Popul Environ
DOI 10.1007/s11111-010-0127-8

ORIGINAL PAPER

Drivers of rural exodus from Amazonian headwaters

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Abstract Rural–urban migration can have both positive and negative environmental consequences for tropical forests. Rural residents exert pressure on the environment through farming, fishing, and forest extraction, yet conversely, protecting rural livelihoods is often the motivation for conserving large areas of threatened forest. This research examines rural settlement within the Brazilian Amazon to shed light on the drivers of on-going rural exodus and its environmental implications. Specifically, we examine the relative importance of public service provision and natural resources in determining settlement patterns along, and rural–urban migration from, eight rivers in road-less regions of the Brazilian Amazon. Data include biophysical, social, and economic variables that were assessed in 184 riverine settlements along rural–urban gradients up to 740 km from the nearest urban center. Settlements were smaller upstream, and lacked key

Electronic supplementary material The online version of this article (doi: 10.1007/s11111-010-0127-8) contains supplementary material, which is available to authorized users.

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Published online: 23 October 2010

services such as schools and healthcare. We found that clustering of rural populations close to urban centers reflects the high costs of living in remote areas, despite abundant natural resources which previously justified migration to headwaters. Impeded dry-season navigability and transport costs restricted the flow of goods and services to and from remote areas, and transaction costs of trade exchange were higher upstream. A lack of school access was the main motivation for rural–urban migration and the abandonment of remote riverine settlements. A key policy implication is that while education services could provide a powerful tool to stabilize and support rural populations, delivery is challenging in remote areas and may also encourage further rural–urban migration in the longer term. Furthermore, river-dwellers in remote areas rarely visited remote urban centers, presumably because these journeys are too costly. We examine the implications of our findings for anti-poverty subsidies and payment for ecosystem services and conclude that transport costs required to receive payment could encourage further depopulation of remote areas.

Keywords Brazil · Migration · Riverine · Rural settlement · Rural–urban · Urbanization

Introduction

Human migration plays a key role in both the destruction and protection of tropical forests (de Jong et al. 2006). Deforestation frontiers advance with the arrival of migrants seeking land and opportunity (Carr 2009), whereas migration of rural farmers away from forest areas is also credited as a respite for threatened forests (Wright and Muller-Landau 2006). Nowhere is this paradox more true than in the Brazilian Amazon. On the one hand, migration to the Amazon region since the 1960s has been associated with colonization and deforestation (Perz 2006), raising concerns that migration was driving the clearance of the world's largest tropical forest. On the other hand, rubber era migration to the Amazon region in the nineteenth century instigated a booming extractive economy in which exploited forests remained largely intact. Current conservation efforts in Amazonia often support rural populations as a means of achieving long-term forest protection (Campos and Nepstad 2006). Even so, migration to and from forest frontiers is only part of the story. Migration *within* Amazonia has also been occurring, for example (Parry et al. 2010), with important implications for the future of both forests *and* residents (Fearnside 2008a; Rodrigues et al. 2009).

To shed light on the environmental implications of Amazonian population dynamics, this paper assesses the biophysical, social, and economic drivers of riverine settlement patterns and rural–urban migration in road-less forested watersheds of the Brazilian Amazon. We hypothesize that the costs and benefits of either remaining sedentary or migrating to urban areas vary with increasing remoteness, and that this balance affects existing settlement patterns and rural–urban migration flows.

Background literature

Studying migration

Migrations are motivated by a complex set of social, economic, political, and environmental factors. A dominant approach in the study of migrations has been the identification of "push and pull" factors which operate in the areas of origin and destination, respectively (Lee 1966). For example, access to health services and education, which are key indicators of human well-being, is important in attracting people away from rural areas (Boyle 2004). In addition, lack of land tenure may encourage out-migration (Fearnside 2001). Economic opportunities in urban centers also attract rural migrants (Aide and Grau 2004). Conversely, declining economic opportunities in rural areas can trigger out-migration, especially when a rural economy largely depends on a single commodity, such as rubber (Dean 1987; Stoian 2000). As an example, in 1980 the 68,000 rubber-tapping families in the Amazon (Fearnside 1989) were adversely affected by the continuous decline of natural rubber prices on international markets (FAO 2003). However, most rural families in tropical countries never migrate (Carr 2008), and individuals and households vary in their migration patterns, even when subject to identical social and economic conditions (Curran 2002). The drivers of migration need to be better understood and analyzed by explicitly incorporating heterogeneity among poor rural households (e.g. age, education, gender, liquid capital, distance to promising job opportunities; World Bank 2003). Importantly, although decisions on when and where to migrate are made by the household (de Jong and Gardner 1981), choices are embedded within social relations, markets, and community so that settlement characteristics are also important determinants of migration (Stark 1991).

Migration to the Amazon

The recent history of the Amazon has been defined by the movement of people in search of land and natural resources. International demand for rubber brought large numbers of migrants to the Amazon from the mid nineteenth century onwards. In Brazil, the rubber industry drew tens of thousands of laborers from the drought-stricken north-east of the country (from 1872 to 1920; Neves 2005). These movements exemplify migration from crowded areas (due to population growth and land shortages) or degraded environments (e.g. drought-stricken) to frontier zones (Bilsborrow 1987, 2002). Although migration to the Amazon reduced dramatically when rubber prices collapsed from 1920, there was a renewed influx of rubber tappers during World War II (Dean 1987). Rubber tappers remained in Amazonia and rubber extraction on a smaller-scale continues to this day (Cardoso 2002). The population of the Brazilian Amazon increased significantly once more when the national government opened the region to development, starting in the late 1960s, leading to unprecedented levels of deforestation (Moran 1983). Census data indicate that six million people moved to the Amazon between 1960 and 1990 (Browder and Godfrey 1997), although migration to the region slowed in the 1980s. There was actually negative net migration to Amazonia between 1980 and 2000, when population growth was instead driven by high fertility and declining mortality (Perz et al. 2005).

Population dynamics within the Amazon

In addition to in-migration from other regions of Brazil, intra-regional migration has also been occurring in Amazonia (Sawyer 1987; Browder and Godfrey 1997). However, analyses of Amazonian migration using governmental census data usually address only inter-state migrations and ignore movements *within* states and *within* municipal counties (e.g. Perz 2006), the sub-state level of governance. Field-based investigation of rural–urban migration is necessary because local-scale migration data from governmental census is not normally available and movements within municipalities account for most intra-regional migration in Amazonia (Browder and Godfrey 1997). To examine rural–urban migration, boundaries must be defined, although empirically establishing rural and urban populations for demographic analyses can be challenging (Lynch 2005). This is particularly relevant when using census data from the Brazilian Amazon (Pantoja 2005) due to the occurrence of multi-sited households in which families maintain both urban and rural residences to benefit urban-based services and rural natural resources (Winklerprins 2002; Padoch et al. 2008; Pinedo-Vasquez and Padoch 2009).

