Rural–urban migration brings conservation threats and opportunities to Amazonian watersheds

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Abstract

The spatial distribution and growth of human populations have 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. However, harvesting of aquatic and terrestrial wildlife by nonresidents continued into headwater regions, 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 unclear property rights threatens overharvesting and unregulated land speculation in abandoned headwaters.

Introduction

Decades of rural–urban migration have reduced rural populations in many tropical forest areas, especially in Latin America (United Nations 2005). Yet the environmental impact of rural depopulation remains an issue of contention among conservation scientists.

On the one hand, farming and foraging by burgeoning rural populations have long been seen as threats to tropical forests (Myers *et al.* 2000). The environmental impacts of human activities 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 declines (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). Rural people can be key agents in sustaining biodiversity through agro-ecological practices that maximize the matrix value of anthropogenic landscapes (Vandermeer & Perfecto 2007).

The polemic nature of the perceived role of rural people in tropical forest conservation has been facilitated by a disregard of the potential spatial heterogeneity in settlement distribution, stability and migration dynamics of rural populations (Chomitz 2007). Commentary has been largely restricted to a coarse urban–rural distinction (e.g., Aide & Grau 2004), even though spatial context determines the costs and benefits of intervention and management (Naidoo *et al.* 2006). Although peri-urban population dynamics and livelihoods have received recent attention (Stoian 2005; Padoch *et al.* 2008), remote hinterlands have been ignored, despite the importance of headwaters for biodiversity conservation (Peres & Terborgh 1995).

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 some rural populations are declining, human population density in peri-urban rural areas can in fact increase. In contrast, remote rural areas such as river headwaters might have succumbed to the highest 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 nonstructural forms of disturbance (Redford 1992) by both resident and transient resource users. Human activity in forested areas is often dedicated to the harvesting of plants and animals (Pimentel *et al.* 1997). Unlike slash-and-burn agriculture, extractive industries are often seasonal and highly mobile, and can carry on regardless of net rural out-migration. The spatial extent and severity of nontimber resource extraction are also difficult to monitor remotely (Peres *et al.* 2006).

We examined spatial patterns of human population distribution and growth in the State of Amazonas, Brazil. This 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 changes in the distribution and size of the human rural population are nonuniform, 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 a 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 nonresidents.

Methods

Rural areas in Brazil form part of a municipal county administered from a single urban center. During the implementation of the governmental decadal census, each of the 62 municipalities of Amazonas is subdivided into census sectors (range = 8–89 sectors per municipality, and the State capital (Manaus): 1,607 sectors; Figure 1a, b). We collected data from two main sources (Figure 1); (1) national census data that allow us to (a) assess rural–urban gradients in population density within 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 size = 44,494 ± 29,978 km$^{2;}$ Figure 1a); and (2) field data obtained in 2007 from eight subtributaries in Amazonas, in which we censused the riverine populations, gathered interview data on migration intentions and recorded land abandonment (see Supporting Information).

Census data

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. 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 from each rural sector to its municipal urban center 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 in Supporting Information), and calculated the travel distance from each census sector to its local urban center (Figure 1c; Supporting Information).

Riverine field surveys

We surveyed eight urban–rural gradients across Amazonas, from January to November 2007 (Figure 1a). In each urban center we assembled a team of local people with lifelong experience along a given river. We selected subtributaries whose confluence with a larger river was near an urban center, and traveled up to 740 km (calculated in a GIS) to the last permanently settled household along each river. All active and abandoned settlements were spatially referenced. We interviewed river-dwellers at 16–34 randomly chosen settlements along each river (mean = 23). At each settlement (median size = 2 households) we asked one randomly chosen household about their migration intent.

