Rural-urban migration and abandoned Amazonian headwaters

Luke Parry[1,2,3], Silvana K. Amaral[4], Brett Day[1], Carlos A. Peres[1]

[1]School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, United Kingdom

[2] Center for International Forestry Research (CIFOR), P.O. Box 6596, JKPWB, Jakarta 10065, Indonesia

[3] Lancaster Environment Centre, University of Lancaster, Lancaster LA1 4YQ, United Kingdom

[4] Instituto Nacional de Pesquisas Espaciais (INPE), Av. dos Astronautas, 1758 São José dos Campos, SP, 12227-010, Brazil

Correspondence:
Luke Parry, Lancaster Environment Centre, University of Lancaster, Lancaster LA1 4YQ, United Kingdom
Tel: (44)1524 510276; Fax: (44)1524 593192; Email: lukeparry1@gmail.com

Email addresses: silvana@dpi.inpe.br; brett.day@uea.ac.uk; c.peres@uea.ac.uk;

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Abstract

The spatial distribution and growth of human populations has been overlooked by current debates concerning the impact of rural-urban migration for forest conservation in tropical countries. We investigated human settlement and population change in the Brazilian Amazon, combining government census data with field surveys along rivers. Rural populations were clustered and growing within 300 km of urban centers, whereas depopulation and land abandonment dominated farther from towns. The permanently inhabited extent of rivers contracted by 33 ± 8 SE % in recent decades, and households farther upriver were more likely to be considering rural-urban migration. Human harvesting of aquatic and terrestrial wildlife continued in headwater regions by non-residents, hundreds of kilometers beyond the last household on any given river. Policy-makers should consider that expanding cities may drive deforestation and overexploitation near towns while a tragedy of the commons threatens overharvesting and unregulated land speculation in abandoned headwaters.

Introduction

Decades of rural-urban migration have reduced rural populations in many areas of the forested tropics, especially in Latin America (United Nations 2005). The environmental impact of rural depopulation remains an issue of contention amongst conservation scientists.

On the one hand the farms, fires and foraging of burgeoning rural populations have long been seen as threats to tropical forests (Myers et al. 2000). The environmental impacts of human activity such as agriculture (Achard *et al*. 2002) are assumed to be correlated with human population size (Brown & Pearce 1994). Forest recovery is therefore predicted when the number of farmers decline (Walker 1993, but see Fearnside 2008), which is assumed to serve the conservation interests of tropical forest species (Wright & Muller-Landau 2006). Rural-urban migration has thus been portrayed as a coincidental solution to the pending extinction of tropical forest species (Aide & Grau 2004; Wright & Muller-Landau 2006; Young 2006).

Conversely, many conservation scientists encourage efforts to sustain rural populations (Sheil & Boissiere 2006; Viana & Campos 2007). When given land tenure, rural people can assist conservation by maintaining forest cover to ensure environmental services such as carbon retention and water cycling, and prevent illegal land-grabbing and violence (Campos & Nepstad 2006). Collectively, rural people can support biodiversity through agro-ecological practices that maximize the value of matrix landscapes (Vandermeer & Perfecto 2007). Indeed, 'rural hotspots' have been posited as critical for conservation efforts in areas where both biodiversity and vulnerable traditional livelihoods are threatened (Harvey et al. 2008).

The polemic nature of the perceived role of rural people in conserving tropical forests has been facilitated by a disregard of potential spatial heterogeneity in settlement distribution, stability and migration dynamics of rural populations. Commentary has been largely restricted to a coarse urban-rural distinction (e.g. Aide & Grau 2004), despite probable differences between peri-urban areas and remote rural hinterlands (see McDonnell & Pickett 1990). Conservation value and vulnerability of rural areas is spatially heterogeneous, and headwaters may be particularly important (Peres & Terborgh 1995; Fernandes *et al*. 2004). Likewise, the costs and benefits of intervention and management are spatially-dependant (Naidoo et al. 2006).

Expanding cities exert larger ecological footprints (Folke *et al*. 1997; Grimm *et al*. 2008), partly through higher food demands, which drive agricultural production and extractive industries. Consequently, while rural populations may be declining, human population density in peri-urban rural areas may actually be increasing. In contrast, remote rural areas such as river headwaters may have succumbed to the highest levels of depopulation as they are farther from urban markets and likely to be more economically marginal.