Population-environment studies in the Amazon have generally focused on the causes and environmental impacts of migration to the deforestation frontier (Carr 2009), typically to areas made accessible by new roads and ignored population dynamics in areas away from the deforestation frontier. Amazonian river-dwellers, who are often former rubber-tappers or their descendants, remain largely forgotten in migration analyses, despite the fact that they number several million people (Hiraoka 1992; Harris 2000). Overall, rural–urban migration (also known as rural exodus) and urbanization in Amazonian regions dominated by rivers rather than roads has received little attention by scholars.

Traditional riverine livelihoods

Riverine households in the Amazon tend to have diverse livelihoods portfolio of fishing, agriculture, plus some cattle-raising, forest extractivism and occasional wage labor (Lima and Pozzobon 2009). Settlements can be broadly separated into those on the seasonally flooded *várzea* and those in unflooded *terra firme* areas. The livelihoods of *várzea* inhabitants are subject to dramatic seasonal change with the rising and falling of river levels (Harris 2000). Fishing provides significant sources of food and income to these communities, particularly in the low-water season when fish are easier to catch. Cattle are frequently raised on the fertile floodplains of the lower Amazon though pastures and cropland are flooded in the wet season. Forest extraction also provides income to rural Amazonians, particularly for those living on or near *terra firme* forests with Brazil nut groves and other harvestable plant products (Stoian and Henkemans 2000). River-dwelling Amazonians almost invariably practice small-scale agriculture, which is dominated by cultivation of manioc. Kinship serves as the basis for cooperation in labor and access to land

(Lima 2004). Trading has traditionally been operated through systems of debt-peonage though this declined with the demise of the rubber barons. Barter exchange continues in some (often remote) areas, with boat-based traders (*regatões*) operating more informal systems of debt relations (McGrath 2004).

A spatial basis for rural–urban migration

Principles of economic geography dictate that out-migration is more likely from remote rural areas in Amazonia than from localities nearer to urban centers. Farmlands and forests near towns are more valuable (Von Thunen 1826)—transport costs dictate strong incentives to focus agricultural production near urban markets, despite the trade-off with land availability (Snrech 1996). In remote areas, economic activities are hampered by poor market access and limited access to information on prices, for example (e.g. Börner et al. 2007). These spatial economic inequalities can drive out-migration (Ravenstein 1889). Remote areas of pre-frontier regions have experienced rural depopulation in the last decades and most rural people now live near urban centers (Chomitz 2007). In the Brazilian Amazon, rural populations are clustered (and growing) near to urban centers and land abandonment has dominated in more remote areas (Parry et al. 2010). Population growth near to urban centers might be because expanding rainforest cities have increased agricultural demand from surrounding areas (Stoian and Henkemans 2000; Lynch 2005).

Drivers of rural–urban migration in the Amazon

The rural population of Amazonia's pre-frontier regions (what could be considered the 'heart' of the Amazon, away from the Arc of Deforestation, a vast area of intense forest clearance along the forest's southern and eastern boundaries) has been exposed to dramatic social and economic change. These include changes in international demand for key forest products and government initiatives to improve rural education and healthcare. Rural–urban migration in the Amazon may also be motivated by the desire to receive government subsidy. In Brazil, universal subsidies such as retirement pensions and the family grant *Bolsa Família* [a federal poverty alleviation program (Hall 2008a)] provide powerful incentives to regularly visit or inhabit cities, where subsidies are collected. However, environmental characteristics such as spatial differences in river navigability, land availability, and wildlife abundance determine rural settlement patterns (Gross 1975; McGrath 1989; Denevan 1996) and could also be important drivers of migration.

The drivers of rural out-migration in the Amazon likely operate at various organizational scales and comprise a suite of biophysical, social, and economic factors. In rural Amazonia, both detribalized peasants and indigenous people are mobile and relocate in response to changing socio-economic conditions (Winklerprins 2002; Alexiades 2009). However, due to a paucity of research, there is no sound basis for understanding the likely effects of socio-economic changes on rural–urban migration across the Amazon. Identifying community and household characteristics (including demographic, political, social, economic, and ecological factors) associated with migration has key policy relevance to rural development and environmental conservation (Carr 2009).

Socioeconomic impacts of rural–urban migration and urbanization

There has been rapid urbanization across the Brazilian Amazon in recent decades (Guedes et al. 2009), in parallel with the decline of rural populations in many tropical countries due to rural–urban migration (UN 2005). The number of urban centers in the Brazilian Amazon with more than 5,000 inhabitants grew from just 22 in 1960 to 133 by 1991 (Browder and Godfrey 1997), contributing to the shift from predominantly rural to urban population by 1980. Such rapid urbanization in developing countries is often associated with urban squalor and poverty (Torres et al. 2006; Bezemer and Headey 2008). Such has been the case in the Brazilian Amazon, where the unplanned growth of urban areas has led to problems of deficient infrastructure, inadequate social and medical services, rapid shantytown growth, pollution, and unemployment (Browder and Godfrey 1997; Little 2001; Castro 2009).

Environmental impacts of rural–urban migration

The environmental impacts of rural–urban migration for rural areas continue to be debated (see Fearnside 2008b). While rural depopulation could offer respite for tropical forest ecosystems through land abandonment and forest recovery (Aide and Grau 2004; Wright and Muller-Landau 2006), there may also be net conservation *costs* if rural–urban migration continues to erode traditional populations in forested regions. Rural Amazonians have promoted forest conservation through gaining land rights and the creation of sustainable-use reserves designed to ensure land tenure and prevent land speculation and its often-associated violence (Campos and Nepstad 2006). Some conservationists therefore encourage efforts to sustain rural populations as a means to maintain forest cover and environmental services through forest stewardship (Vandermeer and Perfecto 2007; Harvey et al. 2008). Hence, rural population dynamics in the forested tropics have important consequences for conservation (Oglethorpe et al. 2007). Efforts to conserve forests and their environmental services through partnerships with traditional communities could be rendered ineffective if policy-makers cannot predict the likely effects of social, economic and environmental change on the distribution and migrations of rural populations.

