NIH Public Access
Author Manuscript
Popul Environ. Author manuscript; available in PMC 2012 November 03.

Published in final edited form as:
Popul Environ. 2009 May ; 30(4-5): 159–192. doi:10.1007/s11111-009-0083-3.

Revisiting the hierarchy of urban areas in the Brazilian Amazon: a multilevel approach

Gilvan Guedes,
Department of Sociology, Brown University, Maxcy Hall 112 George Street, Providence, RI 02912, USA

Anthropological Center for Training and Research on Global Environmental Change, Indiana University, Bloomington, IN, USA

Department of Demography, University of Minas Gerais, Belo Horizonte, Brazil

Sandra Costa, and
Anthropological Center for Training and Research on Global Environmental Change, Indiana University, Bloomington, IN, USA

Department of Regional Planning, University of Vale do Paraíba, São José dos Campos, Brazil

Eduardo Brondízio
Anthropological Center for Training and Research on Global Environmental Change, Indiana University, Bloomington, IN, USA

Department of Anthropology, Indiana University, Bloomington, IN, USA

Gilvan Guedes: Gilvan_Guedes@brown.edu; Sandra Costa: smcosta@indiana.edu; Eduardo Brondízio: ebrondiz@indiana.edu

Abstract

The Legal Brazilian Amazon, while the largest rainforest in the world, is also a region where most residents are urban. Despite close linkages between rural and urban processes in the region, rural areas have been the predominant focus of Amazon-based population-environment scholarship. Offering a focus on urban areas within the Brazilian Amazon, this paper examines the emergence of urban hierarchies within the region. Using a combination of nationally representative data and community based surveys, applied to a multivariate cluster methodology (Grade of Membership), we observe the emergence of sub-regional urban networks characterized by economic and political inter-dependency, population movement, and provision of services. These networks link rural areas, small towns, and medium and large cities. We also identify the emergence of medium-size cities as important nodes at a sub-regional level. In all, the work provides insight on the proposed model of 'disarticulated urbanization' within the Amazon by calling attention to the increasing role of regional and sub-regional urban networks in shaping the future expansion of land use and population distribution in the Amazon. We conclude with a discussion of implications for increasing intra-regional connectivity and fragmentation of conservation areas and ecosystems in the region.

Correspondence to: Gilvan Guedes, Gilvan_Guedes@brown.edugrguedes@indiana.edu.

Keywords

Brazilian Amazon; Urban hierarchy; Grade of membership; Disarticulated urbanization; Community and urban formation

Introduction

The Legal Brazilian Amazon (LBA)1 shares the reputation of being the largest rainforest in the world and an area of exponential urban development. It encompasses an area of 5,217,423 sq. km, representing 61% of the Brazilian territory and comprising, in 2007, a population of 22,303,252 (i.e., 12% of Brazilian population), over 70% of which live in urban areas. Despite the increasing prominence of cities in the region, population-environment research in the Amazon has focused mainly on rural areas.

There is a growing, but still limited, literature discussing and proposing analytical models of urbanization dynamics in the Amazon. Such models consider the spatial-temporal dimensions of urbanization dynamics and their relation to road-river networks, as well as their social and economic interconnections and consequences. Such studies date back at least to the 1940s (Wagley 1953; Rocha 1968). Not until the 1980s, however, when a clear regional trend in urbanization began to be seen, that more systematic scholarship developed on this topic (for instance, Becker 1985; Sawyer 1987; Machado 1989, 1994, 1999; Corrêa 1987; Browder and Godfrey 1996, 1997; Perz 2000; Browder 2002; Simmons et al. 2002; Padoch et al. 2008).

In the midst of this increasing urbanization, heterogeneity of urban spaces and the resulting complexity of networks, have led some authors to consider whether classical urban hierarchical models can explain the formation of the larger Amazonian urban system and contribute to understand the trajectories and consequences of regional urbanization. In this paper, we use a combination of multivariate fuzzy cluster analysis and spatial analysis to examine the level of primacy among Amazonian cities, their relative importance and infrastructural differences, and their level of interdependency resulting from inter-urban demographic movements. We test the proposition by Browder and Godfrey (1997) of the inexistence of a regional urban hierarchy (“disarticulated urbanization”) and use the methodological approach presented by Garcia et al. (2007) to analyze this proposition. We define hierarchy as the relative ranking of cities based on their level of primacy, complexity of functions, and relative importance within the region, measured by such factors as available city services, attraction of migrants, and population size. Specifically, we integrate and examine the following variables to define the relative level of urban importance and hierarchy within the region: date of municipality creation, urban density, presence and area of natural reserves, presence of roads and rivers, urban infrastructure and services, migration flows, commuting movements and health care provisions. We hypothesize that lower levels of analysis will correspond with higher probabilities of verifying a more symmetrical urban system, i.e., an urban hierarchy in the Amazon exists only below the regional level.

Our model combines different databases within a spatially explicit framework: data from the Brazilian Demographic Census (IBGE 1991, 2000), data from the Brazilian National Hospital Information System and Brazilian National Archive of Hospital Establishment (MS

[1]The Legal Brazilian Amazon—defined for planning and administrative purposes by the federal government in 1966 by Law No. 5173—includes 760 municipalities currently distributed across nine states: Pará, Amazonas, Mato Grosso, Rondônia, Roraima, Amapá, Acre, Maranhão, and Tocantins. The western side of Maranhão is included in the Legal Brazilian Amazon, while the other states are completely included in the administrative region.

1998, 2002a, b), and data from a socioeconomic survey of rural communities in the municipalities of Santarém, Belterra, Placas, Ruropolis, Monte Alegre, and Itaituba, all in the state of Pará (ACT 2004). The combination of nationally representative surveys and community-level data allows us to test the classical articulated urban model (e.g., Christaller 1966) at three different spatial levels: regional, sub-regional, and local. Our analysis of regional urban articulation complements other efforts that have called attention to intra-regional differences (e.g., Perz 2000; Becker 2005) and attempted to stratify and qualify sub-regional urban networks using similar methodology as presented here (e.g., Garcia et al. 2007; IPEA 2002).

This paper is organized as follows. First, we present a literature review of the history of Amazonian urbanization, along with a discussion of the approaches used for analyzing both multi-level regional urban hierarchies and intra-regional urban differences. Next, we discuss the data analysis, including description of the data sets and the Grade of Membership (GoM) model. Finally, we present our results and discussion of urban hierarchies.

In addition to testing theoretical propositions and methodological approaches, our analysis aims at providing subsidies to current efforts to develop regional and state level ecological-economic zoning2 (ZEE) and to inform prognostic models of deforestation and expansion of human occupation in different parts of the region. To date, most prognostic models forecasting regional land use change have discussed urban dynamics using proxies of population growth rates and road connections. Attention to the formation of urban networks, their axis of expansion, and their intersection with a growing but largely disconnected system of protected areas is necessary to understand the future of population distribution, the surrounding human landscapes around protected areas, gradients of land and resource rent value, pollution sources and sinks, the formation of market chains, and regional variations in patterns of economic development.

Urban hierarchy and regionalization of the Amazon region

Urban networks

The city, as defined, is both an element and an economic and social system within a world system that stimulates economic development and technical improvement (Clark 2003; Santos 1997). Different criteria have been adopted to define specifically what a city is and to establish the way cities are connected to each other. However, the complexity of urban spaces, in terms of social relations, economic activities and the range of services offered to residents, makes its definition a difficult task.

Cities are related to "urban places" which are associated to local jurisdictional institutions, such as municipalities, townships, and localities (Henderson 1997). Cities also can be referred to as metropolitan areas, which are collections of contiguous urban spaces within a structurally functional system. Cities are important for offering employment, infrastructure, information, educational services, and essential goods and services (Amorim Filho and Serra 2001). Nevertheless, given their relative value to people, how can we classify cities, or order them in terms of importance, within a complex urban network? Understanding the formation and articulation of urban networks in different levels of organization is an important component of urban and regional planning, particularly in areas experiencing rapid urban expansion such as the Amazon.

[2]Economic-ecological zoning (EEZ) is a spatially explicit planning instrument, usually developed at the state level, which includes an assessment of environmental and socioeconomic conditions and provides directions aiming at reconciling economic activities and environmental conservation (Sombroek and Carvalho 2000).

One important discussion about urban hierarchies was proposed by Christaller originally in 1933 (1966). Christaller, studying urban development in southern Germany, proposed the Theory of Central Places, which defines general principles that regulate the number, size and distribution of towns. Observing the spatial arrangement of settlements in the mostly flat topography of southern Germany, Chistaller noted that towns of a certain size were approximately equidistant. Analyzing the functions of these towns and their hinterlands, he developed a model for predicting patterns of settlement locations using geometric shapes.

Central Place Theory is based on various restrictive assumptions or principles, with settlements (villages, towns or cities) having: (a) consumers rationally favoring the nearest market, (b) transportation costs being equal in all directions and proportional to distance, (c) perfect market competition, which implies no excess economic surplus, (d) gathering of services having similar levels in the same centers, and (e) a hierarchy of services according to their frequency of use.3 Despite not being essential to the theory, additional assumptions are used as tools for deriving its geometrical models, by considering settlements with (a) an isotropic surface, (b) an evenly distributed population, (c) similar purchasing power of all consumers, and (d) markets developing an hexagonal area of influence (Mushinski and Weiler 2002; Shonkwiler and Harris 1996).

Because transportation cost is equal in all directions and there are no underserved or over-served market areas through the surface, for any given order, settlements will be equidistance from each other. Generally stated, the higher the order of a settlement, that is, the more complex its function, the further apart it will be from another same-order settlement and the larger the area it will service. The order of a settlement within a hierarchy is positively associated with its area of influence and negatively related to the number of settlements (Christaller 1966). The distance and spatial organization can vary according to three principles: marketing, transportation and administration. The basic difference regarding the influence of a specific principle on settlement arrangement is the number of places under the influence of a settlement, with market forces producing the narrower influence zone (theoretical assumption a) and administrative function yielding a wider zone of influence.

The concept of central place provides a heuristic starting point to define cities (Hall 2002). Central place can be defined as a settlement that provides one or more services for its hinterland. All cities (small, median, and large) can be considered central places and all are endowed with relative central functions. Cities, in this sense, are providers of goods and services to populations living in their surrounding localities. The centrality of a town is related to the level of relative importance within an urban network, particularly in its scope and type of functions provided to residents, its area of influence, and its population size. As such, a ‘central place’ hierarchy expresses a systematic and cumulative hierarchical pattern organized into a series of functions that defines the proportional distance and quantities of central places within a given region. For example, the higher the hierarchical level of a city, the larger its functional role in providing services to surrounding residents (e.g., higher order services). Low order settlements provide simple basic services (e.g., post-offices, churches, elementary schools, and grocery stores); while high order settlements offer specialized services (e.g., department stores, universities, and specialized hospitals). Importantly, as noted by Christaller, cities can change their place within a regional hierarchy over time.