Constraining the environmental impacts of rural populations to deforestation and fire by sedentary agriculturalists ignores important non-structural forms of disturbance (Redford 1992) by both resident and transient resource users. Human activity in forested areas is often dedicated to the harvesting of natural resources, such as fish, wild meat, and timber (Pimentel *et al*. 1997). Unlike slash-and-burn agriculture, extractive industries are often seasonal and highly mobile, and may carry on regardless of rural emigration of permanent residents. The spatial extent and severity of non-timber extraction are also difficult to monitor remotely (Peres et al. 2006).

We examine spatial patterns of human population distribution and growth in the state of Amazonas, Brazil. Amazonas is the largest Brazilian state (~1.57 million km^2) with 97% of its original forest cover still intact (INPE 2008). However, Amazonas is vulnerable to the expansion of the 'Arc of Deforestation', and infrastructure projects such as road-building, hydroelectric dams and long-distance hydrocarbon pipelines (Fearnside & Graça 2006; Finer *et al*. 2008). We hypothesize that the distribution and growth/decline of the human rural population is non-uniform, and question whether considering only the permanent rural population is a satisfactory measure of environmental pressure. Specifically, we test the following hypotheses: 1) most rural people live near urban centers, 2) there has been net rural population growth near towns, and a net decline far from towns in areas not bisected by roads, and 3) resource extraction continues beyond areas of permanent settlements by non-resident seasonal extractors.

Methods

Rural areas in Brazil form part of a municipal county administered from a single urban centre. For administration of a census, each of the state's 62 municipalities is divided into census sectors (range = 8 – 89 sectors per municipality, and Manaus, the State capital: 1607 sectors; Fig. 1a,b). We collected data from two main sources (Fig. 1); (1) national census data which allows us to (a) assess rural-urban gradients in population density in census sectors across the entire state (2007 census), and (b) compare changes in the distribution of the rural population between the 1991 and 2007 censuses (nine municipalities; mean = 44,494 ± 29,978 km^2); and (2) field data obtained in 2007 from eight sub-regions of Amazonas, in which we censused the riverine populations of eight sub-tributaries in order to assess fine-scale patterns of rural settlement, including interview data on migration intentions. Six of the surveyed rivers were also represented in the 1991 to 2007 census data (in 7 counties, due to shared boundaries), described above. We also had detailed census data for two unsurveyed municipalities, Jutai and Manicoré. Census comparisons were not possible for two of the rivers we surveyed (Rio Coari and Rio Aracá) as 1991 census maps were unavailable.

Population distribution

We assessed the spatial distribution of the rural population for Amazonas using 2007 census data from the Brazilian Institute of Geography and Statistics (IBGE). We used ArcGIS 9.2 (ESRI, Redlands, California). for all spatial analyses. Of the 1,691 rural census sectors, 105 were small (<10 km^2) representing a single village. To avoid small village area from over-inflating population densities, we incorporated these sectors into their larger surrounding sector. We derived human population density estimates from the area of each sector polygon (N = 1,586) and sector-level census data. We estimated travel distance to each rural sector from its municipal urban centre using the Network Analyst extension. We first created a travel network for Amazonas, based on all navigable rivers and paved/unpaved roads, including unofficial roads located using GoogleEarth (Appendix I).

The travel distance of each point along a sector's perimeter was estimated (Fig. 1c). We derived an average distance for each sector by averaging the minimum and maximum travel distances of sector edge points on our travel network.

Population growth

We compared human population densities between 1991and 2007 for census sectors within 9 municipalities (Fig. 1a). Whilst 1991 sector-level census data are available for all municipalities, extensive changes were made to the number-coding and layout of sectors between each census, hindering spatially explicit comparisons. Shapefiles were unavailable for the 1991 census so we digitized paper copies of large-scale municipal census maps from IBGE to produce polygons for each sector. Where a sector had been subdivided between censuses, we coalesced relevant population data, to produce a comparable human population density measure for the same geographic area across censuses (N = 138 rural polygons).