Hypotheses

We hypothesize that in Amazonia the costs and benefits of either remaining sedentary or migrating to urban areas vary with increasing remoteness and that this balance affects existing settlement patterns and rural–urban migration. We also make the following predictions: (1) there are major social and economic costs to living in remote areas of Amazonia, which increase with distance from urban centers; (2) the causes of migration have changed through time and the current primary drivers of rural–urban migration are improving access to public services, particularly education, health care, and anti-poverty subsidies. We hypothesize that these pressures currently outweigh the opposing incentives offered by inhabiting remote areas, namely the ample availability of land and natural resources. We test these hypotheses using an empirical approach combining qualitative and quantitative data from 184 settlements located along rural–urban gradients in eight watersheds in Amazonas state, Brazil. Net benefits of rural settlement versus rural–urban migration are likely to vary across space so the distribution, stability and movement of populations are ill-suited to a crude rural–urban dichotomy (Browder 1995; Almeida 1996). The concept of rural–urban gradients has been usefully applied to understanding spatial patterns of deforestation and human population distributions (Chomitz and Thomas 2003; Chomitz 2007), though it has not been explicitly incorporated into studies of migration and *changes* in rural population size. We explore our findings in the context of governmental policies of subsidy and strategies to support rural Amazonians.

Methods

Study area

The state of Amazonas contains 1.3 million km^2 of intact forest (INPE 2008), which is vulnerable to the arrival of the Arc of Deforestation, as well as infrastructure projects such as road-building, hydroelectric dams and long-distance gas pipelines (Fearnside and de Alencastro Graça 2006; Finer et al. 2008). Currently, Amazonas has few paved highways and a transport network dominated by rivers as well as air transport to support the high-tech industrial development of the state capital, Manaus (Fenley et al. 2007). The state has a population of 3.2 million people (IBGE 2007), of which 2.5 million (77%) live in urban areas. Some 65% (1.6 million) of the urban population live in Manaus. Although Amazonas has the largest indigenous population of any Brazilian state (105,165 people: FUNAI 2007), 85% of the rural population are non-indigenous, mostly river-dwelling *ribeirinhos* (also known as *caboclos*, sensu Parker 1985). *Ribeirinhos* are rural Amazonians of mixed Amerindian, Portuguese and north-eastern Brazilian ancestry.

Field surveys

We assessed riverine settlement and rural–urban migration in eight randomly selected road-less watersheds of Amazonas from February to November 2007 (Fig. 1). We selected areas that were largely independent of one another and of varying distances from Manaus. In each area, we surveyed a sub-tributary, whose confluence with a larger river was close to an urban center. Three of the rivers are tributaries of the Rio Purús (Rio Pauini, Rio Ituxi, Rio Jacare), two of the Rio Solimões (upper Amazon) (Rio Coari, Rio Tefé) one of the Rio Baixo Amazonas (lower Amazon) (Rio Maués), one tributary of the Rio Madeira (Rio Abacaxi) and one tributary of the Rio Negro (Rio Aracá). We sought to understand settlement and

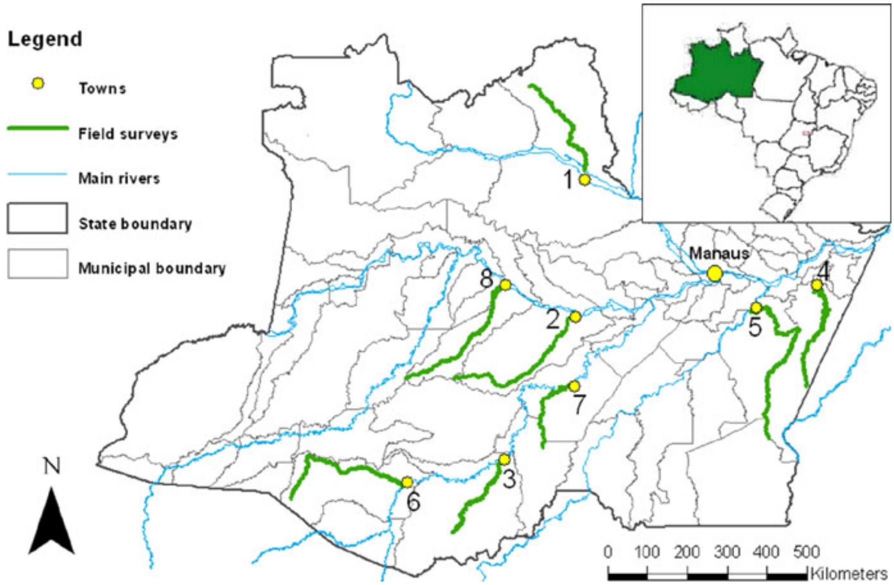

Fig. 1 Map of the rivers visited during 2007 field surveys along rural–urban gradients in Amazonas State (*main map*), Brazil (*inset map*). *Numbers* correspond to urban centers (and rivers surveyed, in parentheses): 1–8, respectively, Barcelos (Rio Aracá); Coari (Rio Coari); Lábrea (Rio Ituxi), Maués (Rio Maués/Parauari), Nova Olinda do Norte (Rio Abacaxis), Pauini (Rio Pauini), Tapauá (Rio Jacaré), Tefé (Rio Tefé)

migration outside of sustainable-use reserves, indigenous territories and strictly protected areas (see Electronic Supplementary Material (ESM)). In each area, we travelled upriver as far as the last household ($\leq$ 740 km), and then returned slowly downstream, stopping and conducting structured interviews at settlements on route. We interviewed river-dwellers at 16–34 randomly chosen settlements along each river (mean = 23), a total of 184 settlements across the eight rivers. At each surveyed settlement (herein settlement), we conducted one settlement-level interview and one household-level interview (see ESM). The relatively large number of settlements surveyed suggests this approach was sufficient to capture inter-settlement variation in socio-environmental cost-benefits and migration patterns. However, sampling a single household in each settlement inevitably limits insights into intra-settlement variation in social and economic characteristics, particularly for settlements with a greater number of households.

Settlement survey

The settlement questionnaire was structured around several themes including: demographics, transport and navigability, access to public services, trade and government subsidy, natural resources, and agriculture (see ESM for information on interviewing). Further details on the data collected are summarized in ESM Table 1.

