Socioeconomic dimensions, migration, and deforestation: an integrated model of territory organization for the Brazilian Amazon

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Abstract

This paper characterizes the urban network layout of the socioeconomic space in the Brazilian Amazon through an integrated model, focusing on the levels of socioeconomic organization and the interrelationships among regions determined through migratory movements. The territory organization of the Brazilian Amazon, meaning the socioeconomic network of municipalities, takes into account the diversity of the human settlements and their potentials for environmental changes. It is a starting point for understanding the socioeconomic and demographic spatial arrangement of the Brazilian Amazon and its influence on the deforestation dynamics. We developed a model of territory organization based on the coordination of five components: i) the hierarchy of central places (poles) established by the concentration of urban specialized services, ii) the geographical distance between central poles and other centers, iii) the pole's populations, iv) the migratory movements among them, and v) a socioeconomic dimension index. These components are combined into a gravitational model to produce measures and maps of the socioeconomic municipality network of the Brazilian Amazon. As a result, out of 792 municipalities in the Brazilian Amazon, nine were classified as macro-poles, 28 were classified as meso-poles and 48 as micro-poles. The areas of influence of these poles were determined according to three hierarchy levels. The identified Amazon region network comprises a nested spatial pattern of municipalities not constrained by the state boundaries, pointing out the influence of the socioeconomic space and population movements on the mobility of the deforestation frontier. This picture provides insights to foresee deforestation as well as to direct sustainable development policies suitable for each region's specificity.

Keywords: socioeconomic dimension, migration, territory organization, deforestation, Amazon.

Introduction

Socioeconomic dynamics drive the fast pace of deforestation in the Brazilian Amazon. But the intensity of the deforestation process varies greatly across the basin due to regional differences, including physiographic attributes, access to infrastructure, such as paved roads, population characteristics and dynamics, socioeconomic organization as well as ages of frontier. Hence the understanding of the territorial distribution of both economic activity and socio-demographic dynamics is a starting point to evaluate a region's potential for environmental changes, such as deforestation. This fact is implicit in the concept of anthropic pressure, which is the pressure imposed on the environment by the socioeconomic conditions of human settlement (Monteiro and Sawyer, 2001). Additionally, the establishment of a territorial hierarchy, representing nested spatial levels of socioeconomic and demographic organization, sets the basis to design differentiated regional development plans aiming at the sustainable use and conservation of the Amazon natural resources.

The main objective of this study is to establish a model of territory organization for the Brazilian Amazon, based upon two components. The first deals with the hierarchy of cities as a function of urban specialized services. The theory of central places (Christaller, 1966) refers to a nodal urban hierarchy consisted of larger centers polarizing the surrounding smaller centers. The main rationale is that the largest population centers, in which urban services are concentrated, have the largest potential for attracting socioeconomic activities and for spreading them to surrounding centers (Lemos, 1991). To address this issue, an Index of Services (*IS*) was sought, based on the ratio between the gross domestic product for the service sector (*SDP*) and the total gross domestic product (*GDP*). Hence the highest Indices of Services determine the major centers acting like attracting regional poles, i.e. central places. Harvey (1989) envisaged the territory as a plastic space made of interactions of places through flow of people, resources, and information. With this in mind, the second component combines three variables in order to determine the network of the Brazilian Amazon municipalities. First, an index of socioeconomic dimension (*SDI*) is built for each municipality. We hypothesize that this index can be used to infer the anthropic pressure exerted by a population within a specific territory unit – such as the municipalities or larger regions formed by their aggregation – on the deforestation process. We combine the following five dimensional axes to produce the *SDI* summary: 1) population concentration and dynamics; 2) economic development; 3) agrarian infrastructure; 4) agricultural and timber production, and 5) social development. A positive effect on the deforestation process is ascribed for the first four dimensions, and a negative effect for the fifth. Thus *SDI* deals with the socioeconomic potential of a population (the second variable) for environmental changes. As a measure of attraction, the population, strengthened by *SDI*, is employed in a gravitational model, in conjunction with the total migratory movement among the central place and the surrounding municipalities (the third variable), to make up the influence area of the central place.

Previous studies have provided methods to map the urban network layout and its associated socioeconomic space in Brazil in order to direct regional development policies (e.g. IPEA/IBGE/NESUR, 1999; Lemos *et al*., 1999, and Garcia, 2002). It is worth mentioning that the two first works did not explicitly involve migration, the only variable from census data able to measure flux over time and space. Only Garcia (2002), using the same framework of Lemos *et al.* (1999), proposed a regionalization for the Brazilian territory based on population movements among central poles and areas under their influences. Nevertheless, none of these studies provided a methodology specifically addressed to the potential of socioeconomic and demographic dimensions for environmental changes in the Amazon region. Therefore, this study attempts to characterize the level of socioeconomic dimension and the interrelationships among municipalities, given by migratory movements, to establish a network of regions, aiming to shed light on the way these regions interconnect to influence the mobility of the deforestation frontier across the basin.

Methodology

The urban centers were identified and ranked according to their supply of services, referred to here as the "service economy" through the Index of Services (*IS*), as follows (Lemos, 1991):

$$IS_i = \frac{SDP_i}{GDP_i} * \left(1 - e^{\frac{\ln(0.05)*SDP_i}{SDP_{ref}}} \right) \quad (1)$$

where IS_i is a ratio between the service economy domestic product (SDP_i) and the gross domestic product ($GDPi$) of a municipality *i*, standardized by a reference service economy domestic product (SDP_{ref}), specifically the largest regional SDP_i. A qualitative aspect was added to the value of the *IS*, e.g. all capital cities were ranked high. We established three categories of centers by defining threshold values for *IS*: macro-poles, meso-poles and micro-poles.