Urban networks, thus, can be considered as a set of functionally articulated, interconnected cities. These networks are formed with vertices or ties representing different cities, towns or villages that are endowed with urban functions, and the flows between them are achieved by

[3]We thank one of four reviewers for the suggestion of principals (d) and (e).

roads or other forms of transportation, as well as systems of communication (Corrêa 1991). Urban networks therefore underlie the articulation of different groups and economic and political systems within and between societies.

Considering these aspects, some authors (Gohn 1999; IPEA 2002; Clark 1982, 2003) have used population size to rank cities according to their importance within an urban network. Generally, there are five types of cities (Hall 2002): global cities (i.e., more than 10 million inhabitants, dominating the global market and political economic decisions), mega-cities or global metropolises (i.e., more than 10 million inhabitants, high level of poverty and urban problems), national and regional metropolises (i.e., more than 1 million of inhabitants), regional centers or median cities (i.e., population between 50 and 800,000 inhabitants), and small cities (i.e., <50,000 inhabitants). The extent to which these criteria apply to regions such as the Amazon, however, is questionable for two main reasons. First, the position of a city within an urban hierarchy depends on the size of the largest urban center. In the Legal Brazilian Amazon, the largest urban center—Manaus—has a population estimated for 2007 of <2 million inhabitants (IBGE 2007), far less than the population threshold of global or mega-cites from IPEA typology. Second, with increasing prominence of non-central functions in some parts of the Amazon, such as cities specialized in ecotourism and agribusiness, the applicability of evolutionary theories to describe its urban systems has become progressively unrealistic and incapable of fully describe its regional heterogeneity.

The urban hierarchy in the Amazon region

Despite the region's reputation as a rural environment experiencing deforestation, Amazonia has been largely urbanized since at least 1980. New urban centers have multiplied across the landscape in previously inaccessible "terra firme" (upland) forest areas, inspiring different discussions about the nature of urban networks in the Amazon region (Becker 1985, 2005; Martine and Turchi 1988; Sawyer 1987; Browder and Godfrey 1997; Vicentini 2006).

According to the IBGE (2007), in 2007 the Legal Brazilian Amazon had a population density of 4.3 persons per square kilometer; five times lower than the corresponding Brazilian population density. In general, all states of the Legal Brazilian Amazon have low population density (Roraima and Amazonas having the lowest with 2 hab/km^2), with the very exception of Maranhão (>18 hab/km^2; Table 1).

In a sharp contrast with the low density observed at the state level, some state capitals in the Amazon have population density reaching over 1,000 inhabitants per square kilometer (Table 2).4 This is the case of São Luís and Belém, state capitals of Maranhão and Pará, respectively. On the other extreme, state capitals such as Rio Branco and Porto Velho have density under 30 inhabitants per square kilometer, a ratio closer to the national average. Independent of population density, all state capitals of the Legal Brazilian Amazon have an urbanization ratio over 90%, with some reaching almost 100%. The one exception, however, is Porto Velho, the capital of Rondônia. According to Browder and Godfrey (1997), Porto Velho has only an administrative relevance, while Ji-Paraná, the second biggest city of Rondônia, is the economic center of the state. According to the Population Tally of 2007 (IBGE 2007), Ji-Paraná had an urbanization ratio of 88%, in contrast to the 40% of Porto Velho. Its population density is also approximately 50% higher than Porto Velho's (15.6 compared to 10.8 persons/km^2, respectively).

[4]Unfortunatelly the statistics about urban area of Amazonian municipalities were not available from online sources. For that reason, we present in Table 2 the population density of the entire municipalities (state capitals) instead of their urban areas. This table, however, is shown illustratively only. For our GoM analysis, we use the urban perimeter from IBGE, although the distinction between urban and rural still carries some imprecision.

In all, part of the regional variation in population density is due to the large variance in municipality areas. Even so, we find exception such as Rio Branco and Porto Velho. Both have similar population densities but very distinct municipality areas. As suggested by one of our reviewers, this is a reflection of differences in the actual urban density underlying the results in Table 2 and suggested by the less variable results for urbanization ratios across state capitals.

Drawing upon the political economy literature of intersectorial articulation (Goodman et al. 1984; Roberts 1991), capitalist penetration (Armstrong and McGee 1985; Sawyer 1984), and world systems perspectives (Brum 1988; Katzman 1976), urbanization in the region has been interpreted as a deliberate strategy to stimulate regional economic development and alleviate demographic pressures in other parts of Brazil. As a result, many Amazonian cities received batches of small farmers leaving agrarian settlements to live in urban areas, as well as groups of migrants attracted by a tertiary sector in development and, for the most part, by public institutions (Sawyer and Carvalho 1986). This rapid growth has led to cities being unable to offer proper services, such as water and sanitation, to their urban populations (Lira 2008). This process, termed "over-urbanization" by Browder and Godfrey (1997), occurs when urban population growth is unaccompanied by the necessary economic growth and technological change, leading to an asymmetrical and unorganized urbanization. Some authors have considered this process a "ruralization" of the urban (Martine and Turchi 1988), although Browder and Godfrey (1997) presents empirical evidence questioning Martine and Turchi (1988) argument by showing that the majority of Amazonian urban migrants had originated in other urban centers (urban-urban migration). Even so, Becker (2005) affirms that these areas maintain the identity of cities, at least in an Amazonian context, despite their lack of infrastructure and services. The fact is that "many imperative urban problems stay unaddressed in Amazonia, including deficient infrastructure, social and medical services, rapid shantytown growth and pollution" (Browder and Godfrey 1997: 3).

In part, because cities in the Amazon have developed with strong links to the surrounding rural environment, different authors have proposed approaches and theories to explain the unique process of urban development and urban networks found within the Amazon. For example, Browder and Godfrey (1997: 11–15) suggest a pluralistic theory of disarticulated urbanization to explain the lack of an urban hierarchy in the Amazon and the existence of a nontraditional urban network. According to these authors, this disarticulated nature of urbanization in the Amazon is a result of multiple processes and factors, such as: (a) the Amazon is a heterogeneous social space; (b) the configuration of settlement systems in Amazonia is irregular and polymorphous, without a clear principle of spatial organization; (c) urban growth is functionally disarticulated from agricultural development in many parts of the region; (d) rapid urbanization is not linked to regional industrialization; (e) urbanization in Amazonia is linked to economic forces operating at the global level, but not necessarily subordinated to a world economic system; (f) urban centers in Amazonia are technological crossroads that link specific activities to global circuits of information and exchange; (g) the contemporary Amazonian urban frontier is largely geopolitical but remains politically disarticulated from a central state system; (h) the rural–urban dichotomy is problematic in Amazonia due to complex and regionally heterogenous patterns of population movement and migration; and, (i) environmental change caused by tropical deforestation, including water contamination and resource depletion, is increasingly mediated by urbanbased interests. We add to this list of forces molding the complex urbanization process in the Amazon, (1) the recent settling of most urban centers, (2) the new interest in regional ecotourism, which has been affecting land prices and linkages between urban and rural areas, and (3) initiatives from the government to demarcate reserves and promote local governance of resource use systems (Fearnside 2003; Becker and Léna 2002; Motta 2002).

The confluence of multiple factors has produced settlement systems in the Amazon Region which are disarticulated from any single master principle of spatial order, and a spatial organization "largely asymmetrical providing scant evidence of orderly, nested hierarchies predicted by Central-Place Theory" (Browder and Godfrey 1997: 95). The influence of migration on urbanization dynamics in the Amazon is an illustrative example of its disarticulated nature. Because some cities in the Amazon whose economies are based on extractivist activities have been proved to fail in maintaining a sustainable job market for a long period, a proportion of their population tends to out-migrate towards new active extractivist or agrarian frontiers in search of emerging opportunities. These population shifts the dynamics of growth away from a previously urban center, creating a turning point in its trajectory of urban development and affecting the provision of services and infrastructure to its surrounding areas. In some cases, these cities become hollow or ghost cities with declining local importance and economic stagnation. These patterns are not predicted by the Central Place Theory or any other evolutionary and linear progressive approaches, such as the Turner theory of frontier development from agrarian to urban centers (Turner 1920).

In other instances, historical cities linked to government-led agrarian settlement projects have become locus for new corporativist projects. In Santarém, a major export harbor recently has been created, using private as well as government funding, in order to facilitate the channeling of the recent large scale soybean production in the region and grain production coming from the center-western region of Brazil, connected to Santarém through the highway BR-163 (Liberal 2002). In this area, two frontier systems are present: unsuccessful government-led colonization projects and recently promoted large-scale systems of soybean export, representing a recent penetration of large-scale capital in a previously small-scale rural production system. Santarém, although a city of sub-regional importance for more than a century, is now directly linked to global cities as a result of ambitious planning by the Brazilian government to outcompete the US in soybean production and export.

The peculiarities of the region's urban network systems, as illustrated above, also have led some authors to propose approaches to discuss the "regionalization" of the Amazon (a typology of regional blocks) by highlighting intra-regional urban differences (e.g., Perz 2000). Such efforts to disaggregate the Amazon into intraregional blocks are aimed at showing economic discrepancies within the region and, ultimately, support approaches to regional development and planning that are sensitive to social-economic differences. Perz (2000), discussing the socio-environmental dimensions of urban areas, pointed out that Amazonian cities can differ considerably "from one part of the region to another" (p. 190). He suggests several questions and approaches to examine whether and how the quality of life in Amazonian cities improves over time, arguing that it is possible to discriminate between urban areas of different status and environmental quality and between newly-formed and more established urban areas.

The Brazilian Applied Economic Research Institute (IPEA 2002) has developed extensive research characterizing the Brazilian urban network by region, using criteria based on urban size, urban function, functional dependency, and area of city influence. In the Amazon, the IPEA recognizes one Metropolitan Agglomeration (Belém), six cities as first order Regional Urban Centers (Palmas, Porto Velho, Rio Branco, Manaus, Boa Vista, and Macapá), and four cities as second order Regional Urban Centers (Santarém, Marabá located in the state of Pará, Araguaína located in Tocantins, and Ji-Paraná located in Rondônia). Yet, it is important to consider Manaus as having a first level of importance in the region, in many aspects, similar to Belém. Manaus is the backbone of the state of Amazonas and plays important roles for the entire western part of the Amazon. It is strongly connected to national and international markets through its industrial system. Arguably, however, Belém continues to play its historical role as an urban area connected to and influencing the Amazon region as a whole.

Additionally, Garcia et al. (2007) have characterized urban networks in the Brazilian Amazon using a model that integrates levels of socioeconomic organization of municipalities and their interrelationships, as determined mainly through the strength of migratory movements. Their proposed model of territorial organization includes five components: (1) the hierarchy of central places (poles) established by the concentration of urban specialized services, (2) the geographical distance between central poles and other centers, (3) population size, (4) the level of migratory movements among municipalities, and (5) a socioeconomic index. These components were combined into a gravitational model, using Grade of Membership (GoM), to produce measures and maps of municipal networks in the Brazilian Amazon. As a result, out of 792 municipalities in the Brazilian Amazon, nine were classified as macro-poles, 29 were classified as meso-poles and 48 as micro-poles. The areas of influence of these poles were determined according to the three hierarchy levels: macro (e.g., all nine state capitals), median (e.g., median municipalities) and micro poles (e.g., 116 municipalities).