Household survey

We sampled one household per settlement and used these data as the basis for models of rural–urban migration choice, embedded within settlement-level data, and to provide qualitative insights into the motivational basis and history of household resettlement events. We randomly selected households for interview, by asking a member of the settlement to pull a name out of a bag (which was irrelevant when settlements consisted of a single household). We always strived to have both the female and male head of household present for the household interview (see ESM). The household questionnaire was structured around several themes including: household demography, migration history, current migration intent and motivations, income and household wealth (see ESM Table 2). We assessed household wealth by ownership of valuable items used within the household (Walker et al. 2000) (e.g. electrical goods) and key valuable items for livelihoods (e.g. shotgun) (see ESM).

Data analysis

Hypothesis 1 There are major social and economic costs to living in remote parts of Amazonia which increase with distance from urban centers.

From the settlement-level survey data, we examined how biophysical, social and economic conditions changed with increasing travel distance from urban centers, according to our predicted drivers of settlement growth and rural–urban migration (transport to urban areas, access to public services, trade and government subsidy, and natural resources). Data were taken from interviews, plus our own observations and spatial data recorded during fieldwork. All distances refer to riverine travel distances ± SE, rather than straight-line distances. In addition, we used ArcGIS 9.2 (ESRI, Redlands, California) to assess the availability of unflooded land within a 5 km radius of each settlement. We used a basin-wide flooded forest raster image for this analysis (see Hess et al. 2003).

Hypothesis 2 Drivers of migration are related to the provision of public services rather than availability of natural resources.

The drivers of migration were initially examined using qualitative insights into migration histories and current migration intent and motivations, based on household interviews. We then created quantitative empirical models to quantify the relative importance of our hypothesized drivers of migration.

Qualitative insights: migration history and current motivations

Interview data on past migrations and current intentions were databased and categorized. Motivations for past and current migration were categorized into: transport, trade, labor/unemployment, natural resources (forest product collection, or land availability), and social issues (new start, personal problems or social networks, in which settling with or near a relative was the primary motive for migration). Pertinent quotes from interviews are also presented, where appropriate.

Statistical models for drivers of settlement growth

Using data from settlement surveys, we assessed drivers of settlement growth (change in number of households) between 1991 and 2007 for settlements visited along 7 of the 8 study rivers (the Rio Maúes was excluded as these data were collected during this pilot survey and were not wholly comparable to subsequent rivers). Our data provided information on the hypothesized drivers of rural–urban migration in road-less areas of Amazonia, as reduced settlement growth implies out-migration from the settlement (assuming constant fertility and mortality). We identified key variables relevant to these hypothesized drivers and constructed a model of settlement growth between 1991 and 2007 using four structural parameters, including biophysical and public service provision variables. Biophysical variables selected included travel distance from the local urban center (*distance*), and a binary score of river navigability (*nav*), defined in terms of whether any given location was passable in the low-water (dry) season to a $\geq$ 9 m long boat powered by an inboard diesel engine. Fluvial distance was used as a proxy for other factors as it was shown to be highly correlated with costs and benefits of settlement, including travel time, subsidy uptake, land availability, and communications facilities (see Results). We distinguish between distance and navigability because navigability can be abruptly discontinued (e.g. due to shallow water and seasonal rapids) and could impose a severe constraint on service provision. In contrast, fluvial distance incurs gradual linear costs on rural people in terms of fuel and time expenditure, as well as benefits associated with higher abundance of natural resources, for example. We included two measures of public service provision, education (*educ*) and health (*health*) for 1991 and 2007. We tested the model using the statistical platform R 2.7.2 and the *lme4* library. See ESM for full details of model construction.

Random utility model of current migration intent

We sought to test the relative importance of settlement and household characteristics in predicting rural–urban migration choices by riverine households. For this purpose, we used interview data from settlements and households and constructed a random utility model (McFadden 1974). These models are more commonly used to understand spatial decision-making in fisheries (e.g. Hutton et al. 2004), though are ideal to examine household choices within a settlement context. They model discrete decisions (e.g. migrate to an urban area or not) and do not assume homogeneity among individual actors. They do assume that utility drives individual choice with a deterministic and a stochastic error (random) component. See ESM for details of model construction and variables used. We tested rural–urban migration against six variables representing household characteristics and five settlement utilities, in which variables describe the difference in a utility between a settlement and its local urban center.

Results

The rural settlements we mapped ranged in size from single isolated households to a large village (281 households). On average, settlements were small (median number of households = 2). Settlements within 100 km of urban centers tended to be larger, and there was a trend of decreasing settlement size farther from urban centers (Fig. 2). The demographic composition of households also changed with distance from urban centers. Households within 100 km of urban centers were larger on average (6.5 individuals ± 0.3 SE) compared to surveyed households at 100–200 km (5.1 ± 0.3), 200–300 km (4.8 ± 0.5) or greater than 300 km (5.8 ± 0.7). Larger households near to centers was mainly due to a higher number of children (0–14 years), with 3.0 ± 0.3 compared to 2.5 ± 0.5 (100–200 km); and only 1.8 ± 0.3 (200–300 km) and 1.7 ± 0.4 (>300 km) (Fig. 3). There was an increasingly male-bias to households farther from towns, with a higher number of male children, adults and older people beyond 100 km of urban centers. The male bias was strongest for the farthest distance category (> 300 km) where surveyed households had no older women (> 59 years) and on average just 1.2 women aged 15–59 years compared to 2.0 men of that age range (Fig. 3).

Hypothesis 1 Costs and benefits of distance: exploration and identification of key variables.