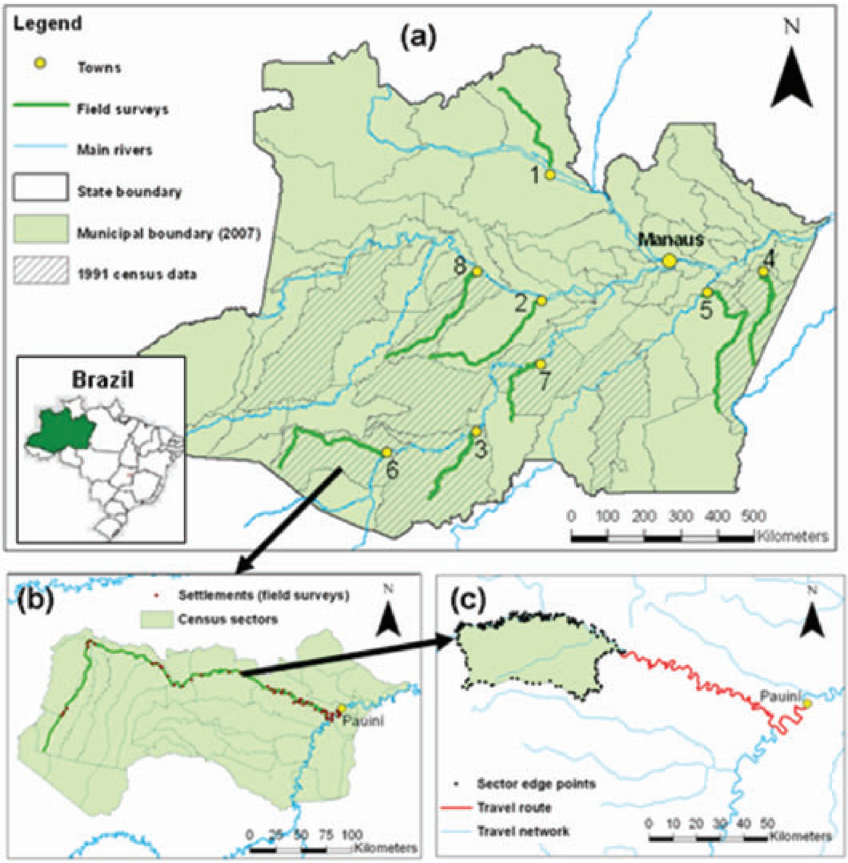

Figure 1 **(a)** Map of study sites for rivers surveyed within the State of Amazonas, Brazil. Numbers correspond to names of urban centers: 1–8, respectively, Barcelos (where we surveyed the Rio Aracá, shown in green); Coari (Rio Coari); Lábrea (Rio Ituxi), Maués (Rio Maués/Parauari), Nova Olinda do Norte (Rio Abacaxi), Pauini (Rio Pauini), Tapauá (Rio Jacare), Tefé (Rio Tefe). **(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 center and a census sector.

Extent of historical occupation

We established the farthest point along each subtributary 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), and (3) old charts.

Resource extraction beyond permanent settlements

We assessed patterns of commercial extraction of wild animals and plants (Table 1) through semistructured interviews with river-dwellers, boat traders encountered during field work, informants in urban centers, and our own boat crews. We established via interviews the name, stream description, and travel time (by a vessel of known power and estimated velocity) of the farthest sites reached by extractors. We plotted site locations and estimated 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.

Analysis

We used a generalized linear mixed-effects 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). We nested the model using municipality as a random effect to avoid spatial pseudoreplication. We used a standard least-squares model in JMP 7.0 (SAS Institute Inc., Cary, NC, USA) to test the effect of fluvial travel distance to urban centers on the population growth of comparable roadless census polygons from 1991 to 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 and any sector bisected by a road (see Supporting Information). We used a binary

Table 1 Activities of nonresident resource extractors beyond the last permanent rural settlement along eight subtributaries in Amazonas State, Brazil

Resource harvested	No. of rivers with collection beyond last settlement	Species exploited	Season	No. of extractors beyond last permanent settlement	Max. distance from urban center (km)	Mean positive extension km (range)	Origin of resource extractors
Fish	6	Various	All year	2–50	800	185 (5–525)	Local town; regional town; state capitals
Forest animals	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
Turtles	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)	Other state
Fiber	1	*Leopoldinia piassaba*	All year	30	440	50 (50)	Local town

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 both census and field data. Human population density decreases with fluvial travel distance from towns (GLMM, model explained 90.7% of the variance in population density ($\log(x + 1)$), of which distance accounted for 63.8% and municipality 36.2%; df = 1584; $F = -7.09$, $P < 0.001$; $y = 3.45–0.077x$; Figure 2). On average, 77 ± 4% SE of households along the rivers we surveyed were within 100 km of their urban center (Figure 3), whereas wet season navigability of motorized canoes extended along a fluvial distance of 710 km (range = 373–920 km). The distribution of rural populations throughout 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 entire rural population of the nine municipalities examined (Figure 1a). On average, the rural population in roadless census sectors located within 300 km of urban centers experienced net growth over this period (Figure 4; Appendix II in Supporting Information). However, 46% (59/128) of all sectors experienced a population decline and 68% (273,093 km^2) of the area covered by the nine municipalities experienced depopulation. Roadless census sectors farther from the municipal urban center were 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: $F_{1,125} = 27.8$, $P = <0.001$; distance*year: $F_{2,250} = 9.3$, $P = 0.0001$).