Riverine field surveys

We assessed settlement patterns, migration and land abandonment along eight urban-rural gradients dispersed across Amazonas, from January to November 2007 (Fig. 1a). We selected sub-tributaries whose confluence with a larger river was near an urban center, and travelled to the last permanently settled household on each river (≤740 km). In each urban center we assembled a team of local people with lifelong experience along a given river. All active and abandoned settlements were spatially referenced. We calculated the fluvial distance of each settlement from its urban centre in a GIS. We interviewed river-dwellers at 16-34 randomly-chosen settlements along each river (mean

= 23). At each location we asked one randomly-chosen household about their migration intent. We estimated population size of settlements that were not visited using community health data from local municipal Health Departments. When these data were unavailable, we established the number of households and estimated the number of people per household based on an estimate of 5 people per household.

Historical inhabited extent

We established the farthest point along each sub-tributary that had been permanently inhabited within the last ~25 years. Settlement extent was compared to the navigable length of rivers, defined as the farthest point upstream reachable by a motorized canoe in the high-water season. We collected and critically compared data from (1) local informants, particularly those living far upstream, (2) shapefiles of historical rubber settlements from a governmental agency (Amazonian Protection System, SIPAM), (3) old charts of the State.

Resource extraction beyond permanent settlements

We assessed patterns of extraction of wild animals and plants (fish, hunted mammals and birds, chelonians, timber, plant fibers, and Brazil nuts; Table I) through semi-structured interviews with river-dwellers, boat traders encountered during field work, informants in urban centers, and our own boat crews. When locations visited by extractors were upstream of our farthest locations visited, we established via interviews the name, stream description and travel time (by a vessel of known power and estimated velocity) of the farthest places reached by extractors. We then calculated the actual locations and fluvial distances from urban centers using the maps and shapefiles listed above. We estimated the maximum spatial extent of *each* extraction activity along each river.

Data analysis

We used a Generalized Linear Mixed Model (GLMM) to test for a relationship between human population density of census sectors and travel distance to urban center using the *lmer* function in R 2.7.2 (The R Development Core Team). Population density was normalized using log-transformation, assuming a Gaussian error distribution. We nested the model by municipality to avoid spatial pseudo-replication. We used a Standard Least Squares model in JMP 7.0 (SAS Institute, Cary, USA) to test the effect of travel distance to urban centers on the population growth of comparable roadless census polygons over a 16-yr period (1991 and 2007). We used log-transformed population data and municipality as a random effect. We excluded all sectors whose polygon area overlapped > 50% with an indigenous territory (ISA 2006) and any sector bisected by a road. Finally, we used a binary logistic regression to test for the positional stability of interviewed households in terms of their intent to resettle, with “no move” and “maybe/yes move” as the response variable. A Wilcoxon signed-ranks test was used to test for differences between the historical and contemporary extent to which each river was inhabited.

Results

Population distribution

Rural populations are clustered near urban centers, as indicated by the Amazonas-wide analysis of census data and field data. Human population density decreases significantly with fluvial travel distance from towns (GLMM, df = 1584, F = -7.09, $p < 0.001$; y = 3.45 - 0.077x; Fig. 2). On average, 77 ± 4% SE of households along the rivers we surveyed lived within 100 km of their urban centre (Fig. 3), whereas wet season navigability of motorized canoes extended along a fluvial distance of 710 km (range = 373 - 920). The distribution of rural populations in Amazonas is therefore highly clustered and heavily skewed to areas near towns.

Population growth and stability

Between 1991 and 2007 there was a 1.7 % increase (119,271 to 121,252 people) in the rural population of the nine municipalities examined (Fig. 2a). On average, the rural population in roadless census sectors located within 300 km of urban centers experienced net growth over this period (Fig. 4). However, 46% (59/128) of all sectors experienced a declining population and 68% (273,093 km^2) of the area covered by the 9 municipalities experienced depopulation. Roadless census sectors farther from the municipal urban center were significantly less populated in 2007 than in 1991 (Standard Least Squares model, $R^2 = 0.22$, municipality explaining 8.9% of the variance in population growth: df = 2, $F = 27.8$, p = <0.001; distance*year: df = 2, F = 9.3, p = 0.0001).