The Socioeconomic Dimension Index (*SDI*) is calculated by applying the Grade of Membership (GOM) fuzzy classification method – see Manton *et al.* (1994) for theory and Gold and Woodbury (1990); Sawyer and Beltrão (1991); Hughes *et al.* (1996) for application examples – to socioeconomic and agriculture census data, such as population density and growth rate, urbanization level and rate; gross domestic products, municipal income taxes and budget; number and types of agricultural implements; production from animal husbandry, agriculture, and forestry; education, habitation, and health parameters. These data were stratified into a five-dimensional space, with axes that were named (1) population concentration and dynamics, (2) economic development, (3) agrarian infrastructure, (4) agricultural and timber production, and (5) social development. High levels of the first four dimensions are combined with low level of social development to produce the socioeconomic dimension index for each municipality, which is interpreted as a proxy for the anthropic pressure on deforestation. Only this synthetic index is presented in this paper. The rationale for establishing these components and choosing their constituent variables is that population growth and migration, together with economic growth, stimulate deforestation (Skole *et al*., 1994; Laurance**,** 1999; Soares-Filho *et al*., 2004). In addition, logging (Nepstad *et al*., 1999) plus agriculture and ranching expansion are listed as major current causes of deforestation in the Brazilian Amazon (Margulis, 2002*;* Mertens *et al*., 2002; Alencar *et al*., 2004). Conversely, social development, as illustrated in the inverted U-shape Kuznets curve (Stern *et al.*, 1996), could represent frontier governance (Nepstad *et al*., 2002), counteracting environmental degradation resulting from economic development. Variables for each of the dimensions are listed in Table 1.

Once a hierarchy of regional poles is established, which can include a varying number of economic poles depending on a chosen cut-off threshold for *IS*, the interaction between a pole and a municipality is calculated according to the equation 2):

$$Iv_{ij} = \frac{P_i(1+SDI_i)*P_j(1+SDI_j)}{d_{ij}^{\xi}} \qquad (2)$$

where Iv_{ij} represents the interaction between pole *i* and municipality *j*, given by their populations (P_i and P_j) and socioeconomic dimension indices (SDI_i and SDI_j), weighted by the distance (in this case, the geodetic distance) between them raised to the power of ξ, an attrition coefficient so that:

$$\xi = 1 + e^{\left(\frac{\ln(0.001)}{vmt_{ref}} * vmt_{IJ} \right)} \quad (3)$$

where vmt_{ij} is the overall migratory flux between pole *i* and municipality *j* and vmt_{ref} is the reference migratory flux, namely the largest intermunicipal migratory flux.

Migratory fluxes were calculated based on information of place of residence five years prior to August 1st, 2000, collected in the 2000 Demographic Census. Those residing outside the municipality in the reference period are considered in-migrants, conversely those residing in the municipality in the reference period but outside it in 2000 are the out-migrants. The difference between the two is the net migration and the sum is the overall volume of population exchange (Garcia, 2002).

Hence, Iv_{ij} measures the dependence of a municipality on a regional center, defined as the attraction exerted by the center's population. In this case, the population attraction of a central place is stressed by its socioeconomic dimension index, as we assume that larger populations with higher anthropic pressure – as determined by *SDI* – impact deeper the environment. In this gravitational model, the dependence of a municipality to a pole is strengthened by the two-way migratory fluxes and weakened by the geographical distance. Finally, we mapped the poles' areas of influence by assigning to a particular pole all municipalities where its respective Iv_{ij} is greatest.

Results

City hierarchy

Out of 792 municipalities in the Brazilian Amazon, nine were classified as macro-poles, 28 were classified as meso-poles and 48 as micro-poles. Municipalities with *IS* higher than 20 percent are the macro-poles. This upper limit was set to embrace all and only the state capitals, excluding Palmas – Tocantins state capital. Two more thresholds were set by determining the nature breaks of *IS* distribution frequency. Those with *IS* higher than 4.2 percent were classified as meso-poles and those with *IS* higher than 0.5

percent were the micro-poles. Furthermore, the qualitative aspects related to the importance of a municipality as an administrative center, its relationship with their neighbors, namely its non-contiguity to other poles, and its geographical location, would add or subtract municipalities from poles defined by the *IS* thresholds.

The following eight state capital cities were classified as regional macro-poles, according to *IS* values above 20%: São Luis, Cuiabá, Porto Velho, Rio Branco, Manaus, Boa Vista, Belém and Macapá (Table 2). Palmas, the capital city of Tocantins state, with *IS* of 7.8%, was added to this list because of its administrative and political functions (Table 2).

The 19 non-contiguous municipalities classified as meso-poles, with *IS* above 4.2%, comprise the above macro-poles, as a meso-pole is also a micro-pole – thus a macro-pole is also a meso-pole and a micro-pole –, and the cities of Rondonópolis, Ji-Paraná, Imperatriz, Palmas, Santarém, Sinop, Cacoal, Marabá, Cáceres, Barra do Garças and Vilhena. Additional nine municipalities were added to this level because of their known importance as regional centers (Table 2).