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

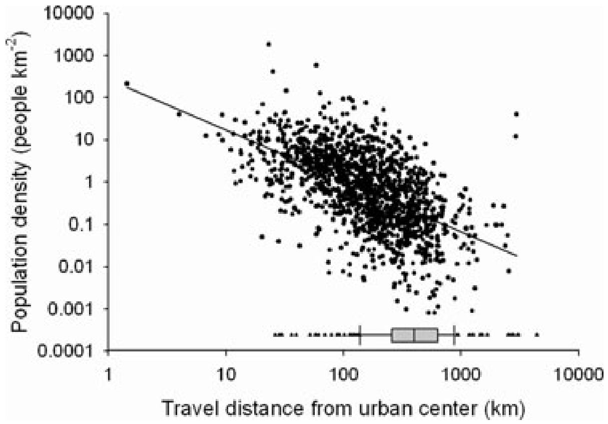

Figure 2 Distribution of the rural population in 2007 in the State of Amazonas, Brazil, in relation to the fluvial travel distance of census sectors ($N = 1{,}586$) from municipal urban centers ($n = 62$). Horizontal box-plot represents unpopulated census sectors.

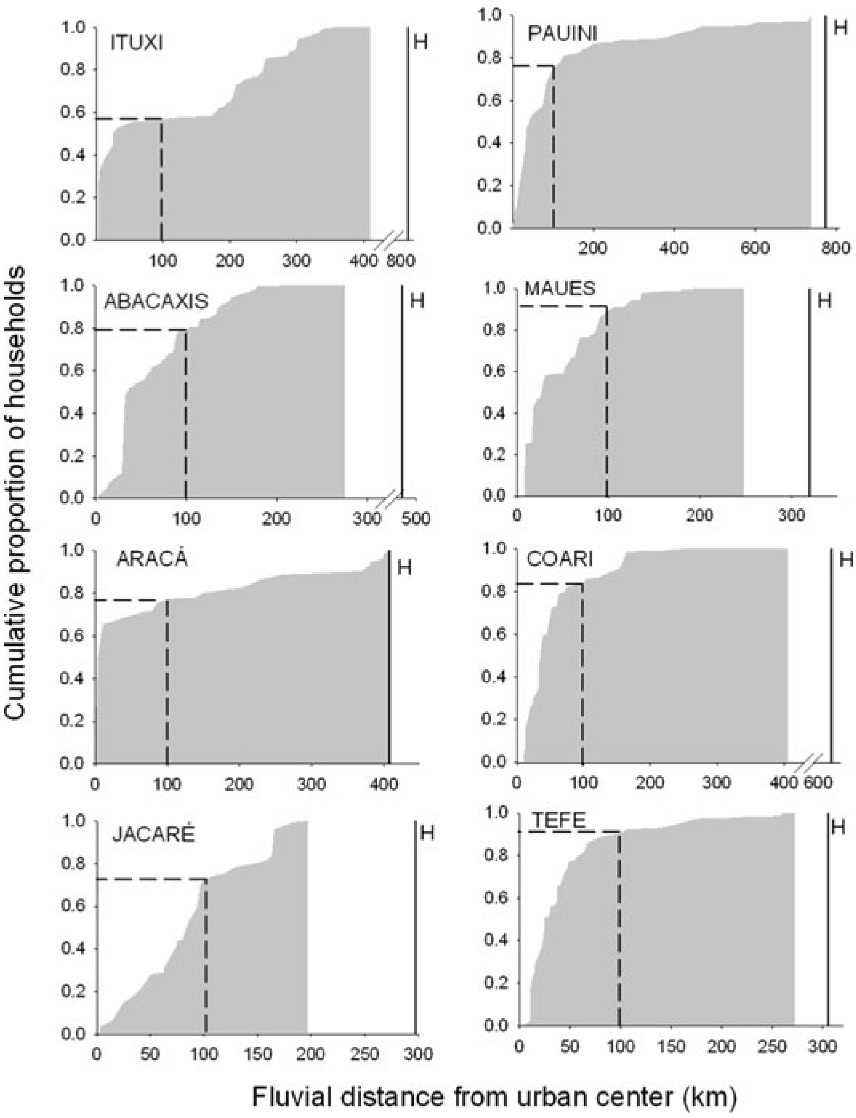

Figure 3 Accumulation curves of the riverine populations along eight subtributaries in Amazonas State, Brazil. The farthest point historically inhabited (during the second half of the 20th century) is indicated with a straight line and "H." Dashed lines indicate the proportion of households living within 100 km (approximate to maximum river distance travelable in one day) of their urban center.

of rivers, compared to 77 ± 8% SE 25 years previously (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 (Figure 5), whereas the most distant quartile upriver accounted for 46 ± 10% of all abandoned settlements.

Settlements near towns were more stable since households farther upriver were more likely to be planning resettlement to a new location (logistic regression; $c = 22.47$, df = 8, $P = 0.004$). Within 100 km of urban centers, 11% of families intended 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 (63%) or another urban center within Amazonas (10%). Only one family intended to resettle farther upriver from the nearest town. Hence, trends of negative population growth far from towns 