In this paper, we develop a conceptual model of urban system formation (Fig. 1), from the level of rural properties and rural communities, to their interconnections to small and medium cities, and to subsequent connections to large cities at sub-regional and regional levels. These large cities, at a regional level, comprise a wider network, exchanging population (through migration and commuting movement), capital, services and commodities among them. The model also considers these large cities as having possible direct connections to small cities and communities, as well as small towns having direct linkage with outer areas through the presence of large-scale capital financing production systems or transportation networks (such as harbors, airports, and credit for large-scale grain production farms), underscoring the disarticulated nature of the Amazonian urban system, as argued by Browder and Godfrey (1997).

The model is flexible enough to recognize the presence and persistence of traditional urban hierarchies at smaller scales, such as local or sub-regional levels. As argued by Browder and Godfrey (1996, 1997), the Brazilian Amazon is a quasiexperiment for urban geographers, where new areas are beginning to be populated, and urban systems assume different forms over time. Old cities have been exposed to different government policies and influenced by external forces, while traditional local political elites have been challenged by new ascending social groups. As a result, cities change their relative position within an urban network over time. For instance, areas undergoing processes characteristic of frontier occupation (e.g., intensive extractivism, rapid land cover change, active land market, fast population turnover, and disorganized forms of occupation) may, eventually, develop more symmetric urban systems and networks as they mature. The occurrence of many such cases throughout the region, thus, adds to the already heterogeneous urban landscape of the Brazilian Amazon.

Several conditions render the urbanization of the contemporary Legal Brazilian Amazon different from that experienced in other parts of the world, and not least southern Germany in the first half of twentieth century, which gave rise to the ‘Central Place Theory’. First, the Amazon basin has an irregular surface both in topographic and biophysical terms (e.g., soils, topography, resource distribution, and seasonality). Upland and wetland environments differ considerably across the region. Because of differences in occupation history, government policies, landscape accessibility and distribution of resources, population are not evenly distributed. The lower density of northwestern and southwestern Amazonia contrasts with the highly populated northeastern and southeastern parts of the region. Since different frontier systems developed in different areas, purchasing power of potential consumers greatly varies across regions. Local dependency on external food supply contrasts with areas of self-provisioning; fast growing shantytowns create demands for services and new political priorities. Differences in food supply and uneven service distribution create various forms of market influence, within and across parts of the region. Furthermore, diverse forms of frontier expansion incorporate external capital at different scales and intensities, while generating market concentration in certain areas and market absence in others. Finally, government participation in the Amazon has varied not only across space, but also through time. Political alliances between the federal government and national/foreign capital have brought support to some areas and total disregard to others. Furthermore, change of political regimes in 1985, from a military to a civilbased government, dramatically affected the level and forms of political participation of government agencies and civil organizations in regional urban development.

In all, we contribute with a conceptual framework which aims at advancing the notion of disarticulated urbanization by addressing the urban network creation and development at different levels and by calibrating an empirical multilevel model with data from the Brazilian Amazon region at regional, sub-regional, and local levels of data aggregation. This is particularly important in the Amazonian context because of the increasing presence of node cities, as we will discuss later in the text, which provide services and infrastructure to their surrounding areas, such as in more traditional spatial organizations.

Data acquisition and model development

Data acquisition

As described above, we used several data sources to study and analyze urban growth, development, and hierarchy at three different spatial levels of the Legal Brazilian Amazon—regional, sub-regional and local (Fig. 1).

The Legal Brazilian Amazon is composed of a total of 760 municipalities, 334 of which were created after the Brazilian Constitution of 1988 (IBGE 2007). At the time of the 2000 Brazilian Demographic Census, 747 municipalities were found within the region. Therefore, our analytical sample includes 747 observations at the level of municipalities, derived from micro level data collected by the Brazilian Demographic Census (IBGE 1991, 2000).[5] Because some variables, such as infrastructure and household income, were only available for private and permanent households, we discarded other types of households in the analyses (i.e., private but temporary households and collective households[6]). The discarded household observations correspond to 1.92% of the population in 2000. Thus, our final sample includes 530,188 households and 2,368,515 individuals. Nevertheless, for analysis of commuting movements within the region, we preserved a sample of 2,404,083 individuals living in 541,573 households in order to avoid sample selection bias.

We also used databases from the Brazilian National Council of Municipalities (CNM 2007), the Brazilian Hospital Information System (MS 1998, 2002a, b), the Brazilian Population Tally (IBGE 2007) and the Brazilian National Archive of Health Establishments (MS 2002a, b) for analysis of the regional and sub-regional urban levels.

For the local level, we used ethnographic field data, community surveys, and archival research collected by members of the Anthropological Center for Training and Research on Environmental Global Change at Indiana University of 181 communities located in the

[5]For analysis of trends in urbanization, we used the Brazilian Demographic censuses from 1970 to 2000.
[6]In the Portuguese, “domicílios coletivos”.

municipalities of Santarém, Belterra, and Monte Alegre (ACT 2004). Our community sample, surveyed in 2004, ranges, in terms of population size, from 10 to over 5,000 individuals. These communities are formally recognized by municipalities (i.e., listed in public records for health and school services) and by the regional Catholic diocese. These communities vary in their distances to local towns and urban centers, and also vary in their date of creation, from <5 years old up to the colonial era (i.e., 200 years old). Table 4 presents a list and descriptions of all variables used for analyses.

The profiles generated from the local level present a limitation: the absence of a variable representing connections between rural communities and between rural communities and urban centers (e.g., commuting, frequency of visits). In order to overcome the absence of a proxy for demographic and functional linkage, we selected the municipality of Santarém to analyze commuting movement from urban areas of neighboring municipalities included as part of our community-level sample. As shown below, Santarém appears in our regional level as an urban area with a sub-regional first level importance and includes the communities with the better relative position at the local level.

The grade of membership model

Model description—The Grade of Membership (GoM) model is a statistical methodology used to delineate clusters of elements (or 'profiles' of a group of elements based on their characteristics) within a heterogeneous and multidimensional dataset (Woodbury et al. 1978; Manton et al. 1994; Lamb 1996; Portrait et al. 1999, 2001; Cassady et al. 2001). The main difference between GoM and the majority of other clustering techniques is that the former does not consider individuals and objects to be organized in well-defined (i.e., 'crispy') sets. The GoM model is classified as a fuzzy cluster technique because the same individual is allowed to have a certain level of pertinence to multiple sets. This is an important aspect of GoM because individual heterogeneity at the category level can be estimated, producing a finer description of the sample heterogeneity (Machado 1997).

As discussed by Garcia et al. (2007), in addition to population size and density, other factors that are relevant when defining an urban hierarchy include geographical isolation, migration, and social development, especially provision of services and infrastructure. We argue that elements such as the date of municipality formation, and natural characteristics, such as proximity to rivers and/or roads and areas of natural reserves and parks, contribute to or constrain position of the municipality in the urban hierarchy and its trajectory over time. As most of the transportation networks in the Legal Brazilian Amazon is still incipient and precarious, roads and rivers networks along with federal regulations regarding access to natural reserves represent specific geographical, anthropogenic and institutional constrains, affecting the probability of traditional hierarchical formation.

In the GoM model, we generated profiles of urban areas, which differed from the ones proposed by Garcia et al. (2007) in four different ways: (a) our unit of analysis was the urban area of each municipality,[7] not the entire municipality; (b) our sample included only the municipalities within the Legal Brazilian Amazon; (c) we included geographical characteristics of the municipalities, such as the area of natural reserves and parks and the presence of roads/rivers within the municipality; (d) we included the date of municipality

[7]The urban area is based on the classification adopted by IBGE in the Brazilian Census, according to the municipality law from September 1, 1991 (IBGE 1991, 2000). Therefore, for all the variables used from the Demographic Census, we selected the observations classified as in the urban sector, which includes: (a) urbanized area (city); (b) not urbanized area (distrital seats), and (c) isolated urban area. We recognize that the classification of observations into urban sector is somewhat imprecise and may include more than one settlement, but is the closest we can get using the micro data from IBGE. For the geographical variables, we considered the urban perimeter also provided by IBGE. We explicitly recognize that some bias still persists due to likely variation in measurement from one census to the other.

creation for each city in our sample. We believe that the inclusion of the last two factors and the addition of local level data will greatly improve upon other empirical models of urban hierarchy that have not included these factors.

The empirical application of GoM implies that:

1. Two or more well-defined profiles, called extreme or reference profiles, are identified from the non-observed association among the categories of variables in the model;
2. Reference profiles correspond to crispy sets with same mathematical properties;
3. Each individual possesses degrees of pertinence to extreme, or reference, profiles. For example, if an individual displays all the characteristics of one of the reference profiles, his/her degree of pertinence to that profile will be 100% and, consequentially, 0% to the other. Thus, the closer the person is to one reference profile, the higher his/her degree of pertinence is to that profile and lower to the others.
4. It is common for individuals to have no predominant characteristics of any specific reference profile (i.e., individuals who are equidistant to all extreme, or reference, profiles).
5. An individual's degree of pertinence to the reference groups constitutes a fuzzy set. Therefore, a larger number of variables will improve the definition of the fuzzy set;
6. Non-observed heterogeneity is not considered a problem for the GoM because the elements of the sets are individual attributes;
7. Parameters are estimated through iterative processes. This implies that smaller sample sizes will require shorter time for the likelihood function to converge to its maximum value.
8. The previous assertions attest that GoM has the desirable property of analyzing categorical data for small samples with a large number of variables and of dealing with endogeneity.

In the GoM method, an estimate of the degree of pertinence for each individual relative to all the sets is created, resulting in a fuzzy set or partition for each individual. This fuzzy partition of each individual is used to delineate the extreme, or reference, profiles. For each element in a fuzzy set, there is a score of the degree of pertinence, g_{ik}, which represents the degree to which that element "I" belongs to the reference group, *k*. These scores vary from 0 to 1. Zero indicates that the element does not belong to the set and one means that it entirely belongs to the set. The value g_{ik} represents the proportion or intensity of pertinence to each of the extreme profiles. Thus, the following constraints to each parameter (or score for each individual) apply:

$$g_{ik} \geq 0 \quad \text{for each } i \text{ and } j$$

$$\sum_{k=1}^{k} g_{ik}=1 \quad \text{for each } i$$

The following assumptions apply for the model specification and the estimation of the parameters (scores):

1. The random variables represented by Y_{ijl} where "*i*" refers to the individual, "*j*" to the variable and "*l*" to each category of the variable are independent across "*i*". That is, the answers given by each individual are independent;
2. The g_{ik} ($k = 1, 2, \ldots, k$) are moments of the random vector $\zeta_i = (\zeta_{il}, \ldots, \zeta_{ik})$ with distribution function $H(x) = P(\zeta_i \le x)$. Thus, GoM scores are the result of random variables when an individual is selected in the population under analysis. The distribution of the samples of realization (the scores in the sample) gives the estimates of the distributional function H(x);
3. If the degree of pertinence, g_{ik}, is known, the answers to the questions Y_{ijl} by individual "*i*" are independent across categories for the same variable;
4. The probability to answer "*l*", for the *j*th question, for the individual with the *k*th extreme profile, is λ_{kjl}. By assumption, there is at least one individual who is a well-defined ('crispy') member of the *k*th profile. This assumption gives the probability that this individual has to answer each category for each question.