116 municipalities were initially classified as micro-poles, with *IS* above 0.5%. After excluding contiguous poles with lesser *IS*, they were reduced to 48: above macro and meso-poles plus Parauapebas, Tangará da Serra, Gurupi, Caxias, Bacabal, Tucuruí, Cruzeiro do Sul, Araguaína, Tefé, Guajará-Mirim, Jaru, Redenção, Altamira, Codó, Juína, Itaituba, Barra do Corda, Paragominas, Almeirim, Pontes e Lacerda, Balsas, Alta Floresta D'Oeste, Colíder, Juara, Breves, Parintins, Guarantã do Norte, Ariquemes, and Alta Floresta (Table 2).

Socioeconomic Dimension Index

Each municipality is assigned to a grade of membership within the extreme profiles that encompass the highest and lowest categories of variables constituting each of the five axes – population concentration, economic development, agrarian infrastructure, agricultural and timber production, and social development. The grade of membership varies from 0 to 1 depending on the number of equal characteristics between the municipality and the extreme profile. Higher the grade of membership of a municipality, closer is it to the extreme profile. These indices are then combined to produce the synthetic index of Socioeconomic Dimension (*SDI*); high *SDI* values correspond to high-ranking positions in the four first dimensions and low in the fifth. For example, the municipality with grade of membership close to 1.0 for population concentration and dynamics axis, is similar to its top profile, which has the largest urban population in 2000, highest population density, lowest urbanization level and rate, and highest rate of population growth. Top profile for social development index possess high educational level, good medical care and garbage collecting systems, high percent of water and electricity supplies, street paving and illumination, and large number of households with telephone and TV sets. Similar interpretation is valid for the grades of membership of the other three axes, whose variables show a direct relation to the top profiles. High values of the synthetic index *SDI*, therefore, combine high population concentration and growth with low urbanization, high economic development, high agrarian infrastructure, large agricultural and timber production, and low social development.

Levels of socioeconomic dimensions were established using the natural breaks in the distribution frequency of this variable: low for values from 0 to 0.25; medium-low from 0.25 to 0.33; medium from 0.33 to 0.66; high medium from 0.66 to 0.75 and high from 0.75 to 1.00. Fig. 1c exhibits the distribution of the municipalities according to the level of socioeconomic dimension. Of the 729 municipalities, 7% have high socioeconomic dimension, whereas 22% have low.

A comparison between the maps of density of deforested land (Fig1a) and the socioeconomic dimension index (Fig1c) demonstrates that there is a close match between municipalities with high deforested percentage and those with high to moderate *SDI*, notably in states of Mato Grosso, Rondônia and Acre, and more specifically in Eastern Pará and Western Maranhão state. Other municipalities with high *SDI* but low deforested density can be associated to regions with high deforestation within 2000 and 2001 (Fig. 2b), such as the municipalities along the Cuiabá-Santarém highway in Southern Pará. In this way, this analysis also indicates that other areas with high *SDI*, but still low current deforestation, such as Santarém's nearby municipalities, the municipalities surrounding Manaus towards Roraima and along the Amazon river, Aripuanã in Mato Grosso state, and Huimatá, in Amazonas state, along Porto-Velho/Manaus highway, may potentially become hotspots of deforestation in the near future (Fig. 1c). Data recently released by DETER, INPE's deforestation alerting system, agree with this interpretation (Valeriano *et al.* (2005). Moreover, the state of Mato Grosso, whose municipalities present the highest *SDI*, accounts for 48% of 26130 km^2 of deforestation estimated by INPE for the Brazilian Amazon within 2003-2004 period (INPE, 2005).

Economic Poles' Migration data

Table 2 shows data for the number of in-migrants and out-migrants, the net migrants, and the overall volume of migration among each of the 48 regional poles and the remaining Brazilian municipalities within 1995 and 2000. One can observe that there is a trend between the polarizing capacity of a pole and its overall migration volume. In other words, higher is the economic importance of a pole, measured in terms of its *IS*, larger is its overall migration volume, even if its net migration is not expressive (Garcia *et. al*., 2004). For example, the macro-pole of São Luis and the micro-pole of Parauapebas possess similar net migration figures (7,100 and 6,400, respectively). Nevertheless, São Luis overall migration is fivefold that of Paraupebas, what makes evident the greater importance and dynamism of São Luis.

Areas of influence of the economic poles

The Index of Gravitational Interaction (*Iv*) measures a two-way influence: of the pole over remaining municipalities and of these over the pole. High values of this index mean high socioeconomic dimensions – translated as a high anthropic pressure – and large populations, both for the pole and municipality, short distance and large migration exchange. Thus, high *Iv* can be interpreted as a strong connection between these two regions facilitated by proximity and population movement. As a result of this connection, an anthropic pressure gradient, influencing the deforestation process, is established from the pole to the satellite regions. The highest *Iv* between a given municipality and an economic pole defines which center is the pole of influence for this municipality. After the calculation of the *Iv*, a network of regions under influence of the economic poles was identified (Fig. 2).

Of the 48 micro-poles, the municipality of São Luis polarized the highest number of municipalities; a total of 109. This effect may be ascribed not only to its economic importance but also to the large number of small municipalities in Maranhão state. The second pole was Belém, with 72 municipalities of influence, followed by Palmas, with 67. The smallest centers were Almeirim (2), Guajará Mirim (3) and Tefé (2). But, in terms of areal expression, the poles influencing the largest regions were Manaus, Cuiabá, Belém, Altamira, and Rio Branco. Manaus, a burgeoning economic metropolis situated in the heart of the forest, is a particular case, thanks to the large amount of fiscal incentives conveyed to its industrial park. Altamira, the largest Brazilian municipality and thus an anomaly in itself, hinders a detailed view of the migratory fluxes within this region, and Rio Branco, although holding an inexpressive economic importance, is the most remote Brazilian state capital. The set of municipalities polarized by the same micro-pole defines the micro-regions of influence, as depicted in Fig. 2a.