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 1). Fishing and hunting were the most widespread activities, undertaken up to 800 km fluvial distance from the nearest urban center, and 525 km beyond the last permanent residence. Timber extraction and the harvest of nontimber forest products, such as Brazil nuts and turtles (and their eggs) were also

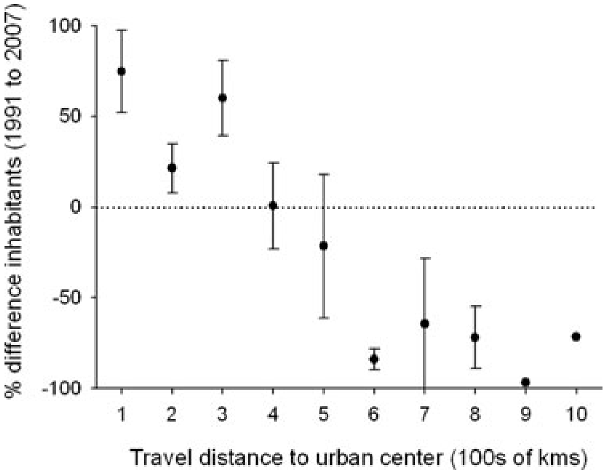

Figure 4 Change in population size over time (between 1991 and 2007) for coalesced census districts that were not bisected by roads, and outside of indigenous territories, within nine municipalities of the State of Amazonas, Brazil.

widespread toward headwater regions. Rural residents from the rivers we surveyed expressed concern about the high offtakes of commercial operators and believed that this had led to reduced stocks of fish, turtles, and hunted forest animals.

Discussion

Rural–urban migration has profoundly altered patterns of riverine settlement in the Brazilian State of Amazonas. Human populations 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. However, 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 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; Chomitz 2007).

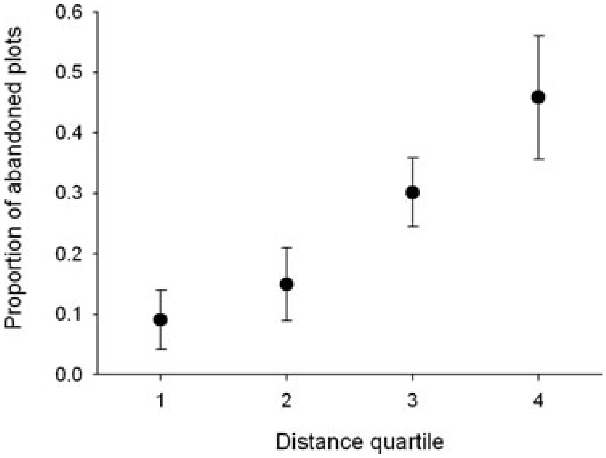

Figure 5 Distribution of abandoned smallholdings along eight urban–rural gradients in the State of Amazonas, Brazil. The proportion (±SE) of abandoned household plots along a given river is shown in relation to quartiles of the permanently inhabited extent of rivers.