   This assumption can be represented as:

$$\lambda_{kjl} \ge 0 \quad \text{for each } k, j \text{ and } l$$

$$\sum_{k=1}^{k} \lambda_{kjl} = 1 \quad \text{for each } k \text{ and } j$$

5. The probability of an answer at level "*l*", of the *j*th question, by individual "*i*", conditional to the score g_{ik} is given by:

$$P(Y_{ijl}=1) = \sum_{k=1}^{k} g_{ik} \lambda_{kjl} = 1$$

The probability model, based on a random sample, is the multiplication of the multinomial model by the probability for each cell, given by:

$$E(Y_{ijl}) = \sum_{k=1}^{k} g_{ik} \lambda_{kjl}$$

where g_{ik} is, by assumption, known and equal to or bigger than zero. The maximum likelihood model is, then, described as:

$$L(y) = \prod_{i-1}^{I} \prod_{j=1}^{J} \prod_{l=1}^{L} \left(\sum_{k=1}^{k} g_{ik} \lambda_{kjl} \right)^{yijl}$$

Defining the extreme profiles—The number of extreme profiles can be established according to two criteria: (1) by means of a theoretical orientation (Sawyer et al. 2002), or (2) by a technical criterion, as suggested by Manton et al. (1994). According to the authors, a model with $k + 1$ profiles can be compared to a model with k profiles using the values of the Akaike criterion (AIC) for each extreme profile as the test statistics. A generalization of the estimated AIC of the maximum likelihood function allows the selection of the model with the smallest distance from the data, even in cases where the structural model is unknown. In our analysis, we based our criterion on the number of hierarchical regional levels proposed by Browder and Godfrey (1996, 1997).8 Thus, we fixed three reference groups, using a theoretical orientation, which are the three hierarchical levels proposed by the authors.

Besides defining the *number* of reference groups, the next step is to define *who* they are. To identify them, there are three alternatives: (1) by random selection, (2) via external restriction using an attribute or (3) fixing the degree of pertinence of a subgroup in order to delineate the final profiles (i.e., estimation in two stages, as applied by Seplaki et al. 2004; Sawyer et al. 2002). In this paper, we used random selection to freely describe the heterogeneity arisen from our sample. Random selection is an attractive method for defining reference groups because it allows all attributes to have equal weight. The other methods are more appealing only when there is a consensus about the most important variable in delimiting the nature of a reference group.

We selected seven groups of variables to include in the GoM model showed in Table 4. The physical infrastructure variables, originally at the household level, were transformed into proportions of households with the selected infrastructure feature by municipality, creating a cumulative distribution that better fit the purpose of defining hierarchy. All these variables were categorized as quantiles (quintiles and deciles) along the cumulative distribution.9 The health care provision variables were analyzed as a proportion of 1,000 habitants and were also categorized in quintiles.

The estimated values of λ_{kjl} were generated by the GoM model. These values represent the probability of a category of a variable to be part of each extreme profile. This value was divided by the percentage of observations in the correspondent category of the same variable in the whole sample. This ratio is known as the Lambda-Marginal Frequency Ratio (LMFR). Operationally, each lambda value (predicted probability) was divided by the relative marginal frequency for each variable used in the analysis. Every time the LMFR ≥ 1.2 for one category of a variable, this category was considered to be dominant in that extreme profile. Using a higher LMFR increases the likelihood of a given variable to not be selected as part of a given profile (see Machado 1997). The threshold is arbitrary and depends on the degree of heterogeneity one wants to capture in the sample (Sawyer et al. 2002). The three extreme profiles thus were described according to the categories of each variable with the LMFR ≥ 1.2 (Table 1).

The algorithm for the mixed profiles

Mixed profiles are considered the core of GoM results. In the previous section, we defined the extreme (pure) profiles. A profile is considered pure when its elements have degrees of pertinence equal to one. Therefore, we can represent the pure types (or extreme profiles) for the regional level as:

$$\mathrm{EP}_{\mathrm{in}} \Rightarrow g_{\mathrm{in}}=1 \text{ with } n=1, 2, 3 \text{ and } i=1, \ldots, 747$$

[8]Garcia et al. (2007) use a slightly different strategy. They define two extreme profiles representing the ends of the ranking and calibrate the observations (municipalities) by means of the degree of pertinence, g_{ik}. This implies a continuous hierarchy, differing from our calibration of three extreme profiles. The additional profile in our calibration is a response to empirical findings from Costa and Brondizio (n.d.) of important node cities representing municipalities with average population size. Even when we tried different calibration, such as the deffuzification with $k = 2$, as proposed by the authors, our general results did not change significantly.

[9]For instance, if a selected urban section of the municipality had 23% of its urban households served with garbage collection service, it was classified as belonging to the third decile of the garbage collection service distribution (from 20 to 29%).

The reference groups are, in general, profiles that might contain unique or rare characteristics in a population. A precise definition of the mixed profiles is relevant insofar as the majority of individuals in a population differ, with some degree, from the pure types. Dissimilarity arises from the heterogeneity in the sample. In our case, the three pure types represented 32.1% of the municipalities in the Legal Brazilian Amazon, meaning that almost 70% of the Amazonian cities differ, somehow and with a certain degree, from the reference groups.

By definition, the bigger the difference of attributes of any given element from the attributes of a given extreme profile, the smaller the preponderance of that pure type in its characterization. Because of that, the criterion of individuals clustered by the preponderance of a specific pure type seemed more appropriate. Based on predominance criteria, we established an algorithm that was able to define three types of mixed profiles, combining different degrees of pertinence to the three extreme profiles previously created:

a. Profiles of high preponderance (PHP):

$$PHP_n \Rightarrow 0.7 > g_{in} > 1 \text{ with } n = 1, 2, 3 \text{ and } i = 1, \ldots, 747$$

b. Profiles of relatively high preponderance (PRHP)

$$PRHP_{nm} \Rightarrow (0.5 \geq g_{in} \geq 0.7) \cap (0.1 \leq g_{in} \leq 0.4)$$

$$\text{with } i = 1, \ldots, 747 \text{ and } n,m = 1, 2, 3 | m \neq n$$

c. Profiles with relative pairwise predominance (PRPP)

$$PRPP_{nm} = g_{in} + g_{im} \geq 0.6666 \cap [(g_{in} < 1.5 g_{im}) \cup (g_{im} \text{ 003C; } 1.5 g_{in})]$$

$$\text{with } i = 1, \ldots, 747 \text{ and } n, m = 1, 2, 3 | m \neq n$$

Interpreting multi-level urban hierarchies in the Amazon

The GoM fuzzy cluster model used seven groups of urban characteristics to generate mixed profiles, characterizing Amazonian urban areas: demographic configuration and dynamics, population movement, spatial dimensions, foundation date, physical infrastructure, social development indicators, and geographical landmarks Table 4).

Table 3 summarizes the distribution of Amazonian municipalities by profile both extreme and mixed), according to the GoM analysis. The profile “Recent Small Cities” clusters the poorest cities, generally only recently created, with those presenting the worst urban infrastructure, the smallest average urban population size, and also representing areas of out-migration. These cities are predominately located close to roads. The profile “Historical Growing Small Cities” incorporates intermediate urban areas, in terms of income, infrastructure, urban population size and migration. Interestingly, these are municipalities that contain the largest area of natural reserves and parks. This group also includes some of the oldest municipalities in the Amazon. The profile “Medium Cities and Urban Agglomerations” represents the other extreme: the richest urban centers in relative regional terms, concentrated at the upper levels of infrastructure and urban population size distribution. These areas attract the largest amount of temporary workers and students with their home residency in a different municipality and permanent immigrants within the region, and generally include a relatively high level of health care provision. These municipalities were founded mostly between 1950 and 1970 and have considerably smaller areas of natural reserves and parks.

Figure 2 shows the profiles generated using the GoM model (profile characteristics are described in Table 3). The figure suggests regional differences in terms of settlement ranking (large, medium, small) and spatial pattern (distance between urban centers). The state of Amazonas, for instance, has one central city (Manaus, the state capital), followed predominantly by small, mostly distant, ones. The virtual absence of medium-size cities in the state, in itself, departs from more “traditional” urban networks systems based on the articulation of large, medium, and small cities. The state of Pará has cities of different sizes and levels of importance, and its most important city, Belém, is located far from most of the others cities in the state. This spatial pattern gives medium-size cities a significant function in relation to lower level ones. In this sense, the disarticulated nature of the Amazon’s urban system arises from the lack of evidence of a hierarchical order and spatial pattern of central cities positioned within their surroundings. This confirms Browder and Godfrey’s (1997) hypothesis of disarticulated urbanization in the region. We also found a pattern of regionalization of cities with similar characteristics. These clusters of “similar” cities do not perfectly coincide with political boundaries, however. Thus, we can roughly categorize the Legal Brazilian Amazon into four main groups: (a) Acre, Amazonas and the Northwest of Pará; (b) Roraima; (c) Rondônia, Mato Grosso, Amapá, and the center-west of Pará, and (d) Eastern Pará, Maranhão, and Tocantins. These four areas approximately correspond to the ones proposed by Perz (2000).

Defining the regional and sub-regional levels

Based on the previous discussion and findings from the first stage of GoM profiles, we reclassified the Amazonian cities into seven different levels of urban hierarchy (Fig. 3): (a) regional first level (Belém, Manaus, Cuiabá, Porto Velho, Macapá, and Boa Vista); (b) regional second level (São Luís, Rio Branco, and Palmas); (c) sub-regional first level (the cities of Imperatriz, Araguaína, Ji-Paraná, Marabá, Santarém, Altamira and Rondonópolis, plus 68 other cities); (d) sub-regional second level (211 cities); (e) local first level (224 cities); (f) local second level (56 cities), and (g) local third level (173 cities).10

The disarticulated nature of urbanization in the Legal Brazilian Amazon suggested by Browder and Godfrey (1997) can be further visualized in Fig. 3. Some small urban areas of limited importance offer the only urban alternative for some populations in hundreds of square kilometers. Similarly, important sub-regional cities are “disconnected” from regional urban centers, creating a pattern that does not correspond to Chirstaller’s theory (1966). This disarticulation also creates unexpected linkages within and between cities and between different states, calling attention to the limits of using municipal area boundaries as units of analysis. The state of Amazonas, as mentioned before, is a good example of this uneven order of distribution of settlements: 90% of cities have less then 50,000 inhabitants and only one city is considered as a regional first level city.

Despite the lack of evidence of a traditional hierarchy at the regional level, it is possible to see the rise of sub-regional hierarchies centered on node service cities in different parts of the region (Costa and Brondizio n.d.). For example, Santarémis a city with sub-regional urban relevance that is surrounded by cities with a lower level urban hierarchy, such as Belterra, Aveiros, Monte Alegre, Rurópolis, and Placas (Fig. 4).