Likewise the micro-pole regions, the meso-pole of São Luis had the highest number of influenced municipalities (143) followed by Belem (87) and Palmas (69). The 28 meso-poles polarize directly the non-pole municipalities, the other micro-poles and consequently the municipalities polarized by the micro-poles. The set of micro-poles and the area of influence polarized by the same meso-pole configure the meso-regions. Fig. 2b illustrates this configuration, in which the meso-region of São Luis comprises the micro-region of São Luis (109 municipalities) and the 26 municipalities of the micro-regions of Barra da Corda and 8 municipalities of the micro-region of Codó.

The regional macro-poles directly polarize the non-pole municipalities plus other meso-poles and indirectly their micro-poles of influence. The set of municipalities polarized by a macro-pole is the macro-region of influence. Fig. 2c exhibits the state capital macro-poles and their areas of influence. One can observe that their areas of influence are not constrained by the state political-administrative boundaries.

Conclusion

The urban network, in conjunction with the regional patterns of migration and the municipal socioeconomic dimensions, helps us identify the Amazon frontier mobility, pointing out the current hotspots of deforestation – the deforestation arc – along with the emerging new frontiers. Fig. 3b portrays this integrated view, in which arrows indicate the deforestation trend towards the Amazon innermost frontiers. Bigger the arrow, stronger is the front. Patterns of migration also indicate that most of the in-migrants driving to these inner fronts are coming from nearby consolidated frontiers, showing the way the frontier perpetuates itself (Fig. 3a). Two particular regions stand out from these results. First, the high *SDI* values assigned to municipalities along the Cuiabá-Santarém highway in Southern Pará may account for the expectation of paving this road track (Fig. 1c). Second, Manaus, although with high *SDI*, concentrates much of its potential for deforestation around itself, namely on its urban-rural fringe. Fact that can be attributed to its large flux of urban in-migrants, who are attracted to the numerous jobs offered by its burgeoning industrial park (Table 2). This effect also demonstrates that the economic model of Manaus is exogenous to its region under influence.

According to Becker (2001), the Brazilian Amazon can be regarded as an urban forest. Indeed, 2000's IBGE (Brazilian Institute for Geography and Statistics) census data show that more than 68% of its population lives in urban centers. This view stresses the need for understanding the Amazon socioeconomic space in terms of its urban network. Hence the integrated model presented here, considering the flow of people over economic poles and other centers, has added a new dimension to the grand regional compartments of the Brazilian Amazon, as firstly drawn up by Becker (1990) and later developed by Kampel *et al*. (2001) and Becker (2001). This type of model has also a great potential for foreseeing environmental changes due to anthropic pressure, considering that the socioeconomic space network plays a decisive role in governing human settlement patterns. For example, its framework sets roots for forecasting deforestation at different spatial levels, equivalent to the regions defined at each hierarchy level (Soares-Filho *et al*., 2005a, b).

In comparison to the previous regionalization methods of Lemos *et al*. (1999) and Garcia (2002), the presented approach showed to be more sensitive to territory diversity, providing a wider range of spatial arrangements, as it employed, instead of micro-regions, municipal census data. Also, as exhibited in Fig. 2, all municipalities assigned to a particular region in each of the three hierarchy levels form continuous spatial clusters, demonstrating that the adopted method is highly consistent in terms of spatial continuity, a top requirement for any regionalization method.

The set of equations, describing the present methodology, was conceived to provide a general framework to map the territory organization and thus can be modified to incorporate different views of the urban network and its associated socioeconomic space. For example, geodetic distance could be replaced to other measures of distance that embody the concept of accessibility. In addition, the gravitational mass, in the numerator of equation 2, can be modified to address different geographic approaches. Still, further population studies can incorporate patterns of migration outward Brazil, especially to Peru, Bolivia, and Guiana.

The maps of the poles' areas of influence, presented in Fig. 2, are not meant to define regions in a strict sense, but to depict the way the Amazon socioeconomic space is structured in relation to its urban network and, consequently, how this spatial organization influences the deforestation process. In actuality, there are no clear-cut boundaries between those regions, as all municipalities hold multiple interactions among themselves and with the identified poles. Moreover, the territory organization presented here reflects the Amazon socioeconomic space at the turn of the millenium; this picture is expected to change as new economic centers emerge and other urban connections are established. Of particular interest, the identified regions depict a nested spatial pattern not constrained by the state boundaries. This socioeconomic layout not only highlights the diversity of Amazon territory, but may be useful for redirecting interstate public policies and other proactive measures aiming to conciliate socioeconomic development with the conservation of the Amazon natural heritage.

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Table 1. Variables used for the Socioeconomic Dimension Index, according to their dimensional axis, year of reference, and source of information.