Based on settlement-level interviews in 2007, it is clear that living in remote areas farther from urban centers incurs high costs in terms of access to public services and trade, which reflect the transport difficulties of travelling to and from local urban centers. Figure 4 illustrates public service provision and the transport times to an urban center along one river surveyed, the Rio Coari. The costs and benefits of settlement are explored, using variables that represent the hypothesized

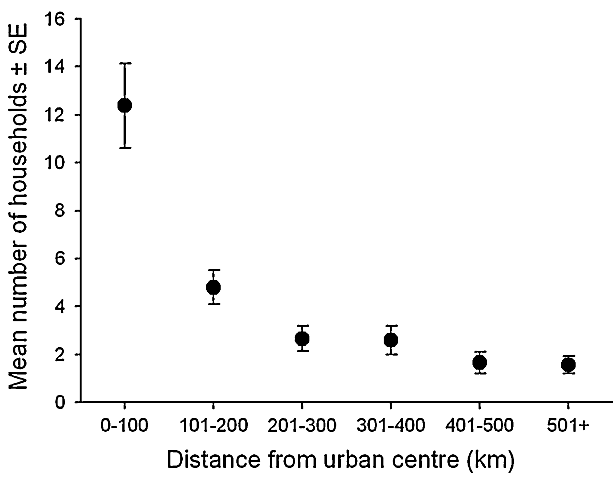

Fig. 2 Size of settlements (mean number of households ± SE) along surveyed rivers (total number of settlements = 434), in relation to travel distance from local urban centers

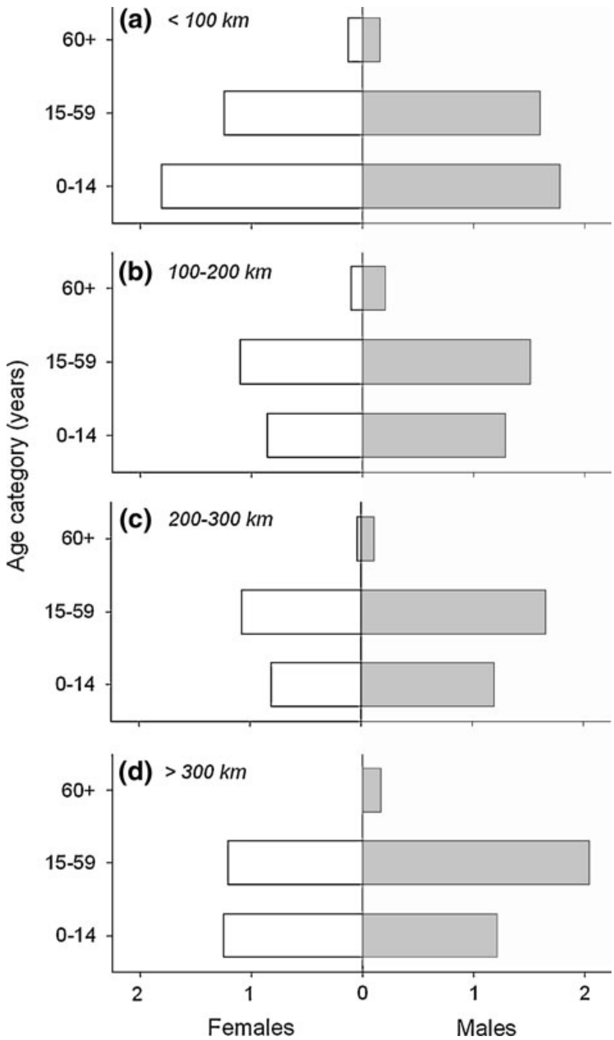

Fig. 3 Age and sex structure of surveyed households by distance from urban centers. $N = 62$ households (0–100 km); 49 (100–200 km); 26 (200–300 km); 24 (300 km +)

drivers of rural–urban migration (natural resources and transport and trade versus public services and subsidies).

Natural resources

River-dwellers living upstream reaped the benefits of low human population densities as they had easier access to unfarmed land and wild animals (Parry 2009). Settlements upstream had closer access to primary forest (Fig. 5). Settlement size exerted a weak negative effect on land availability (Table 1). There was also a greater proportion of unflooded habitat with increasing distance upriver (Fig 6).

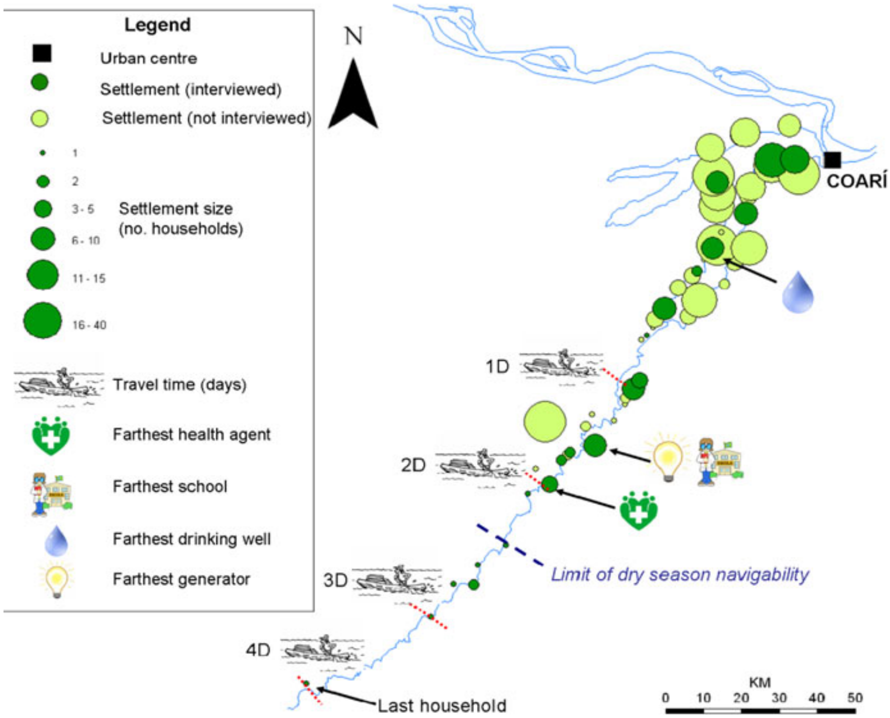

Fig. 4 Map of settlements along the Rio Coari, Amazonas, surveyed in 2007. Settlement sizes are indicated, along with maximal extents of public service provision, travel times to the urban center during the wet season (high water) and the limit beyond which 9 m + diesel inboard boats cannot pass during dry seasons (low water)

Transport and trade

Travel time and total journey time (which includes rests and breakdowns) were strongly related to fluvial distances from urban centers in both the wet and dry seasons (Fig. 7; Table 2). Total journey time was significantly longer than travel time in both the dry and wet seasons (paired t-tests; dry: $t_{159} = -10.13$, $p < 0.001$; wet: $t_{166} = -7.70$, $p < 0.001$). The higher reaches of Amazonian sub-tributaries become impassable to motorized boats during the dry season (Fig. 8) (see ESM). People living upstream visited urban centers less often as there was a significant increase in the return time to urban centers with fluvial distance upstream (Fig. 9; inter-trip interval = 0.835 ln(travel distance) −0.3501; $R^2 = 0.67$; $p = 0.000$; $n = 181$). Journeys to urban centers were extremely rare for river dwellers living far upriver. For example, one interviewee on the upper Rio Pauini living 593 km from the urban center of Pauini (involving an 8–9 day journey) had not visited the town in 15 years.