The emergence of these sub-regional node cities is the result of a growing physical and functional connectivity and the consequence of deficient services and economic conditions for a large group of small cities. These deficiencies increase the level of inter-dependency

[10]The first regional level was based on the main capitals included in the extreme profile, “Medium Cities and Urban Agglomerations”, plus Belém. The second regional level incorporated the other capital cities in the same extreme profile. The first sub-regional level was based on the remaining cities classified as a member of the previous extreme profile. The second sub-regional level included the cities classified in the mixed profile, “Medium cities with good infrastructure”. The first local level includes cities with the highest urban population growth rates. The second local level includes cities with average urban population growth rates. The third local level represents cities with the lowest population growth rate.

between cities and between rural and urban areas, which reinforce the emergence of these node service cities and consolidate their importance over time. Because they are surrounded by towns, rural areas and villages with deprived infrastructure, these sub-regional node cities inevitably attract an influx of immigrants, both permanently and seasonally, from these areas, as can be seen in Fig. 4. The majority of people going to Santarém do so in order to work or study, often from small nearby cities in other municipalities, such as Belterra, Prainha, and Alenquer.

Defining the local level

In a 1978 study of rural communities (*povoados*) along the Belém-Brasília highway, Becker (1978) proposed a methodology to differentiate levels of hierarchy and importance among villages established between 1953 and 1963 along this corridor. Her indicators ranged from basic functions such as schools, churches, and cemeteries, to distinct activities such as the availability of specialized stores (e.g., veterinary products) and processing plants (e.g., dairy). Population size and density also were used as an indicator of hierarchy.

Our study of local level hierarchy among rural communities uses comparable variables to those proposed by Becker. Similar to our above analyses, we apply the grade of membership (GoM) model using a wide array of variables, including infrastructure and services (see Table 4).

Ranking communities by population size, Mojuí dos Campos stands as the most populated community in the region. Other communities, such as Secretária, Vista Alegre and Limão Grande, also appear prominently in this analysis, when ranked in terms of population size and density. Our GoM analysis (Fig. 5), on the other hand, allowed us to test the role of infrastructure and service variables on the delineation of a local level hierarchy. The model found differences not only in terms of population size, but also as a function of the availability of services such as health centers, post office, banks, gas station, and commerce. Community age was generally associated with a higher level of services and population size at the local level. However, communities created in the same period showed different levels of services and population size depending on the municipality in which they were located. For example, old communities located in the municipality of Santarém provided better services, such as the presence of a bank post office and health centers, than old communities located in Belterra and Monte Alegre.

This finding suggests that the overall position of a settlement in a hierarchy depends on its entire zone of influence, including which sub-areas it affects (lower order settlements) and which supra-area it depends on for more complex service provision (higher order settlements). This result may be taken in perspective, because our local level survey comprises a specific area in the Amazon, considered by Browder and Godfrey (1997) as part of the populist frontier. On the other hand, the recent participation of foreign capital in the region (Becker and Léna 2002; Liberal 2002), with the creation of a new harbor in Santarém and its connection with the epicenter of soybean production in Brazil through the BR-163 highway, makes the region an hybrid case of populist and corporativist frontier.11

[11] According to Browder and Godfrey (1997), the main difference between a populist and a corporativist frontier is the degree of capital penetration and the scale of production, although the authors consider other elements which encompass such distinction. While Santarémis part of the government project of small-scale agricultural colonization scheme back to the 1970s, the recent introduction of large scale soybean production and export is redefining its orientation towards the national and global economy. This recent penetration of agribusiness has developed in tandem with surviving smallholders who contribute significantly to regional food production but whose production is mostly based on limited access to technologies.

Discussion

Methodological remarks

In our study, we combined datasets from different sources and scales using a multilevel approach in order to understand the process of urbanization and hierarchy of urban areas in the Brazilian Amazon. Our findings suggest that finer scale data adds constructively to the understanding of urban process in the region, as in the emergence of node cities at the sub-regional level and in the prominence of communities in-between urban centers with a micro-hierarchical position in the provisioning of services and social activities at the local level. The findings are also suggestive of sensitivity of city position along the urban ranking to unit boundaries.

We used a fuzzy cluster analysis to generate profiles of urban areas along an urban hierarchy (according to variables described below in Table 4). As most variables considered important determinants of urban hierarchy are endogenous to the hierarchical position and dynamics of a city or community hierarchy over time, we decided to apply a non-parametric *cluster* analysis. In addition, the option for a *fuzzy* technique was considered in order to test the hypothesis of a *disarticulated* urban hierarchy. As each category of each variable for a single urban area is the element of clustering, the same urban area can have part of its attributes allocated to one group of extreme urban areas while other categories of the same urban area's attribute can be allocated to a different extreme profile. The partition of its attributes results in different degrees of pertinence for the same urban area to different extreme profiles. As a result, small cities with high level of infrastructure can be clustered close to large, main cities in an urban hierarchical typology. For example, as described above, the municipality of Altamira, a remarkably large municipality with a small urban area and with most of its territory covered by reserves, had its urban perimeter classified in a similar relative position in terms of urban hierarchy by the GoM model as the urban perimeter of Belém, although Belém is the main and biggest municipality in the State of Pará, and also the only metropolitan area of the Legal Brazilian Amazon.

Part of the explanation for this case, and an issue of methodological relevance for Amazonian population-environment studies, arises from the unit of analysis applied: the spatial distribution of infrastructure and population in Belém is shared with other municipalities of the metropolitan areas, creating a singular functional entity. However, in our model, we used the urban area of Amazonian municipalities instead of metropolitan areas as unit of analysis. This is why some cities appear in the same hierarchical level in our analysis as Manaus and Belém, while in other studies they are allocated to different levels of hierarchy (IPEA 2002). The sensitivity of a typology to the unit of analysis is a relevant dimension of our results. Garcia et al. (2007), for example, generalize the urban reality when using the entire municipality as the unit of analysis. Changing the unit modifies the relative position of some cities in the urban hierarchy when compared to the classification proposed by the previous authors, as it will be discussed in the next section. This difference in the spatial unit is fundamental when considering an urban hierarchical typology, insofar as discussed above, most Amazonian municipalities comprise a large territory but have a very small urban area. This heterogeneity must be explicitly modeled in any effort when creating an urban hierarchical typology.

This work also contributes to the study of urbanization in the Amazon by combining datasets representing different levels of analysis and using diverse techniques of data collection and processing. Drawing on the methodological tradition of multi-method approaches for social science research (Axinn and Pearce 2006; Ragin 1987; Pearce 2002; Brondizio 2005, 2006), we argue that combining large-scale secondary data with local survey data based on a combination of structured methods with ethnographic approaches for data collection (such as direct observation, semi-structured interviews and participatory rural appraisal) can considerably add to the understanding of multi-level and multi-causal phenomena. First, a local scale mixed-method research design allows deeper understanding of local reality for a fixed budget and time constraint; though it requires direct involvement of the researcher with his/her object of analysis. Second, it adds more flexibility to local specificities, which is less likely in more standardized large-scale surveys. Third, it is better suited for dealing with multiple causation, partially because of the less structured nature of the research design (from sampling design to data analysis), including direct participation and physical presence in the research site. Third, the combination of different approaches and levels of analysis strengthen the final analysis by balancing the weakness of one method or approach with the strength of the other.

More specifically, incipient sub-urban systems and intra-urban variations are not captured in large-scale surveys, such as demographic census and administrative records. The use of our ethnographic based survey allows us to observe the organization of incipient and more established communities within municipalities, shedding light on the principles underlying local level settlement systems and adding to the understanding of urbanization dynamics. Local scale surveys also may contribute to future efforts of modeling urban systems formation or fragmentation in the Amazon. Moreover, local scale surveys might be an important future source for local development program evaluation regarding forest resource management and the role of the new Amazonian commodities, such as the Açaí berry and soybeans, on rural sustainability, environmental consequences and urban dynamics in the forthcoming decades (Brondizio 2008).

Urban hierarchies and implications for urban development and environment

Our findings suggest that three main factors influence urbanization at the level of communities: population size, quality of infrastructure, and availability of services. While comparison of population size alone is limited for differentiating hierarchical levels, it does correlate, although not linearly, to level of functional complexity, as the results shown in Fig. 5 suggest. Our data show that a threshold of 900 inhabitants indicates the presence of specialized services and, thus, a higher position in the hierarchy. Communities with houses built from durable material, access to some form of treated water and sanitation, and services such as a health post, appear higher in the urban hierarchy. On the other extreme, there are several young, small, and precarious communities with limited resources to its residents, implying that the availability of even small additional services is enough to elevate a community's position in the hierarchy.

No clear hierarchical pattern seems to emerge at the local level, as there are similar numbers of communities within each hierarchical category. This is not totally surprising given that many communities receive similar levels of support from municipalities and can access services in urban centers such as Santarém. There are, however, large and important communities located away or in-between regional urban centers. These communities provide important services to other surrounding communities and farms. Becker's (1978) study of rural community hierarchy along the Belém-Brasília highway, for example, demonstrated that village hierarchy was inversely related to proximity to towns and cities. In other words, the closer a village is located to a larger town, the lower its hierarchy is in relation to other villages. Villages at longer distances from towns increase their local importance and their role in providing services to their surroundings. In a region where distances and travel conditions are significant constraints, communities in-between urban centers assume a micro-hierarchical position in the provisioning of services and social activities.

Our model, both theoretical and empirical, emphasizes the heterogeneity of the local level, not only at the level of communities, but also at the level of small cities. As discussed above, most of Amazonian cities are classified as small cities, and many are located in areas where accessibility is precarious. Nonetheless, as also observed among rural communities, some of these cities, because of their proximity to sub-regional urban areas, stand out as relatively important within the local level. This within-local level relevance (micro-hierarchical position) pushes these small cities up in the hierarchical urban scale, increasing the heterogeneity of this local level, neglected in classifications using only population size or density.

If we turn our attention to cities at the sub-regional level, our results suggest a more traditional hierarchy. At this level, node cities, as called by Costa and Brondizio (n.d.), appear in our model as a reference for a set of small surrounding cities. They function as central places to provide services, such as job opportunities, schools and health services, and to attract temporary workers and students who reside in different municipalities. They also have an important position as receptors of migrants coming from the surrounding areas. The relative isolation of some small cities to larger urban centers reinforces their dependence on these sub-regional node cities. These node cities, therefore, play a central role within the Amazonian region, as they often represent the only connection to an urban reality for rural residents and those living in impoverished villages and towns.

At the regional level, different from the macro-poles suggested by Garcia et al. (2007), the capitals of the Amazonian States were, in this article, divided in two distinct urban hierarchical sub-levels: Belém, Manaus, Cuiabá, Porto Velho, Macapá, and Boa Vista are at the top of urban hierarchy in the region, followed by São Luís, Palmas, and Rio Branco as the second most important hierarchical urban cities. From a methodological viewpoint, the inclusion of the entire municipality in the study referred above as the unit of analysis does not allow the unobserved heterogeneity to emerge not just at the local, but also at the regional level, as our typology suggests when separating the capitals in two different levels or regional importance.