I. Population Concentration and Dynamics
Total Population (2000)[1]
Population Density (2000)[1]
Level of Urbanization (2000)[1]
Average Population Growth (1996/2000)[1 & 2]

II. Economic Development
Domestic Gross Product (1996)[5]
Domestic Gross Product: primary sector (1996)[5]
Domestic Gross Product: secondary sector (1996)[5]
Domestic Gross Product: tertiary sector (1996)[5]
Number of Banks (1998)[3]
Total Deposits in Bank - thousand *Reais* (1998)[3]
Total Investments - thousand *Reais* (1998)[3]
Municipality Revenue (1997)[3]
Municipality Total Expenditure (1997)[3]
Share in the Federal Funds of the Municipality (1998)[3]
Land Taxes- (1998)[3]

III. Agrarian Infrastructure
Agricultural Aggregated Value (1995-1996)[6]
Number of tractors (1995-1996)[6]
Sowing Machines (1995-1996)[6]
Harvesters (1995-1996)[6]
Number of Trucks (1995-1996)[6]
Total of Farming Machinery (1995-1996)[6]

IV. Agricultural and Timber Production
Total Area of Agricultural Establishments with less than 200 hectares. (1995-1996)[6]
Total Area of Agricultural Establishments with 200 hectares or more. (1995-1996)[6]
Land Tenure Concentration (1995-1996)[6]
Livestock (2000)[7a]
Annual Rate of Increase of the Livestock (1997-2000)[7a,7b]
Density of Cultivated Area (2000)[8a]
Annual Rate of Increase of the Cultivated Area (1997- 2000)[8a, 8b]
Number of Milling companies (1997)[9]
Timber Log volume per year (1997)[9]
Area Affected by logging (1997)[9]

V. Social Development
Years of Schooling - population at age 7 to 14 (1996)[2]
Years of Schooling - population at age 15 to 24 (1996)[2]
Years of Schooling - head of the household (1996)[2]
Hospitals per 1000 Population (1999)[3]
Hospital beds per 1000 Population (1999)[3]
Ambulatories per 1000 Population (1999)[3]
Health Posts per 1000 Population (1999)[3]
Health Centers per 1000 Population (1999)[3]
Medical Doctor Offices per 1000 Population (1999)[3]
Dentist Offices per 1000 Population (1999)[3]
Ambulatories in General Hospitals per 1000 Population (1999)[3]
Posts of Medical Care per 1000 Population (1999)[3]
Hospital Bedridden Patients per 1000 Population (1999)[3]
Number of Households (2000)[1]
Improvised Private Household (2000)[1]
Collective Household (2000)[1]
Water Supply (2000)[1]
Bathroom or Sanitary Installation (2000)[1]
Garbage Collection/Destination (2000)[1]
Electricity (2000)[1]
Average Number of Television per Household (2000)[1]
Telephone in the Household (2000)[1]
Paved Streets (1999)[4]
Streets with Illumination (1999)[4]

Source: **[1]** IBGE 2000 demographic census; **[2]** IBGE 1996 population tally; **[3]** IBGE 1999 municipal database; **[4]** IBGE 1999 profiles of the Brazilian municipalities; **[5]** Andrade and Serra (1996); **[6]** IBGE 1995-1996 agricultural census; **[7a]** IBGE 2000 municipal cattle herd survey; **[7b]** IBGE 1997 municipal cattle herd survey; **[8a]** IBGE 2000 municipal agricultural survey; **[8b]** IBGE 1997 municipal agricultural survey; **[9]** Verissimo *et. al.*, 2001.

Table 2. Populations, service domestic products (*SDP*) and gross domestic products (*GDP*) in 10^6 *Reais*, Indices of Service (*IS*), net-migration, in-migrants and out-migrants among the Amazon economic poles and other Brazilian municipalities within 1995 and 20000.

