture (Perz and Skole, 2003). Although this pattern is evident for the earlier stages of frontier development, as mentioned above, smallholders tend to deforest a larger proportion of their landholdings over time. However, compared with

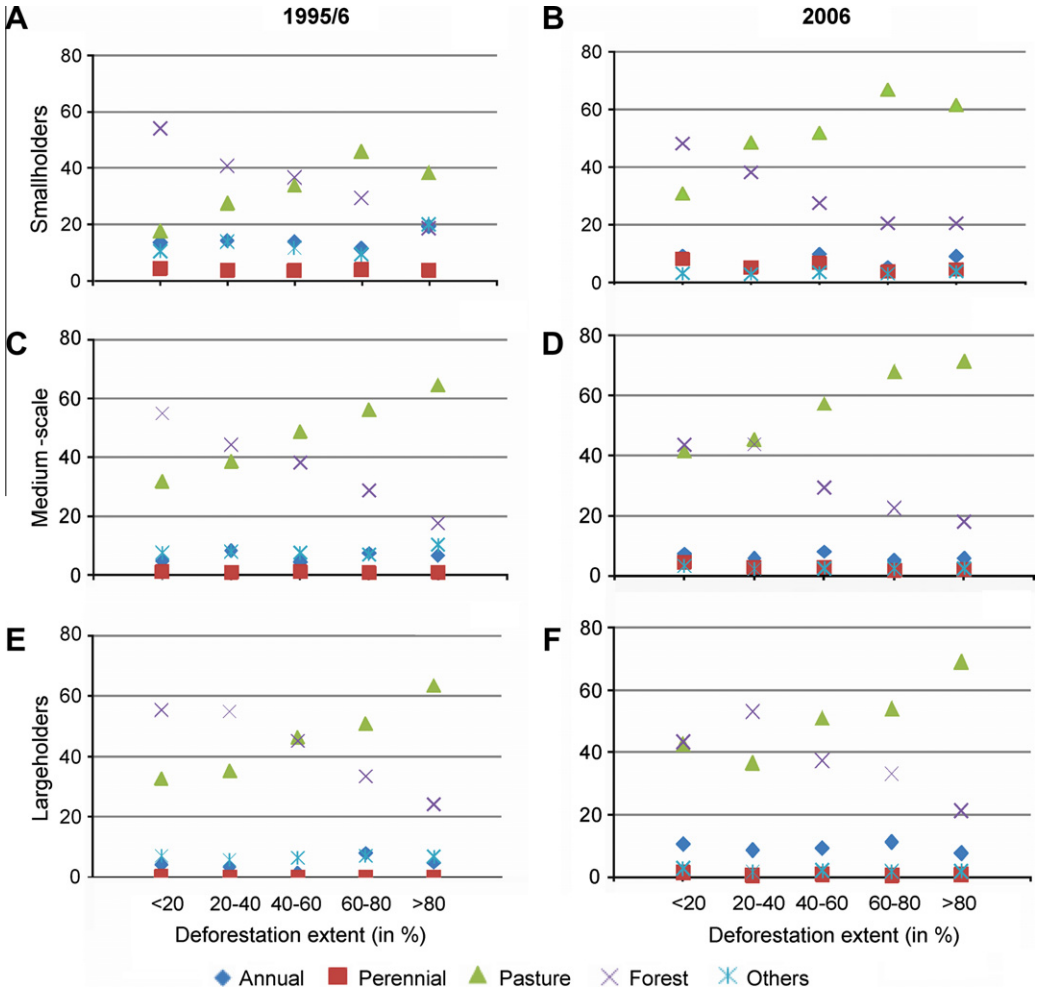

Fig. 4. Average values of presence of various land uses at two time points (1995/1996 and 2006) for smallholders (A and B), medium-scale landholders (C and D), and largeholders (E and F) across a gradient of frontier types defined according to the deforestation extent (%) based on estimates by INPE for 2009. Land use values represent average values, which are taken from the IBGE 2006 Agricultural Census.

Table 3
Average values of select indicators for municipalities classified according to the dominant actor type in the Brazilian Legal Amazon.