Over the last 25 years, there was a mean contraction of 33 ± 8% SE in the permanently inhabited extent of river catchments. On average, permanent settlements currently extend to only 52 ± 9% of the navigable length of rivers, compared to 77 ± 8% SE within the past 25 years (df = 8, z = -2.521; p = 0.012). Indeed, only 9 ± 5% of abandoned settlements we recorded were within the first inhabited quartile of river length (Fig. 5), whereas the most distant quartile upriver accounted for 46 ± 10% of all abandoned settlements.

Settlements near to towns were more stable since households farther upriver were more likely to be considering, or had already decided, to resettle in a new location (logistic regression; $c = 22.47$, $p = 0.004$, df = 8). Within 100 km of urban centers, 11% of families were planning to leave their current location, but this more than doubled (24%) beyond 100 km. Most households planning to resettle in the imminent future intended to move to their nearest urban centre (63%) or another town/city within Amazonas (10%). Only one family intended to resettle farther upriver from the nearest market-town. Hence, trends of negative population growth far from towns (>100 km) look set to continue.

Resource extraction

Commercial extraction of wild plants and animals and their products continued for hundreds of kilometers beyond the last permanent settlement along the rivers we surveyed (Table I). Fishing and hunting were the most widespread activities, undertaken up to 800 km fluvial distance from the nearest urban centre, and 525 km beyond the last permanent residence. Timber extraction and the harvest of non-timber forest products, such as Brazil nuts and adult chelonians and their eggs (mostly turtles, *Podocnemis* spp.) were also widespread towards the headwater regions.

Discussion

Rural -urban migration has altered patterns of riverine settlement in the Brazilian state of Amazonas. Human population densities are clustered and growing within 300 km of municipal urban centers, whereas population decline and land abandonment has dominated farther from towns. The permanently inhabited extent of tributaries has contracted in recent decades, and populations up these tributaries are relatively unstable. The harvesting of aquatic and terrestrial wildlife continues unabated for up to 525 km beyond the last riverine household. Peri-urban and headwater regions face emerging conservation threats even in largely roadless parts of Amazonia. Conservation scientists and policy makers interested in rural populations need to move beyond an urban-rural dichotomy and adopt the paradigm of urban-rural gradients (McDonnell & Pickett 1990).

Peri-urban settlements

As predicted, the vast majority of rural people lived close to their municipal urban center. Human population densities fell several orders of magnitude beyond 100 km of the nearest market towns. Our results also corroborate our prediction of the spatial distribution of population growth. Human population densities have increased within 300 km of towns (equivalent to an average travel time of 3 days), whilst zero or negative growth dominated beyond this distance. Although net forest cover is increasing in some areas of the tropics (Achard et al. 2002), the distance-dependent gradient of rural population change suggests that forest recovery will also be spatially heterogeneous. As a consequence, programs that use direct payments for environmental services (PES) as incentives for rural settlement (e.g. *Bolsa Floresta* in Amazonas: Viana & Campos 2007) should recognize that areas near towns may experience increased human population densities even in the absence of PES. Also, growing human populations will likely exert greater pressures on their environments including overharvesting of wild plant and animal populations.

Headwater depopulation and exploitation

The inhabited extent of the Amazonian sub-tributaries we surveyed fell by a third in recent decades, and headwaters contain most abandoned land. Upriver families were more likely to migrate than those nearer towns, suggesting that rural-urban migration is likely to continue. Amazonas state has largely escaped deforestation to-date, although it is vulnerable to large-scale deforestation in coming decades (Soares-Filho *et al*. 2006). Headwaters are critical for environmental service provision and biodiversity (Fernandes *et al*. 2004) and offer one of the best available conservation opportunities across Amazonia (Peres & Terborgh 1995). The exodus of riverine dwellers from headwaters presents an opportunity for the demarcation of protected areas in newly depopulated wilderness (Mittermeier et al. 2003).

Large-scale deforestation does not require a large human population (Fearnside 2008), and abandonment of unprotected Amazonian headwaters increases the availability of unclaimed land (*terra devoluta*) raising the prospects of illegal land-grabbing and speculation by external actors. Currently, Brazilian land tenure legislation encourages forest clearance as a means of attaining property rights of unclaimed lands (Simmons et al. 2002). Land-grabbing and deforestation is likely in Amazonas, given rising beef prices and the planned bisection of headwaters by paved highways, including those linking the recently paved Manaus-Porto Velho highway (BR-319) with other towns (Fearnside & Graça 2006). Headwater abandonment compromises the potential demarcation of inhabited reserves. We therefore encourage ongoing efforts to sustain low-density rural populations in tropical regions (Viana & Campos 2007).