Ribeirinhos on the eight rivers we surveyed obtained external goods through the sale of agricultural and extractive produce (see ESM). The price of 13 essential foodstuffs and non-food essentials increased significantly with increasing distance upriver (Table 3). The price of items such as sugar, cooking oil and salt was

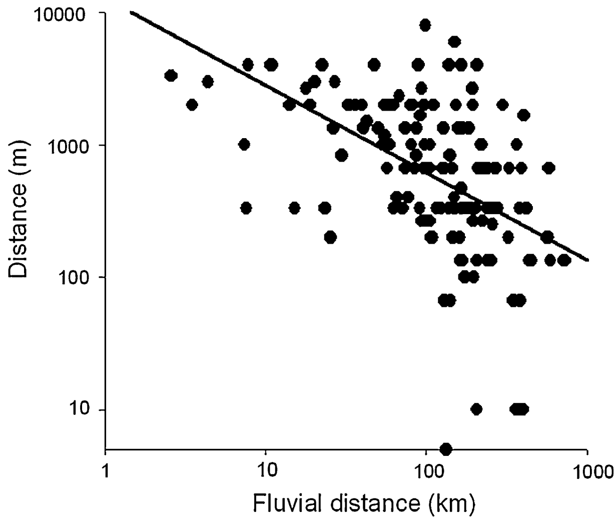

Fig. 5 Distance to primary forest (indicated by interview response) in relation to the travel distance of a rural settlement from its municipal urban center

Table 1 Predictors of access distance to unfarmed primary forest around settlements along Amazonian sub-tributaries in relation to distance from urban centers

	B	SE *B*	*β*
Step 1			
Constant	3.068	0.075	
$\text{Log}_{10}\ (x + 1)$ travel distance (km)	−0.002	0	−0.428
Step 2			
Constant	3.014	0.082	
Travel distance (km)	−0.002	0	−0.399
Settlement size (households)	0.003	0.002	0.115

Step 1 is a model without the inclusion of settlement size as a predictor, whereas this variable is included in Step 2

$R^2 = 0.185$; $\Delta R^2 = 0.012$ ($p = 0.126$). $p < 0.000$

normally twice as expensive as urban supermarkets and often three- to four-times more costly for the most remote settlement on a river. Traders also paid lower exchange prices for five cultivated or extractive products that were bartered for essential goods (Table 4) (see ESM).

Public services

Education

Larger settlements were more likely to have a school, though there was no independent effect of travel distance from an urban center ($\chi^2 = 51.4$, $p < 0.0001$;

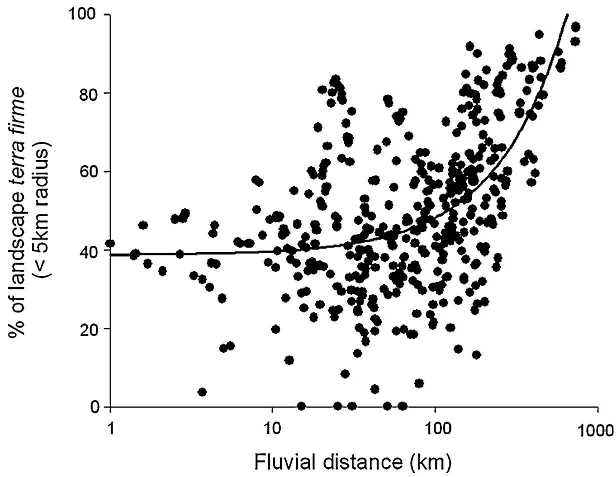

Fig. 6 Relative availability of unflooded land (terra firme) within a 5-km radius of rural settlements in Amazonian sub-tributaries, of varying travel distances from their municipal urban centers

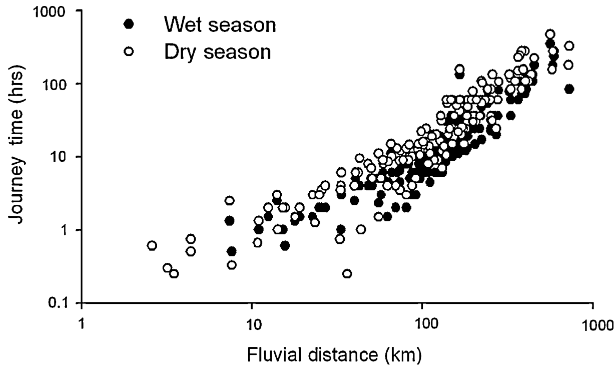

Fig. 7 Journey times to urban centers, from settlements located at various distances along river sub-tributaries in Amazonas, Brazil

Table 2 Relationship between travel time and journey time (which includes rests) with increasing distance (ln) from urban centers along Amazonian sub-tributaries

Season	Time (h)	β	Constant	R^2	p	n
Dry	Travelling only	1.18	−2.88	0.86	0.000	159
Dry	Total journey time	1.35	−3.44	0.85	0.000	159
Wet	Travel only	1.19	−3.29	0.88	0.000	166
Wet	Total journey	1.31	−3.66	0.85	0.000	166

Table 5). Municipal authorities deployed at least one elementary primary school teacher up to 207 ± 23 km from their urban center (range = 139–328 km), corresponding to 64 ± 9% of the inhabited length of sub-tributaries

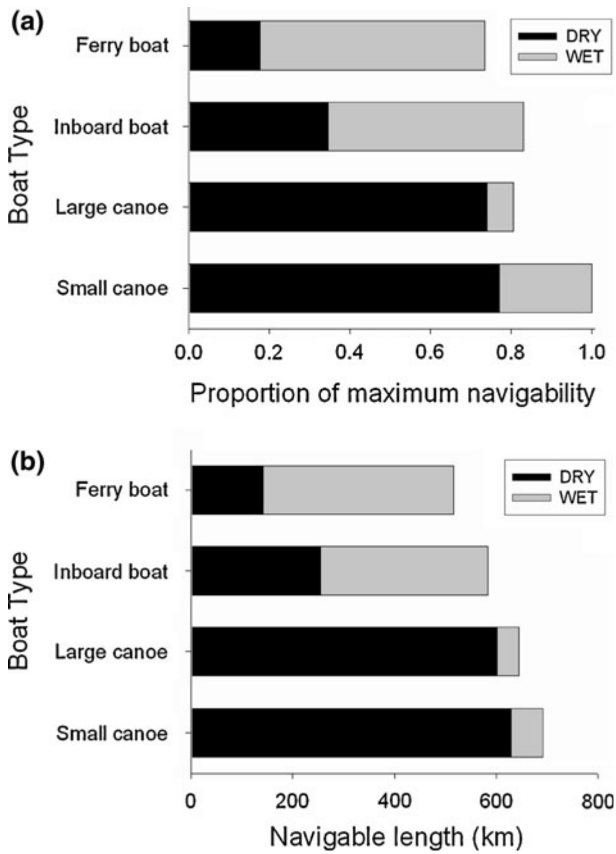

Fig. 8 Distances from urban centers navigable in high and low water seasons, along 8 Amazonian sub-tributaries