Predominant actor type based on a typology defined at the municipal level[a]	Number of municipalities	Deforestation activity in 2000–2009 (%)[b]	Deforestation extent in 2000–2009 (%)[c]	Contribution to total deforestation by 2009 (%)[d]	Density of rural population by square km[e]	Agricultural GDP per capita of rural population. (2008 US$)[f]	Human Development Index in 2000[g]
Predominantly small-scale	134	13.6	38.5	9.6	12.9	810.8	0.63
Small- and medium-scale	42	13.4	55.3	2.5	11.3	980.0	0.61
Predominantly medium-scale	103	7.9	44.6	9.3	6.6	1164.8	0.62
Medium- and large-scale	83	8.0	32.2	7.6	4.4	2078.2	0.66
Predominantly large-scale	221	4.9	35.7	44.8	1.1	6499.7	0.70
Mix (small, medium, and large)	143	7.5	46.6	26.3	4.6	1879.4	0.66
One-way ANOVA probabilities		<0.001	<0.001		<0.001	<0.001	<0.001

[a] Corresponds to the proportion of establishments of different sizes held by small-, medium- and large-scale landholders according to the following criteria: predominantly small-scale (>50, <20, <20), small- and medium-scale (<50, >50, <20), predominantly medium-scale (<20, >50, <20), medium- and large-scale (<20, <50, >50), predominantly large-scale (<20, <20, >50), mix (small, medium, and large) (<50, <50, <50).
[b] Deforestation activity refers the percentage of municipality area deforested between 2000 and 2009, based on estimates from INPE.
[c] Deforestation extent refers to the total deforested area in 2009 by municipality relative to the total original forest cover during 2000–2009, based on INPE estimates.
[d] Estimates by municipality taken from INPE.
[e] Demographic data based on IBGE taken from SIDRA (Sistema IBGE de Recuperação Automática).
[f] Based on IPEA (Instituto de Pesquisa Económica Aplicada) dataset (1USD = R$ 1.8289).
[g] Taken from IPEA dataset based on UNDP estimates.

medium- and large-scale landholders, smallholders dedicate a smaller proportion of their land to pasture, although this proportion tends to increase rapidly with frontier development which is also associated to greater market integration. By contrast, medium- and large-scale landholders tend to leave greater areas of forest during the initial stages of frontier development, but forests are then gradually converted with frontier development to be placed under relatively extensive production systems (Pacheco, 2009a;

Pacheco, 2009b). Thus, in post-frontier situations, 75–79% of the forestland in the landholdings is converted to agricultural uses, of which 82–90% is under pasture (Table 2).

Furthermore, human-induced pressures on the land tend to intensify over time because of increasing population affluence, which grows at a faster rate in areas dominated by smallholders; this in turn leads to increased land occupation and deforestation (Carr et al., 2009). Available data suggest that population density is eight times higher in frontiers dominated by smallholders than in those dominated by largeholders (Table 3). Both diffuse and fishbone spatial patterns of deforestation dominate in the smallholder-dominated frontiers, depending on the initial type of settlement, whereas large-scale geometric clearings are most common in areas where largeholders are the dominant actor (Geist and Lambin, 2001). Increasing interest in soybean production has also stimulated the clearing of large tracts of land for grain production, especially in Mato Grosso (Nepstad et al., 2006; Vera et al., 2008).

Data on the contribution to deforestation made by largeholder farmers and ranchers compared with smallholders are not reliable, although it is clear that large ranches play a significant role in forest cover loss (Cattaneo, 2000; Faminow, 1998). Among the most relevant studies containing estimates of the contribution of different landholder types to deforestation, Fearnside (1993) suggests that 70% of deforestation is attributable to large-scale ranching operations, although Homma and colleagues (1995) claim that half of the deforestation in the Amazon is by shifting cultivators. Chomitz and Thomas (2001) claim that establishments larger than 2000 ha account for about half of all land converted from forest or *Cerrado* to agricultural use. Walker and associates (2000) conclude, from an evaluation undertaken in four areas in the state of Pará, that there is large regional variation in terms of actors' contribution to deforestation, which is related to both settlement history and development interventions.

Estimates based on the 1995/1996 Agricultural Census show that 14.8% of land clearing (most of it forest, with some *cerrado*) is attributable to smallholders, 29.0% occurred on medium-scale establishments, and the remainder (56.2%) took place on large-scale landholdings. However, these estimates only reflect land use within occupied (private) areas (which tend to be undercounted). The 2006 Agricultural Census reported slightly modified proportions, estimating the contributions to total cleared forestland as 16.1%, 30.8%, and 53.1% for small-, medium-, and large-scale landholders, respectively (Table 1). However, as mentioned above, the total deforested area given in the Agricultural Census appears to be an underestimation: the census reports 54.4 million hectares of cleared forestland, whereas the extent of total deforestation according to INPE is about 71.6 million hectares in 2006, the year the census was conducted.