State	**macro-poles *meso-poles	Population	Out-migrant	In-migrant	*Migration volume*	*Net migration*	*SDP*	*GDP*	*IS*
PA	Belém**	1,280,614	105,809	57,432	163,241	-48,377	5668.53	7676.87	70.1
MT	Cuiabá**	483,346	34,696	24,201	58,897	-10,495	2956.53	3399.54	63.9
RO	Porto Velho**	334,661	19,087	20,935	40,022	1,848	2307.70	2472.55	57.8
MA	São Luís**	870,028	48,333	55,479	103,812	7,146	2636.66	3630.90	55.0
MA	Manaus**	1,405,835	44,964	85,569	130,533	40,605	4166.10	7159.99	54.6
AC	Rio Branco**	253,059	11,922	15,888	27,810	3,966	947.21	1155.32	29.8
AP	Macapá**	283,308	12,364	28,764	41,128	16,400	651.05	826.72	21.7
RR	Boa Vista**	200,568	10,157	28,817	38,974	18,660	616.92	798.68	20.7
MT	Rondonópolis*	150,227	12,627	8,520	21,147	-4,107	349.90	448.51	12.5
RO	Ji-Paraná*	106,800	15,080	8,423	23,503	-6,657	298.23	358.41	10.9
MA	Imperatriz*	230,566	32,005	17,020	49,025	-14,985	276.10	360.78	10.1
TO	Palmas**	137,355	8,308	38,759	47,067	30,451	207.97	221.69	7.8
PA	Santarém*	262,538	31,228	12,212	43,440	-19,016	208.68	354.03	7.6
MT	Sinop*	74,831	6,456	12,081	18,537	5,625	137.01	173.48	5.2
RO	Cacoal*	73,568	11,836	5,955	17,791	-5,881	135.71	219.28	5.1
PA	Marabá*	168,020	18,327	18,246	36,573	-81	134.56	248.53	5.0
MT	Cáceres*	85,857	7,728	6,832	14,560	-896	121.51	149.80	4.6
MT	Barra do Garças*	52,092	5,694	4,221	9,915	-1,473	118.26	140.41	4.5
RO	Vilhena*	53,598	5,573	8,844	14,417	3,271	112.46	147.79	4.3
RO	Ariquemes*	74,503	9,442	6,806	16,248	-2,636	105.78	145.04	4.0
PA	Parauapebas*	71,568	6,266	12,721	18,987	6,455	90.98	345.40	3.3
MT	Tangará da Serra*	58,840	6,719	6,776	13,495	57	86.19	127.74	3.3
TO	Gurupi*	65,034	7,535	5,328	12,863	-2,207	82.31	97.57	3.2
MT	Alta Floresta	46,982	8,874	3,348	12,222	-5,526	75.70	102.52	2.9
MA	Caxias*	139,756	8,845	6,265	15,110	-2,580	70.02	104.68	2.7
RO	Guajará-Mirim	38,045	3,248	2,126	5,374	-1,122	69.66	83.18	2.7
RO	Jaru	53,600	11,411	3,272	14,683	-8,139	64.16	109.52	2.5
MA	Bacabal*	91,823	9,579	4,302	13,881	-5,277	59.38	89.16	2.3
PA	Tucuruí*	73,798	7,892	9,597	17,489	1,705	54.38	168.74	2.1
PA	Redenção	63,251	10,141	6,545	16,686	-3,596	50.94	89.04	2.0
AC	Cruzeiro do Sul*	67,441	4,290	2,665	6,955	-1,625	49.91	73.70	1.9
TO	Araguaína*	113,143	14,176	10,982	25,158	-3,194	48.58	72.25	1.9
PA	Altamira	77,439	9,794	5,977	15,771	-3,817	47.52	94.38	1.8
MA	Codó	111,146	6,692	3,902	10,594	-2,790	43.32	70.05	1.7
MT	Juína	38,017	4,697	3,305	8,002	-1,392	41.96	54.40	1.6
PA	Itaituba	94,750	21,247	5,651	26,898	-15,596	41.35	72.35	1.6
MA	Barra do Corda	78,147	7,742	3,468	11,210	-4,274	40.06	59.97	1.5
PA	Paragominas	76,450	10,615	11,108	21,723	493	39.00	198.63	1.5
MA	Tefé*	64,457	4,874	3,170	8,044	-1,704	36.17	68.15	1.4
PA	Almeirim	33,957	6,644	2,834	9,478	-3,810	34.10	120.08	1.3
MT	Pontes e Lacerda	43,012	5,640	4,856	10,496	-784	32.06	65.49	1.2
MA	Balsas	60,163	3,085	5,448	8,533	2,363	28.21	54.55	1.1
RO	Alta Floresta D'Oeste	26,533	2,038	2,034	4,072	-4	25.04	72.79	1.0
MT	Colíder	28,051	6,162	2,525	8,687	-3,637	23.38	39.70	0.9
MT	Juara	30,748	3,231	1,742	4,973	-1,489	23.07	39.39	0.9
PA	Breves	80,158	7,590	3,567	11,157	-4,023	14.77	102.07	0.6
MA	Parintins	90,150	6,153	3,709	9,862	-2,444	14.26	63.11	0.5
MT	Guarantã do Norte	28,200	2,934	3,256	6,190	322	13.52	24.10	0.5

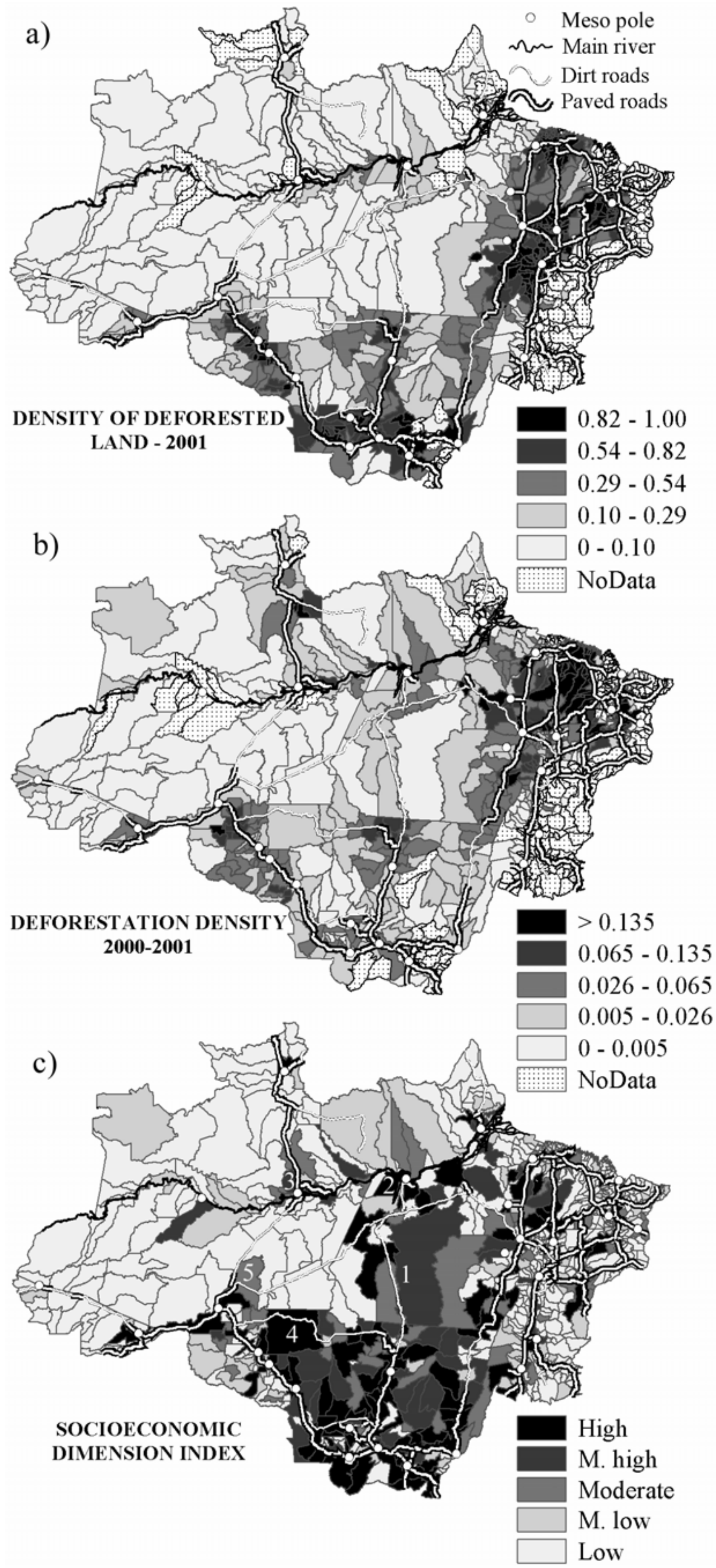
Source: IBGE 2000 demographic census. Andrade and Serra, 1996.