The commercial extraction of wild goods such as Brazil nuts and fish is a major source of employment and income in the Brazilian Amazon (IBGE 2007). When headwaters become depopulated, harvest pressure from subsistence resource users is discontinued, although the potential for over-exploitation remains (c.f. Klooster 2003). We show that the commercial extraction of forest resources and aquatic wildlife occurs well beyond the permanently inhabited extent of rivers. The potential profits of fisheries and forest goods draw extractors from afar (Almeida *et al*. 2003; Stoian 2005). In depopulated areas harvested wildlife is therefore at risk of overexploitation in a tragedy of the commons in which boat-based merchants can transport several tons of natural resources yet lack clear property rights to these resources. Rural communities often exhibit coping strategies in the management of commons resources (de Castro & McGrath 2003), and therefore have greater potential than non-resident actors to exploit a resource sustainably (Ostrom et al. 1999). The lack of institutional presence and unclear property rights in remote abandoned headwaters may allow the perpetuation of an incomplete forest-transition, where the 'mining', rather than management of forest resources continues unabated (Grainger 1995).

Governance and enforcement

Urbanization has led to forest regrowth in rural areas, amounting to a conservation benefit in countries such as Costa Rica and Puerto Rico (Chazdon 2003; Lugo & Helmer

2004). However, good governance is an essential precondition for a stable forest transition in the tropics (Agrawal *et al*. 2008), in terms of both land stewardship and harvest management. In Brazil, the harvesting of timber, fish, terrestrial vertebrates and turtles is regulated 'on paper' by existing legislation. However, monitoring is limited or non-existent in many remote areas, especially given that local people play an important role in denouncing illegal extraction activities to government agencies (Gibson et al. 2005; Zimmerman et al. 2001). Rural smallholders can report and repel land speculators (Campos & Nepstad 2006), including in remote headwater regions hundreds of kilometers from the nearest road (L. Parry, pers.obs.). However, this form of vigilance breaks down beyond the last household on any given river. As recommended by Peres and Terborgh (1995) we suggest that enforcement outposts are established at the mouths of sub-tributaries in order to monitor and regulate the legal or illegal entry of non-resident extractors.

Conclusions

In this study we question whether the rural-urban dichotomy is a useful framework for analyzing migration patterns and the potential for conserving forests and forest species in tropical regions. Apparent contradictions in conservation attitudes to rural populations (Wright & Muller-Landau 2006; Campos & Nepstad 2006) may be explained by spatial heterogeneity in the distribution and growth of rural populations. We hypothesized that patterns of growth and spatial distribution of rural populations are heterogeneous, and that these patterns are highly relevant to current discourse on the role of rural peoples in tropical forest conservation. We show that riverine populations in the central Brazilian Amazon are increasingly clustered near towns, which poses threats in terms of deforestation and overharvesting that are decoupled across the forest landscape. We also show that Amazonian headwaters have been largely emptied of people, exposing them to the peril of overexploitation of natural resources by unmonitored external actors, and a longer-term risk of land speculation and deforestation.

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Table I. Activities of non-resident resource extractors beyond the last permanent settlement along 8 sub-tributaries in Amazonas state, Brazil.

Activity	No. rivers with collection beyond last settlement	Species exploited	Seasonality	No. extractors beyond last permanent settlement	Max distance from urban centre (km)	Mean positive extension km (range)	Origin of resource extractors
Fishing	6	Various	All year	2 - 50	800	185 (5 – 525)	Local town; regional town; state capitals
Hunting	5	Large mammals and game birds	All year	5 - 10	800	230 (100 – 525)	Local town
Timber	4	Various commercially valuable species	All year	5 - 10+	450	85 (5 – 195)	Local town; state capitals
Chelonians	4	*Podocnemis unifilis, P. expansa*	Dry	10	800	280 (100 – 525)	Local town
Brazil nut	3	*Bertholletia excelsa*	Wet	4 - 20	630	195 (100 – 260)	Local town
Gold mining	2	n/a	All year	30 - 200?	370	160 (125 – 190)	Outer state
Fiber	1	*Leopoldinia piassaba*	All year	30	440	50 (50)	Local town