The urban hierarchy proposed in our analysis supports Browder and Godfrey’s theory of disarticulated urbanization as it applies to the level of the Brazilian Amazon. However, we find it is insufficient to explain the emergence of sub-regional urban hierarchies that increasingly define the region in terms of population distribution and economic connections to national and global markets. Our empirical model highlighted some medium cities, such as Altamira and Marabá in Pará, Barra dos Garças in Mato Grosso, Araguaína in Tocantins, Ji-Paraná in Rondônia, Santana in Amapá, Humaitá in Amazonas and Cruzeiro do Sul in Acre, which are not considerable in terms of population size, but are representative in terms of other urban dimensions, such as infrastructure and services and connections to national and international markets.

Our results also emphasize the singularity of urban context in the Amazon region, as noted by Corrêa (1987) and Browder and Godfrey (1997), and complement the interpretation of Garcia et al. (2007) of regional and sub-regional urban hierarchies. Nevertheless, we call attention to the importance of other determinants of urban hierarchies such as date of municipality creation and types of access, such as rivers and roads. Our study is also distinct in using only the urban area and not entire municipalities as the unit of analysis. In addition, the inclusion of a local level dataset allowed us to offer insights about the processes leading to the initial formation of urban centers in areas with high rates of migration, land turnover, and close rural–urban movements and connections.

Regionalization models, on the other hand, while contributing to the differentiation of intra-regional historical and social particularities within continental Amazonia, are very sensitive to the (inclusive) spatial configuration of municipalities, as units of analysis, and thus can lose empirical value. The inclusiveness (historical and cultural, environmental and geographical, social, political, and economic) of each regional block defies its own categorical meaning. In this sense, the aggregation of cities into wider categories of urban regional blocks masks their differential local importance. Our findings, thus, suggest that even small variations in terms of urban hierarchy must be taken into consideration and seen in relative perspective, because of its impact for the population living in these cities and in their surroundings.

Finally, we would like to call attention to the environmental implications of these processes. Along with the exponential growth of urban areas since the late 1980s, the region has seen a similar growth of both reserves and conservation areas and agro-pastoral activities. The confluence of these systems, their spatial overlaps and adjacencies, and their respective institutional arrangements are defining the future axis of occupation and connectivity within the region. The growing network of urban areas in the region is contributing to a situation of high level of connectivity between land use systems and social groups within and between ecosystems and watersheds (Brondizio et al. 2009). As a result, the region is starting to witness blocks of protected areas surrounded by urban and agrarian systems, thus creating 'island conservation' effects and fragmentation of habitats. The propagation of impacts within such situations also increases, particularly given the distribution and size of important watersheds in the region. The case of the Indigenous Park of Xingu provides an illustrative example. Today, the watershed of the Xingu River (which comprises around 51 million ha) cuts across 35 municipalities (with a population close to half a million) and encompasses 27 indigenous groups (with a population over 10,000). While indigenous groups within the park have developed strong institutions to monitor its border successfully, high rates of deforestation and a complex network of roads and cities around the park are undermining the park's environment with water pollution, soil erosion, and forest fires. This is a situation which speaks to many other areas of the Amazon, and which is likely to increase.

Intra-regional connectivity and urban network complexity create new challenges for conservation and regional planning. Projected scenarios of climate change in the region raise further concerns about the impact of urban network expansion in the region and vice versa, the impact of climate change on urban populations. Urban populations are affected by the spread of accidental fire and the lack of water during extended droughts such as those in 1997/1998 and in 2005. These droughts have directly affected the level of pollution in cities such as Manaus and Belém, largely from smoke from nearby burning areas, resulting in respiratory problems for residents, as well as decreased water quality, an already important problem. Understanding the forms and fronts of urban network expansion and their intersection with conservation areas and expanding land use systems is an important component of any program aimed at improving the quality of life for regional populations and finding sustainable solutions for reconciling conservation and development in the Amazon.

Concluding remarks

Our findings suggest that the proposed disarticulated urbanization holds for the Brazilian Amazon at the regional level, but is insufficient to explain urban hierarchies emerging at sub-regional levels. Our urban ranking identifies sub-regional urban centers important for their provisioning of services and infrastructure to their adjacencies, despite their relatively modest population size. These cities function as node cities, linking the local realities to national and, in some instances, global economies. Some of these node cites provide specialized functions to their neighboring areas, rendering them important to surrounding cities of different sizes. Micro-hierarchical specialized functions were also identified at the local level among communities in-between urban centers.

Understanding the trajectories of Amazonian cities and their position and dynamics within a regional urban hierarchy offers an instrument to predict new axes of expansion and the rise of inter-urban networks. Furthermore, the absence of an articulated regional urban hierarchy calls attention to the importance of analyzing these processes at sub-regional and local levels. The importance of sub-regional node cities is increasing in different parts of the Amazonian region as they supply services and assume a position of political and economic relevance for surrounding rural areas and cities and may be a reflective process initiated at the micro-level, as illustrated by node communities.

Our analysis is an effort to motivate research and new studies focused on the emergence of regional, sub-regional, and local inter-urban networks, including how communities and incipient urban centers emerge and change over time. These dynamics underlie the future direction of urban expansion and its consequences for population and environment in the region during the coming decades.

Acknowledgments

We thank Anthony Cak, Scott Hettrick, Álvaro D'Antona, and Andrea Siqueira for logistical support in the field and laboratory, and constructive reviews of this article. We thank four anonymous reviewers and the editor for their valuable comments and suggestions. The larger project of which this is a part benefits from the experience and input of these investigators, and funding from the National Institutes of Health (grant no. HD35811-04/07, Phase II),National Aeronautics and Space Administration (NASA)/LBA (Grant no. NNG06GD86A, Phase III) and National Science Foundation/USD (grant no. BCS-05-27578, Estuary). We finally thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Department of Anthropology, the Antrhopological Center for Training and Research on Global Environmental Change (ACT) at Indiana University, the Centro de Desenvolvimento e Planejamento Regional e Urbano (CEDEPLAR/UFMG), and Departamento de Planejamento Regional (UNIVAP), institutions which the authors belong or collaborate.

Appendix

See Table 4.

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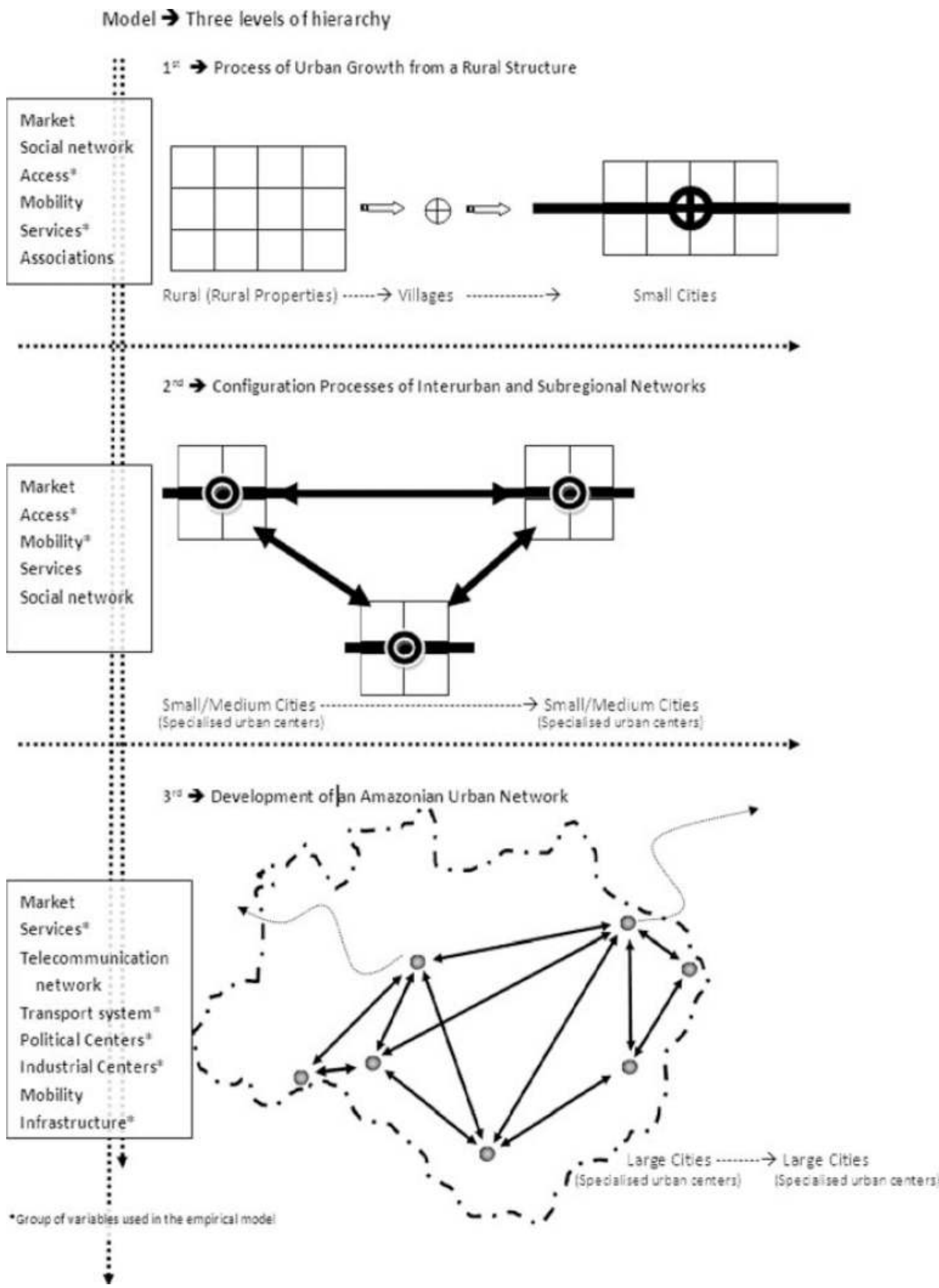

Fig. 1.
Conceptual model of local to regional urban system formation in the Amazon