When considering the typology of municipalities based on the predominant actor type, the contribution to total deforestation is clearly lower in municipalities with a greater presence of smallholders than in those dominated by medium- and large-scale landholders. As mentioned above, the latter are responsible for about half of the total deforestation in the Brazilian Legal Amazon (Table 3). Interestingly, however, deforestation activity is about three times greater in smallholder frontiers than in largeholder areas. This suggests that whereas the latter have reduced the pressure on forestland, smallholders continue to undertake significant forest conversion in order to expand planted pastures.

An important associated discussion, as mentioned earlier, is related to the implications of deforestation for development, thus on the improvement of the economic and social indicators of the locales in which forest conversion is taking place. In this regard, there are no clear correlations between deforestation and agricultural income, and hence local development. Margulis (2004) found a significant increase in GDP per capita in rural areas in almost all states of Amazonia. This author indicates that the "development leaders" were the three states with the highest levels of forest conversion (Pará, Mato Grosso, and Rondônia), and that some very high growth rates registered in the state of Mato Grosso were attributable to the expansion of soybean in the *Cerrado* region of the state. The information in Table 3 supports this view.

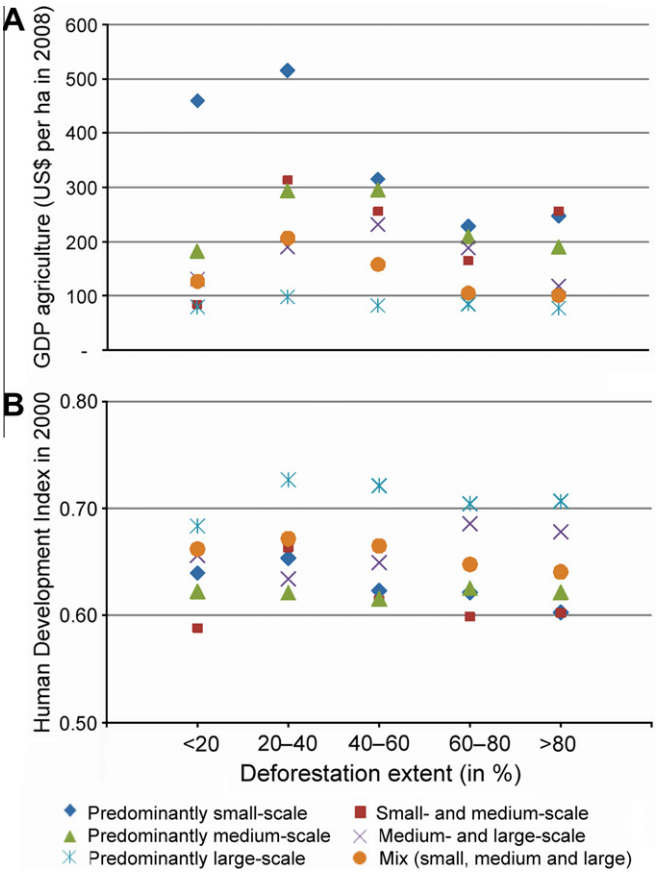

Fig. 5. Variation along a deforestation gradient corresponding to the five frontier classes defined in Table 2: (A) the agricultural gross domestic product (GDP) per unit of land under annual, perennial and pastureland uses, expressed in 2008 US$; and (B) the Human Development Index (HDI) in 2000. The values provided represent median values. GDP values are from IBGE, and HDI values are estimated by UNDP. Both datasets are taken from IPEA.

As of 2008, the agricultural GDP per capita in rural areas was eight times higher in municipalities dominated by largeholders than in those with mostly smallholders among the rural population (Table 3). This suggests that, based on this measure, municipalities with large-scale establishments tend to generate more income. It could be argued, however, that as populations tend to be more affluent in landscapes dominated by smallholders, agricultural income per capita necessarily tends to remain at lower levels in these landscapes compared with those dominated by large-scale soybean plantations and cattle ranching operations. However, smallholder landscapes generate greater agricultural income when measured according to the total amount of land placed under pastureland and annual and perennial crops, which is likely due to the fact that agricultural and pasture production tend to be more intensive under small-scale production systems.

The HDI ranges from 0.61 to 0.70 across actor types, presenting only slight differences (Table 3). These data reveal that municipalities with more large-scale farmers tend to have a higher HDI than those in which smallholders constitute the main type of rural actor. This may be related to population affluence, which intensifies

pressure on social services; however, it could also be explained by the amount of public investment targeting these different frontiers, the analysis of which is beyond the scope of this paper. Interestingly, when looking at the agricultural GDP across the gradient of frontier evolution, higher agricultural incomes appear in situations corresponding to active frontiers, with a declining trend in post-frontier areas (Fig. 5A). An examination of HDI across frontier types also shows that it tends to decline with frontier expansion, although with some differences between landholder types (Fig. 5B). The latter trend has been identified elsewhere, and is likely associated with the dominance of boom-and-bust patterns across the Brazilian Amazon deforestation frontier (see Rodrigues et al., 2009).