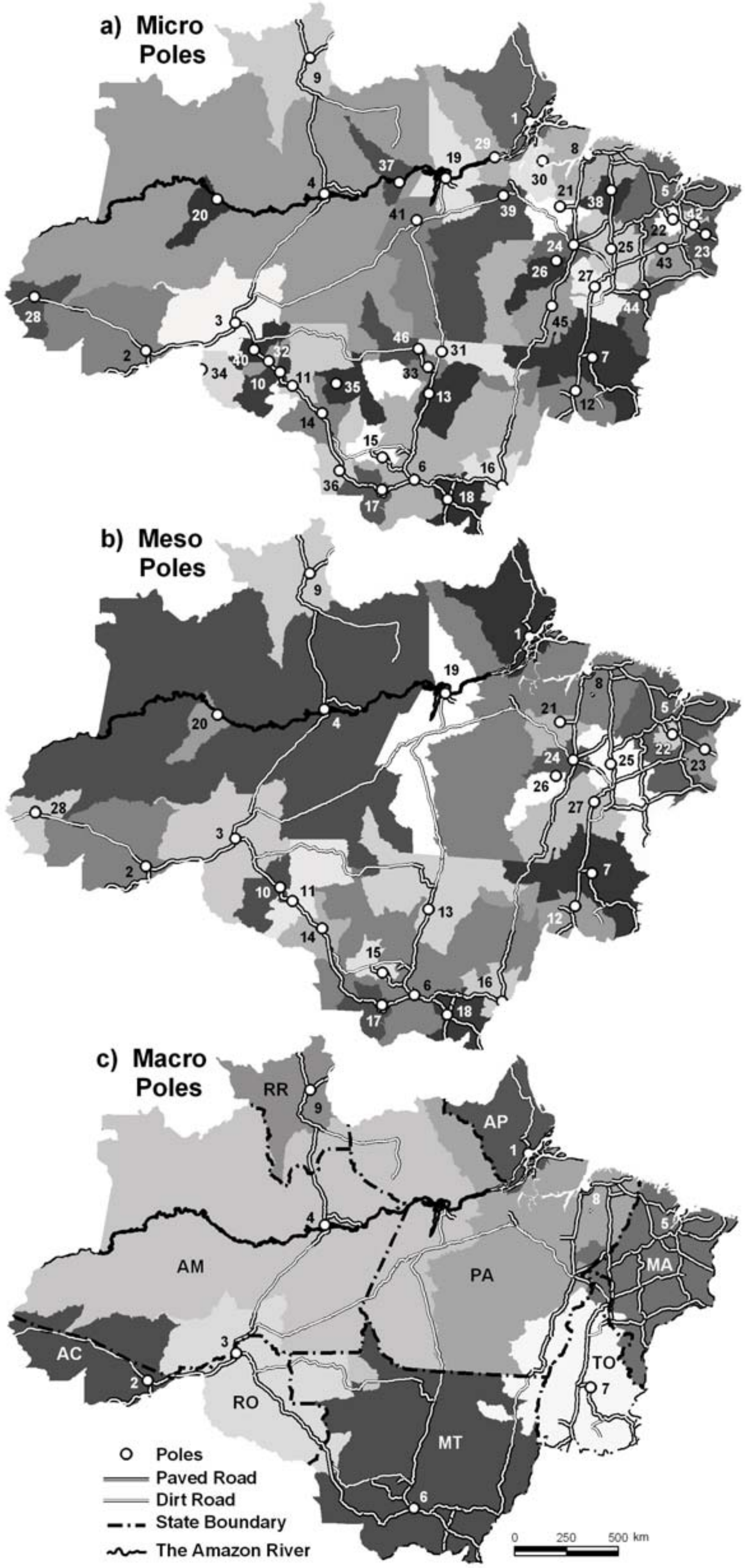
Figure Captions:

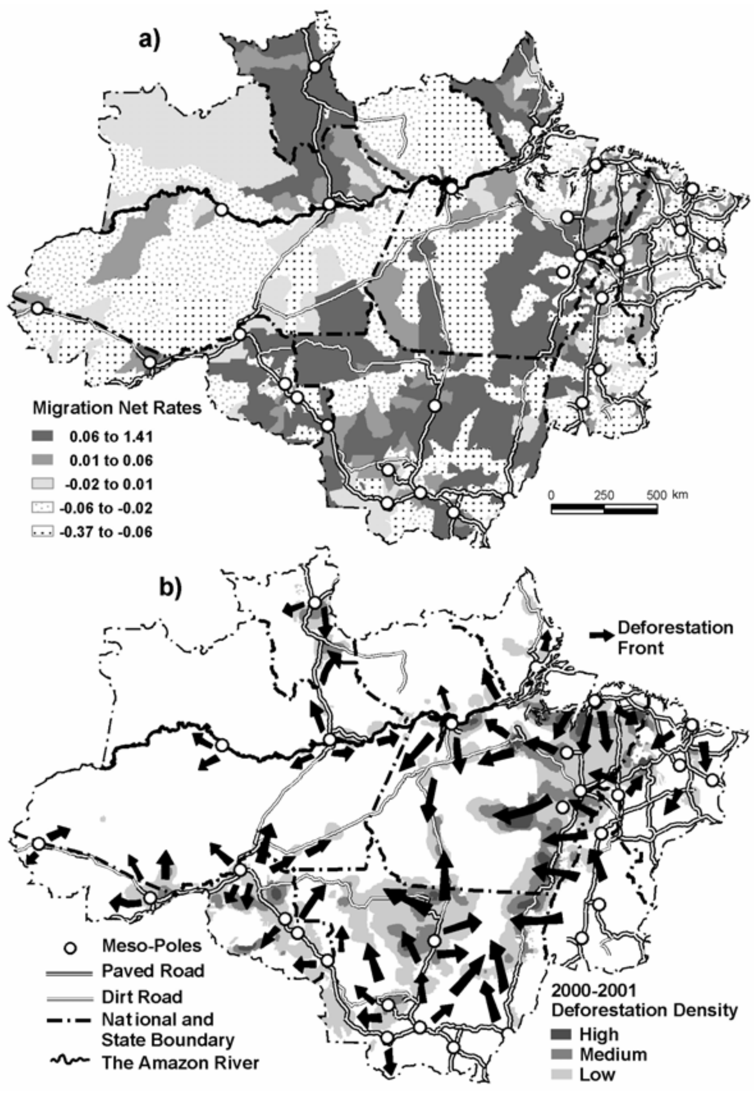
Fig. 1 a) Density of deforested land % (deforested land/(municipality's area - nonforest)), b) deforestation density % (deforestation/municipality's area), and c) Socioeconomic Dimension index for the Brazilian Amazon's municipalities. Deforestation data come from PRODES (INPE, 2005). Cuiabá-Santarém highway 1), Santarém 2), Manaus 3), Aripuanã 4), and Huimatá 5).

Fig. 2 The micro (a), meso (b) and macro-poles (c), and their areas of influence for the Brazilian Amazon in 2000.
Poles: Macapá - 1, Rio Branco - 2, Porto Velho - 3, Manaus - 4, São Luís - 5, Cuiabá - 6, Palmas - 7, Belém - 8, Boa Vista - 9, Ji-Paraná - 10, Cacoal - 11, Gurupi - 12, Sinop - 13, Vilhena - 14, Tangará da Serra - 15, Barra do Garças - 16, Cáceres - 17, Rondonópolis - 18, Santarém - 19, Tefé - 20, Tucuruí - 21, Bacabal - 22, Caxias - 23, Marabá - 24, Imperatriz - 25, Parauapebas - 26, Araguaína - 27, Cruzeiro do Sul - 28, Almeirim - 29, Breves - 30, Guarantã do Norte - 31, Jaru - 32, Colíder - 33, Guajará-Mirim - 34, Juína - 35, Pontes e Lacerda - 36, Parintins - 37, Paragominas - 38, Altamira - 39, Ariquemes - 40, Itaituba - 41, Codó - 42, Barra do Corda - 43, Balsas - 44, Redenção - 45, Alta Floresta – 46.
Acronyms for the Brazilian States: To - Tocantins, PA - Pará, GO - Goiás, MT – Mato Grosso, RO – Rondônia, RR- Roraima, AP – Amapá, AC – Acre.

Fig. 3 a) 1995-2000 migration net rates for the Brazilian Amazon municipalities, b) Major deforestation fronts, derived from the integrated analysis of the Amazon urban network, population movements and Socioeconomic Dimension Index, laid over 2000-2001 deforestation hotspots from Alencar *et al*. (2004).


a)
Meso pole
Main river
Dirt roads
Paved roads
DENSITY OF DEFORESTED LAND - 2001
0.82 - 1.00
0.54 - 0.82
0.29 - 0.54
0.10 - 0.29
0 - 0.10
NoData
b)
DEFORESTATION DENSITY 2000-2001
> 0.135
0.065 - 0.135
0.026 - 0.065
0.005 - 0.026
0 - 0.005
NoData
c)
SOCIOECONOMIC DIMENSION INDEX
1
2
3
4
5
High
M. high
Moderate
M. low
Low


a) Micro Poles
b) Meso Poles
c) Macro Poles
RR
AP
AM
PA
MA
AC
TO
RO
MT
Poles
Paved Road
Dirt Road
State Boundary
The Amazon River
0
250
500 km


a)
Migration Net Rates
0.06 to 1.41
0.01 to 0.06
-0.02 to 0.01
-0.06 to -0.02
-0.37 to -0.06
0 250 500 km
b)
Deforestation Front
Meso-Poles
Paved Road
Dirt Road
National and State Boundary
The Amazon River
2000-2001 Deforestation Density
High
Medium
Low