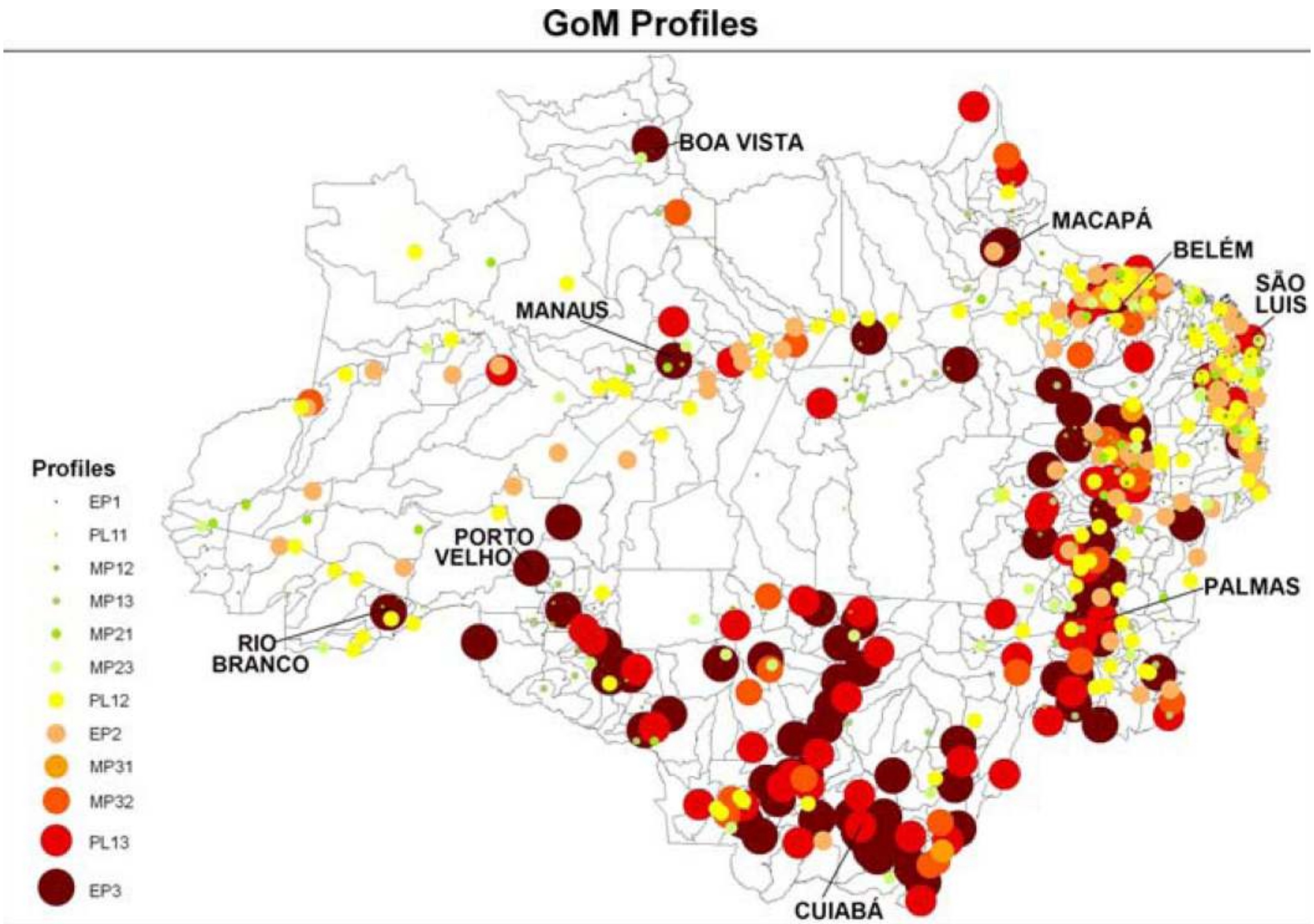

Fig. 2.
Amazonian cities by profiles of socio-demographic and geographical dimensions (profiles explained in Table 1)