FIGURE LEGENDS

Figure 1. (a) Map of study sites for rivers surveyed within the State of Amazonas, Brazil. Numbers correspond to names of urban centres: 1-8, respectively, Barcelos; Coari; Lábrea, Maués, Nova Olinda do Norte, Pauini, Tapauá, Tefé. **(b)** Settlements mapped during field surveys, and census sector boundaries, in the municipality of Pauini. **(c)** Example of a minimal travel route between an urban centre and a census sector.

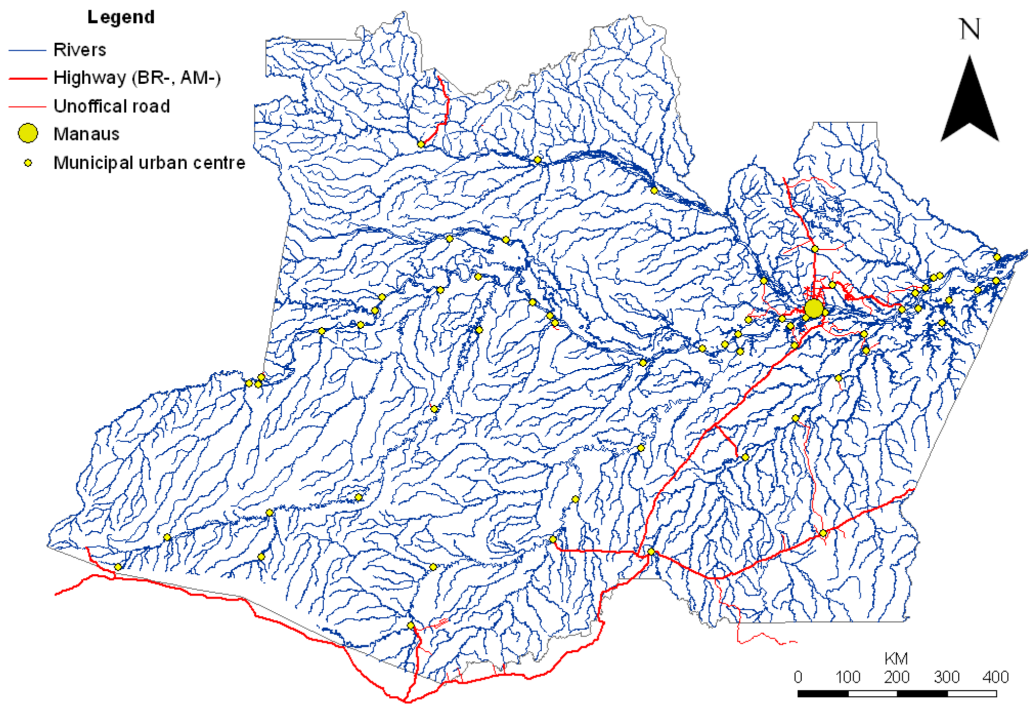
Figure 2. Distribution of the rural population in 2007 in Amazonas, Brazil, in relation to the fluvial travel distance of census districts (N = 1,586) from municipal urban centers (n = 62). Horizontal box-plot represents unpopulated census districts.

Figure 3. Accumulation curves of the riverine populations along 8 sub-tributaries in Amazonas State, Brazil. The furthest point historically inhabited (during the second half of the 20th Century) is indicated with a straight line and 'H'.

Figure 4. Population growth between 1991 and 2007 for coalesced census districts outside of indigenous territories, and that were not bisected by roads, within 9 municipalities of the central Brazilian Amazon.

Figure 5. Distribution of abandoned smallholdings along eight urban-rural gradients in the State of Amazonas, Brazil. The proportion (±SE) of abandoned household plots along a given river are shown in relation to quartiles of the permanently inhabited extent of rivers.

Supplementary material
Appendix I
Travel network of navigable rivers and roads in Amazonas state, Brazil.



Appendix II
Percentage changes in the number of inhabitants between 1991 and 2007 censuses, for 9 municipalities of the State of Amazonas, Brazil.