(range = 23–96%). The most distant third of the inhabited section of rivers consistently lacked a primary school. Even this underestimates the decline in access to education with distance from urban centers because teachers in remote areas were generally unqualified and taught only basic literacy and numeracy. River-dwellers living far upstream also reported that teachers spent up to several weeks a month travelling to (and staying in) the urban center to collect their wages.

Healthcare

Smaller settlements, and settlements farther from urban centers, were less likely to have a community health agent (logistic regression: $\chi^2_2 = 51.4$, $p < 0.0001$; Table 5). Municipal authorities deployed trained health agents to a mean distance of 237 ± 37 km from the urban center (range = 97–434 km). This corresponds to 66 ± 7% of the inhabited section of sub-tributaries (range = 41–100%).

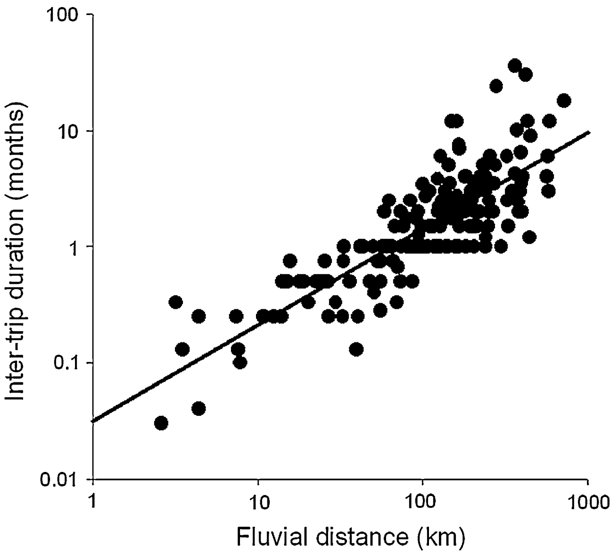

Fig. 9 Mean duration of time intervals between trips in which at least one member of a rural household visited their local urban center

Table 3 Prices and regression relationships between fluvial distance (sqrt km) from the nearest urban center, and the price of basic goods traded along eight sub-tributaries of the Brazilian Amazon

Category	Product	Unit	Mean city price (R$)	Max rural price (R$)	R^2	Slope	Constant	*p*	*n*
Food	Sugar	kg	1.3 ± 0.1	5	0.26	0.06	1.64	0.000	111
	Coffee	100 g	1.1 ± 0.1	4	0.13	0.03	1.21	0.000	93
	Rice	kg	1.7 ± 0.1	6	0.26	0.07	1.96	0.000	85
	Milk	120 g	1.4 ± 0.1	4	0.39	0.07	1.26	0.000	67
	Oil	0.9 L	2.3 ± 0.1	6	0.33	0.10	2.61	0.000	107
	Salt	kg	0.5 ± 0.04	2	0.24	0.03	0.72	0.000	80
Fuel	Diesel	L	2.2 ± 0.1	5	0.19	0.05	2.34	0.000	85
	Petrol	L	3.0 ± 0.1	6	0.43	0.11	2.90	0.000	78
Toiletries	Soap	kg	1.9 ± 0.1	8	0.30	0.09	2.11	0.000	93
	Toothpaste	50 g	1.1 ± 0.1	3	0.54	0.07	1.08	0.000	80
Ammunition	Battery	D cell	1.0 ± 0.0	3	0.18	0.04	1.24	0.000	98
	Shell		3.1 ± 0.1	7	0.24	0.07	3.26	0.000	50
	Lead	kg	8.6 ± 0.4	25	0.18	0.27	9.2	0.000	63

Power

Larger settlements and those closer to urban centers were more likely to have access to electricity (logistic regression: $\chi^2_2 = 102.6$, $p < 0.0001$; Table 5). On average, electrical power was available up to 213 ± 34 km from the nearest urban center (range = 87–388 km). Power came mainly from generators which, when

Table 4 Relationships between the prices paid by river traders for agricultural and harvested wildlife by river traders with increasing fluvial distance (km) from urban centers along eight Amazonian sub-tributaries

Product	Scientific name	Unit	Median city prices (R$)	Min rural price (R$)	R^2	Slope	Constant	*p*	*n*
Toasted manioc	*Manihot* spp.	80 L	44–60	10	0.09	−0.034	49.3	0.007	71
Bushmeat (salted)	Mainly *Tayassu pecari* and *Tapirus terrestris*	kg	3–4	1.5	0.31	−0.003	3.2	0.000	73
Catfish (salted)	e.g. *Pseudoplatystoma spp.*	kg	2.5–4	1	0.32	−0.003	2.9	0.000	45
Brazil nuts	*Bertholletia excelsa*	80 L	40–60	25	0.15	−0.024	54.8	0.005	47
River turtle	*Podocnemis unifilis*	Adult	21–50	7.5	0.29	−0.057	43.6	0.005	22

Table 5 Results of logistic regression analyses of the effects of distance from urban centers and settlement size on the likelihood of rural settlements having public services or receiving any subsidy ($n = 184$)

Service	Predictors	α	SE	*df*	*p*
Education (school or lessons only)	Constant	−2.88	0.68	1	0
	Fluvial distance (km)	−0.004	0.003	1	0.195
	Settlement size (number of households)	0.539	0.09	1	0
	Percentage correctly classified = 90.2% (correct absent = 94.4%; correct present = 84.0%)				
Health agent	Constant	0.134	0.378	1	0.723
	Fluvial distance (km)	−0.004	0.002	1	0.007
	Settlement size (number of households)	0.122	0.035	1	0.001
	Percentage correctly classified = 70.7% (correct absent = 70.7%; correct present = 70.6%)				
Access to electricity	Constant	−0.9	0.474	1	0.058
	Fluvial distance (km)	−0.007	0.002	1	0.003
	Settlement size (number of households)	0.232	0.046	1	0
	Percentage correctly classified = 80.9% (correct absent = 88.9%; correct present = 69.3%)				
1 ≥ household receiving Bolsa Família anti-poverty subsidy	Constant	0.283	0.421	1	0.502
	Fluvial distance (km)	−0.008	0.002	1	0
	Settlement size (number of households)	0.122	0.035	1	0
	Percentage correctly classified = 79.2% (correct absent = 82.5%; correct present = 75.6%)				

functioning, were only used for an average of 3 h 24 min per night and were not used every night as fuel shortages for one or two weeks per month were frequent (see ESM).