6. Conclusions

In this paper, I discuss the main policy and market conditions influencing frontier expansion in the Brazilian Amazon, according to the dominant actor type, and their implications for deforestation and agricultural and human development in the region. I argue that it is necessary to pay particular attention to understand the conditions shaping diverse actors' land-use decision making across different stages of frontier development. The latter is relevant if effective policies are to be devised to minimize the trade-offs between economic and human development and forest conservation.

The trajectories of land use change across different stages of frontier evolution are relatively well known with less forest intervention in pre-frontier areas and less remaining forest in post-frontier ones. Yet, differential situations emerge across these frontiers depending on the actor type (i.e. smallholders, and medium- and large-scale landholders) since all of these actors are engaged to varying degrees in the production of annual crops, perennial crops, and beef as a result of different socio-economic strategies, whether for meeting their subsistence needs, making a profit, or both. The way in which these different actors appropriate and use land resources has important effects in deforestation as well as on their associated economic and social outcomes.

With regard to land appropriation, medium- and large-scale landholders continue to dominate a larger proportion of the Amazon and a skewed land distribution persists which is to large extent associated to the persistence of extensive cattle ranching in the Brazilian Amazon. Nonetheless, over time there is an important increase, in relative terms, of cattle herds in lands occupied by smallholders, which have more intensive practices than do medium- and large-scale landholders. Cattle ranching has contributed to consolidate small-scale farming systems in frontier and post-frontier areas. In addition, the consolidation of large-scale landholdings is not only associated with a relative increase of cattle production productivity in post-frontier areas in comparison to the low production systems in pre-frontier areas, but also with the expansion of annual crops (soybean) under capital-intensive large-scale plantations in Mato Grosso.

The expansion of cattle ranching in the Brazilian Amazon suggests that, as much as it has contributed to increasing land occupation by medium- and large-scale landholders and has supported significant processes of capital accumulation, it also constitutes an important source of livelihood for smallholders, which use a sizable proportion of their landholdings as pasture as part of frontier evolution. This trend also reflects the lack of opportunities smallholders have to make a living from annual and perennial crops, apart from some context-specific cases, as well as the limited opportunities for investment experienced by more capitalized actors that decide to persist with cattle ranching. The expansion of cattle ranching is also associated with growing demand from domestic and global markets, as well as policy incentives. As a result, deforestation is more intense in frontier landscapes occupied by smallholders, even though large-scale landholders are responsible for most of the accumulated deforestation. Furthermore, most of the recent reduction in deforestation in the Amazon, although not discussed in this paper, is likely linked to a decrease in forest clearing in large-scale landholdings.

Understanding the relationship between deforestation and economic and human development is highly significant for policy making in order to enhance development and people's wellbeing while at the same time promote forest conservation. The evidence discussed in this paper suggests that greater population affluence occur in landscapes dominated by smallholders, which places additional pressures on the forests. In the latter landscapes, income per capita is lower than in other frontier types, but income generated by unit of land tends to be higher than in landscapes dominated by medium- and large-scale landholders. Although large-scale producers tend to generate greater rural income per capita, the preeminence of extensive systems of cattle production in frontiers dominated by largeholders means income levels are lower when measured by production value by unit of land. This trend is reversed in relation to intensive soybean production where economic incomes are significantly higher per unit of land.

In this context of diversity among actor types, it is necessary not only to understand which policy instruments will be most effective in promoting sustainable and equitable modes of production in Amazon frontier landscapes, but also which actors will benefit more from such policies. This becomes more relevant with the emergence of concerns for improving the conservation of forest resources in the Amazon region, in the context of climate change and the transition to low-carbon development pathways. If forest conservation goals are to be achieved, it is necessary to develop more innovative formulas for supporting the livelihoods of smallholders and the economic choices of medium- and large-scale landholders. Therefore, stronger enforcement of environmental regulations—which is needed—must be accompanied by incentives to promote sustainable land use practices, as well as to encourage forest conservation, such as through conditional payments for conservation or market-based instruments rewarding compliance with land use regulations. Furthermore, the policy agenda must pay attention to equity issues in order to reverse the largely unequal land tenure structure and promote more equitable distribution of benefits from both development and conservation.

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