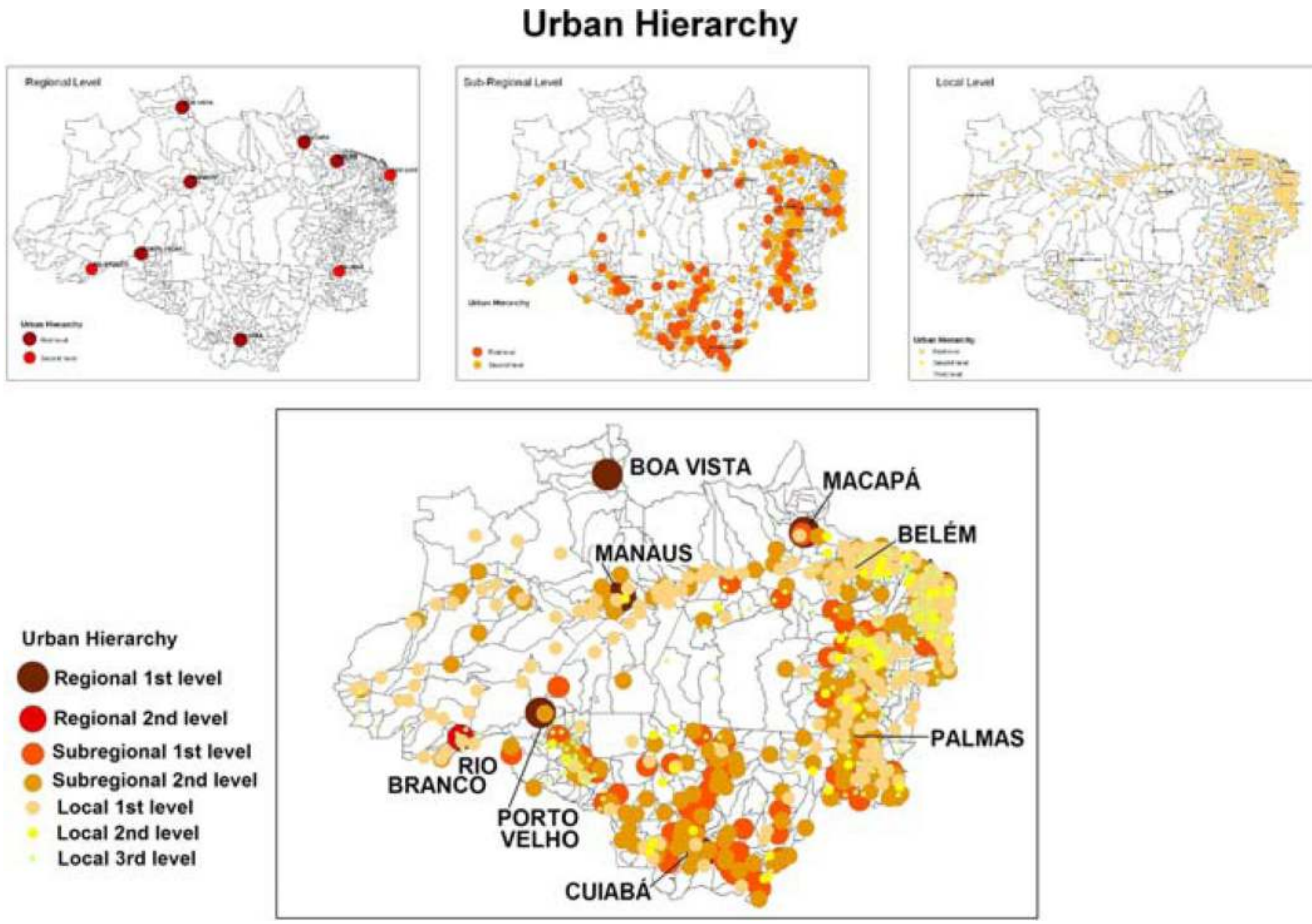

Fig. 3.
Urban hierarchy based on the GoM profiles for the Legal Brazilian Amazon

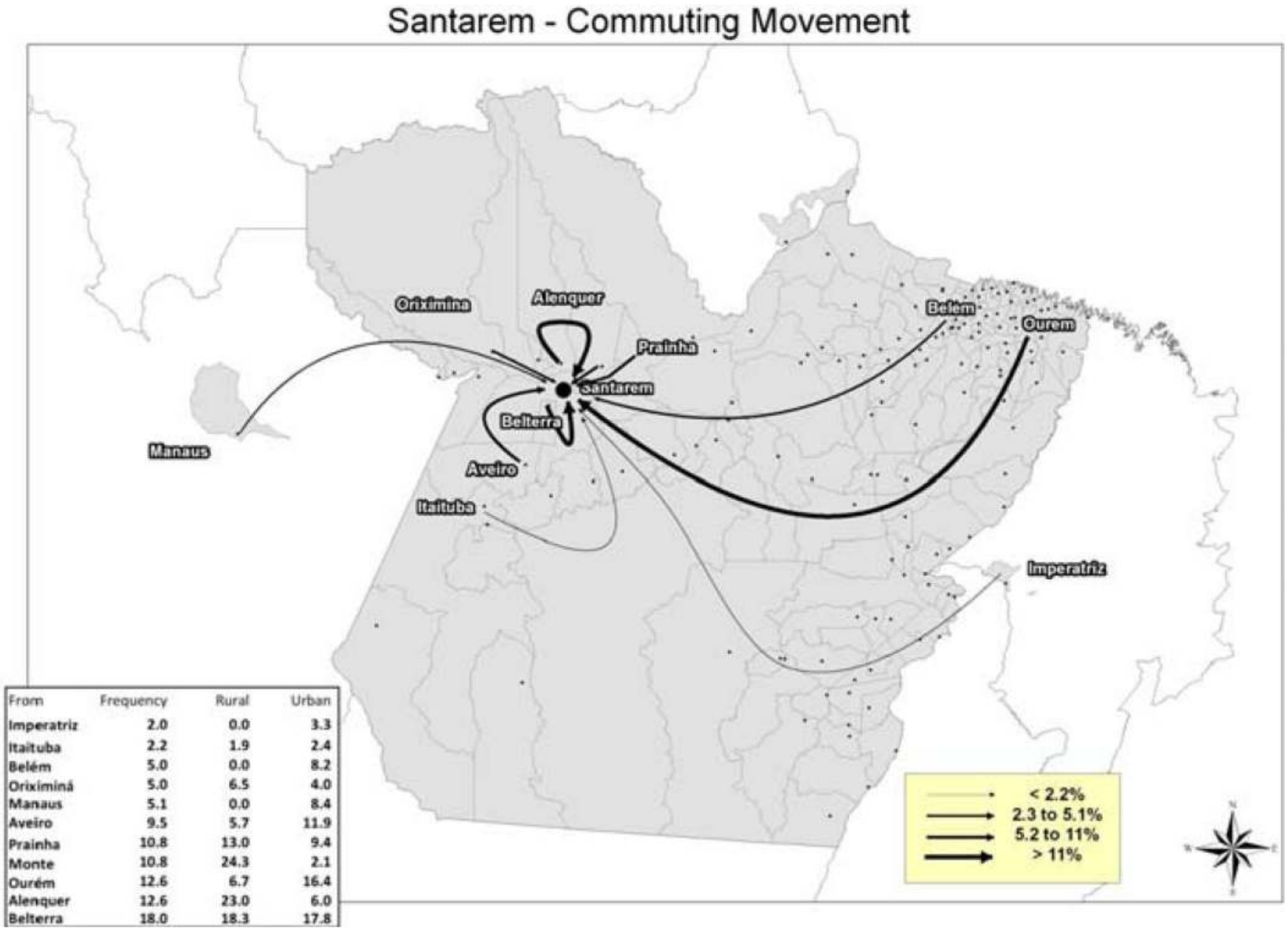

Fig. 4.
Commuting movement to Santarém, state of Pará, 2000

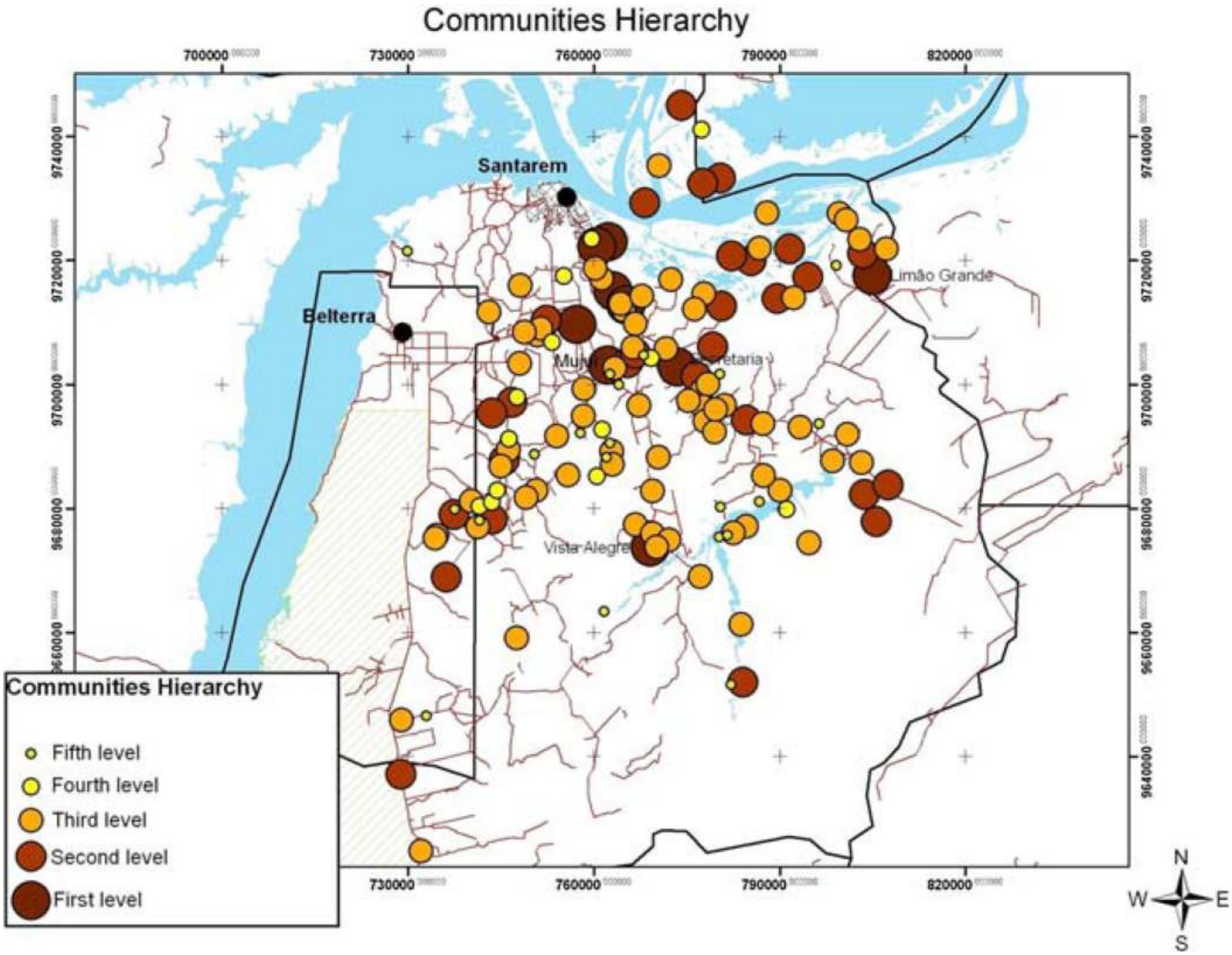

Fig. 5.
Settlement hierarchy at the local level

Table 1

Area, population and population density for the states of the legal Brazilian Amazon

Geographic unit	Area (km^2)	Population	Population density
Acre	153,150	655,385	4.3
Pará	1,253,165	7,065,573	5.6
Amazonas	1,577,820	3,221,939	2.0
Roraima	225,116	395,725	1.8
Amapá	143,454	587,311	4.1
Tocantins	278,421	1,243,627	4.5
Mato Grosso	906,807	2,854,642	3.1
Maranhão	325,940	6,118,995	18.8
Rondônia	238,513	1,453,756	6.1
Legal amazon	5,217,423	22,303,252	4.3
Brazil	8,511,965	183,987,291	21.6

Source: IBGE (2000, 2007)

Table 2

Selected demographic and geographic information for state capitals of the legal Brazilian Amazon

Municipality	Area[a]	Population[b]	Population density	Urban population[b]	Urban ratio
Rio Branco (AC)	9,877	290,639	29.4	269,505	92.7
Manaus (AM)	11,408	1,646,602	144.3	1,636,837	99.4
Macapá (AP)	6,533	344,153	52.7	328,865	95.6
São Luís (MA)	828	957,515	1,156.4	917,155	95.8
Cuiabá (MT)	3,971	526,830	132.7	519,015	98.5
Belém (PA)	1,065	1,408,847	1,322.5	–	99.4[c]
Porto Velho (RO)	34,069	369,345	10.8	148,388	40.2
Boa Vista (RR)	5,687	249,853	43.9	246,156	98.5
Palmas (TO)	2,465	178,386	72.4	175,166	98.2

Source: IPEA Data (2002), IBGE (2000, 2007)

AC Acre; *AM* Amazonas; *AP* Amapá; *MA* Maranhão; *MT* Mato Grosso; *PA* Pará; *RO* Rondônia; *RR* Roraima; *TO* Tocantins

[a]Municipality area based on information from the Brazilian Census of 2000

[b]Based on information from the Brazilian Population Tally of 2007

[c]Belém was not included in the population tally of 2007. This result is based on the 2000 urban ratio

Table 3

Regional level: characterization of the pure types and marginal frequencies (absolute and relative) of the mixed profiles—municipalities of the Legal Brazilian Amazon in 2000

Descripton of the extreme profiles	Profiles with preponderance	Marginal frequency		Average size (Pop.)
		Absolute	Relative	
Recent small cities: Low income, low overall percentage of urban households with fair infrastructure, low supply of health services, near roads, between 10 and 30% of the area with natural reserve or national/state parks, emancipated very recently (after 1990), small number of habitants, low urban ratio and relative small number of the in-migrants in the Legal Brazilian Amazon	Recent small cities (EP1)	92	12.3	2,291
	Small cities with poor infrastructure (PL1)	53	7.1	3,485
	Small cities with fair infrastructure (MP12)	37	5.0	4,528
	Highly forested small cities (MP13)	25	3.3	5,261
	Subtotal	207	27.7	3,355
Historical growing small cities: Average income, intermediate overall percentage of urban households with fair infrastructure, average supply of health services, near rivers, at last 60% of the area as natural reserve or national/state park, small number of habitants, average urban ratio, with high demographic growth rate, emancipated before 1970 and average relative number of in-migrants in the Legal Brazilian Amazon	Historical growing small cities (EP2)	68	9.1	9,156
	Growing small cities with fair infrastructure (PL2)	103	13.8	9,953
	Highly growth small cities (MP21)	22	2.9	6,032
	Growing medium cities (MP23)	31	4.1	12,645
	Subtotal	224	30.0	9,699
Medium cities and urban agglomerations: High income, high overall percentage of urban households with fair infrastructure, high supply of health services, <5% of the area with natural reserve or national/state parks, emancipated mainly between 1950 and 1970, from small to large number of habitants, high urban ratio, average demographic growth, and relative large number of the in-migrants in the Legal Brazilian Amazon	Medium/urban agglomeration (EP3)	80	10.7	77,562
	Medium cities with good infrastructure (PL3)	59	7.9	56,810
	Urbanized recent small cities (MP31)	3	0.4	27,879
	Small cities with average characteristics (MP32)	23	3.1	11,801
	Subtotal	165	22.1	60,072
	Relative pairwise predominance	151	20.2	6,294
	Total	747	100.0	18,379

Data sources: Brazilian Demographic Census (IBGE 1991, 2000), Brazilian population tally (2007), Brazilian hospital information system and national archive of hospital establishments (MS 1998, 2002a, b), Brazilian national council of municipalities (CMN 2007), Cartographic Database (IBGE 2007)

Table 4

Variables used in the fuzzy cluster models in order to establish an urban hierarchy in the Legal Brazilian Amazon

I. Demographic configuration and dynamics
Urban population (2000)[a]
Community population (2004)[f]
Urban population density (2000)[a]
Community population density (2004)[f]
Urban ratio (2000)[a]
Change in urban ratio (1991/2000/2007) [*a,b]
Average urban population growth (1991/2000/2007) [*a,b]
II. Population linkages
In-migrants in urban areas of municipalities (2000)[a]
Out-migrants from urban areas of municipalities (2000)[a]
Commuting movement [from urban/rural to urban] (2000)[a]
III. Spatial dimensions
Countryside/metropolitan area (2000)[a]
Urban perimeter (2000)[a]
Total area of the municipality (2000)[a]
Total area of the community (2004)[f]
Municipality of community location (2000)[a]
IV. History of creation
Year of municipality creation (2007)[c]
Year of community creation (2004)[f]
V. Social development
Total urban household income (2000)[a]
Hospital beds per 1,000 habitants (2002)[d]
Change in hospital beds for 1000 habitants (1998/2002)[d]
Emergency rooms per 100,000 habitants (2002)[d]
Change in emergency rooms per 100,000 habitants (1998/2002)[d]
Type of health establishment (2002)[e]
Level of health attention [primary, secondary or terciary] (2002)[e]
Outpatient facilities per 1,000 habitants (2002)[e]
Number of hospitals in the community (2004)[f]
Number of health centers in the community (2004)[f]
Number of health posts in the community (2004)[f]
Number of school establishments in the community (2004)[f]

Number of shops in the community (2004)[f]
Number of churches in the community (2004)[f]
Number of soccer fields in the community (2004)[f]
Number of public squares in the community (2004)[f]
Number of post offices in the community (2004)[f]
Number of lottery stores in the community (2004)[f]
Presence of banks in the community (2004)[f]
Presence of gas station in the community (2004)[f]
Number of neighborhood associations (2004)[f]
Number of bakeries in the community (2004)[f]
VI. Physical infrastructure
Type of urban household [permanent, temporary or collective] (2000)[a]
Material used in community household construction (2004)[f]
Type of water supply system in urban households (2000)[a]
Type of water supply system in community households (2004)[f]
Availability of piped water in urban households (2000)[a]
Type of water treatment in community households (2004)[f]
Type of sewage system in urban households (2000)[a]
Type of sewage system in community households (2004)[f]
Type of garbage collection in urban households (2000)[a]
Type of garbage collection in community households (2004)[f]
Existence of electric power in urban households (2000)[a]
Existence of electric power in community households (2004)[f]
Existence of public light posts for urban households (2000)[a]
Existence of public light posts for community households (2004)[f]
Degree of paved streets for urban households (2000)[a]
VII. Geophysical landmarks
Presence of river and/or road in the municipality (2007)[c]
Area of municipality under indigenous reserves and national/state parks (2007)[c]

[*] The minimum area of comparison was respected when analyzing municipalities over time

Source: [a] IBGE Demographic census (IBGE 1991, 2000)

[b] IBGE population tally (IBGE 2007)

[c] National council of municipalities (CMN 2007)

[d] MS hospital information system (MS 1998, 2002b)

[e] MS national archive of health establishments (MS 2002a)

[f] ACT santarém community survey (ACT 2004)