As predicted, the majority (77%) of rural people lived close (<100 km) to the urban center of their municipality. 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), while zero or negative growth dominated beyond this distance. Many extractivists living in remote areas along these rivers relocated to rural areas nearer urban centers, particularly during the 1980s (Parry 2009). This suggests that the remote populations documented in 1991 are partly the same as those found in peri-urban areas in 2007 and thus rural–rural migrations have also been important. However, land scarcity near urban centers partly explains the current predominance of migration to towns rather than to peri-urban locations (Parry 2009). Lack of schools is driving the ongoing abandonment of remote areas although many rural families supported children in urban centers and individuals formerly living in rural areas sometimes returned seasonally (Parry 2009), supporting the notion of multi-sited households (WinklerPrins 2002; Padoch *et al.* 2008). Furthermore, migration to small towns is sometimes followed by moving to a large regional capital (Mougeot 1985).

The inhabited extent of the Amazonian subtributaries we surveyed fell by a third in recent decades, and headwater regions contained most abandoned land. Upriver families were more likely to migrate than those nearer towns, indicating that rural–urban migration is likely to continue. Depopulation of remote areas presents both conservation threats and opportunities. Amazonas remains largely forested, although it will be vulnerable to large-scale deforestation in coming decades (Soares-Filho *et al.* 2006). Headwater regions 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 therefore presents an opportunity for the demarcation of protected areas (e.g., Biological Reserves) in depopulated wilderness areas (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 lands (*terras devolutas*) 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 link roads to the paved BR-319 highway (Fearnside & Graça 2006). For those areas not yet abandoned we encourage efforts to sustain low-density rural populations through the federal or state demarcation of inhabited sustainable use reserves (Viana & Campos 2007). Complete headwater abandonment thus compromises the potential demarcation of legally occupied reserves, which form a key component of the overall network of protected areas in Amazonia (Peres & Zimmerman 2001).

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 headwater regions become depopulated, harvest pressure from subsistence resource users is discontinued, although the potential for overexploitation remains by urban and peri-urban residents (Klooster 2003; Stoian 2005). We show that the commercial extraction of forest resources and aquatic wildlife occurs well beyond the permanently inhabited extent of rivers. This nonresident extractivism is driven by diverse local, regional, and global commodity chains (Jensen 2009). In Amazonia scaled fish, for example, supply local and regional centers, whereas catfishes are destined for export (Almeida *et al.* 2001). Even small teams of harvesters (see Table 1) exploiting seasonally abundant turtles or catfish in remote areas may remove a large number of reproductive adults from the population, therefore exposing populations to overexploitation. Whereas Amazonian communities often exhibit coping strategies in the management of commons resources (de Castro & McGrath 2003), nonresident actors often lack the property rights necessary to exploit a resource sustainably (Ostrom *et al.* 1999). The lack of institutional presence and unclear property rights in remote abandoned headwaters of Amazonas may allow the perpetuation of an incomplete forest-transition, where the "mining," rather than management of forest resources continues unabated (Grainger 1995).

Urbanization has led to forest regrowth in rural areas, amounting to conservation benefits in countries such as Costa Rica and Puerto Rico (Chazdon 2003; Lugo & Helmer 2004). Nevertheless, 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 by existing legislation. However, monitoring is limited or nonexistent 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). Rural smallholders can report and repel land speculators (Campos & Nepstad 2006), including 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 & Terborgh (1995), we suggest that strategically placed enforcement outposts are established at the mouths of subtributaries in order to monitor and regulate the legal or illegal access of nonresident extractors into entire watersheds.

In this study, we question whether the urban–rural dichotomy is a useful framework for relating human migration patterns to potential opportunities and threats for forest cover and biodiversity conservation 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 show that riverine populations in the Brazilian Amazon are increasingly clustered near towns, which poses clear threats in terms of deforestation and overharvesting that are decoupled across the forest landscape. We also show that headwater regions of lowland Amazonia 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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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Travel network of navigable rivers and roads in the State of Amazonas, Brazil.

Appendix S2. Percentage changes in the number of inhabitants between 1991 and 2007 censuses, for 9 municipalities of the State of Amazonas, Brazil.

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