Communication

People living farther upriver had less access to communication with their urban center. In addition to longer urban center return-times, they had fewer means of receiving information from urban centers (such as local government and civic society broadcasts, health campaigns, and agricultural and extractive programs) and were less likely to have a payphone (see ESM).

Government subsidies, trade and wealth

Monthly household income from governmental salaries or subsidies decreased with distance from urban centers, declining three-fold from US$128 within 100 km of

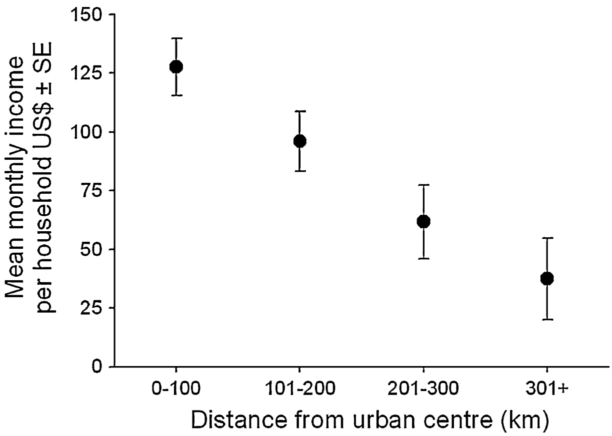

Fig. 10 Mean household income ± SE per month from government employment (e.g. in schools) or government subsidy (anti-poverty grant, rural pension etc.) for settlements in different distance categories from urban centers

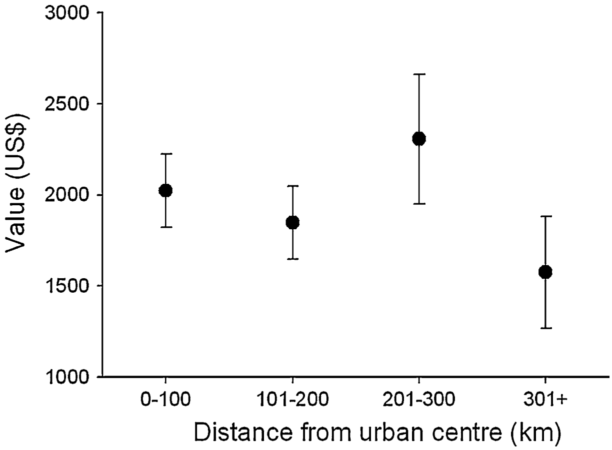

Fig. 11 Mean household wealth, based on possession of key goods used in the household, livelihoods and transport, in different distance categories from urban centers

urban centers to US$37 in settlements beyond 300 km (Fig. 10). Larger settlements and those closer to urban centers were more likely to have at least one family receiving the *Bolsa Familia* subsidy (logistic regression: $\chi^2_2 = 74.9$, $p < 0.0001$; Table 5). Around half (49.4%) of the estimated 1,404 households within 100 km of urban centers were receiving *Bolsa Família* in 2007, compared to only 11.1% of rural families beyond 100 km of their local urban center. On average, the aggregate value of household possessions we inventoried was US$1,956, ranging from US$0 for one ranch laborer to US$8,291. Based on the ownership of valuable domestic items and other livelihoods assets, household wealth did not significantly decrease upriver (Fig. 11).

Summary

Living far up Amazonian sub-tributaries incurs high social and economic costs, but these costs can be partly compensated by the benefits of abundant land and natural resources. Seasonally restricted navigability and greater transport time (and cost) place major barriers to the supply of goods and services upriver, as well as exposing river dwellers to increasingly high transaction costs of barter exchange with traders. Basic public services, including education, healthcare, and electricity, were normally lacking beyond 200 km distance from urban centers. Remote households also visited urban centers less frequently, which may partly explain low uptake of the anti-poverty subsidy, *Bolsa Família*.

Hypothesis 2 Drivers of migration are related to the provision of public services rather than availability of natural resources.

The motivations for rural–urban migration are explored, using qualitative insights from interviews, and empirical statistical models.

Qualitative insights: migration history and current motivations

These data are summarized in Figs. 12, 13, ESM Fig. 1 and ESM Fig. 2, which show that previous migrations to current rural locations were driven by a range of social and economic motives, which varied in time and space. Migration drivers have changed—rural–urban migration is currently the predominant form of re-settlement planned, with the desire to access education being the main motive (Fig. 13).

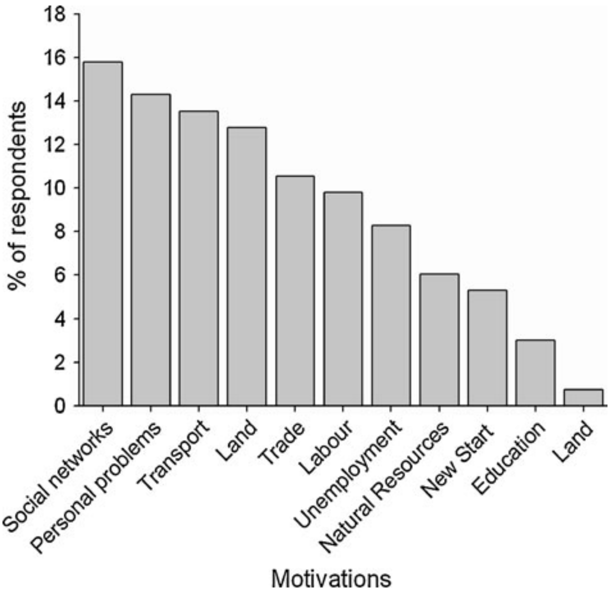

Fig. 12 Primary motive given for migration to the current rural location

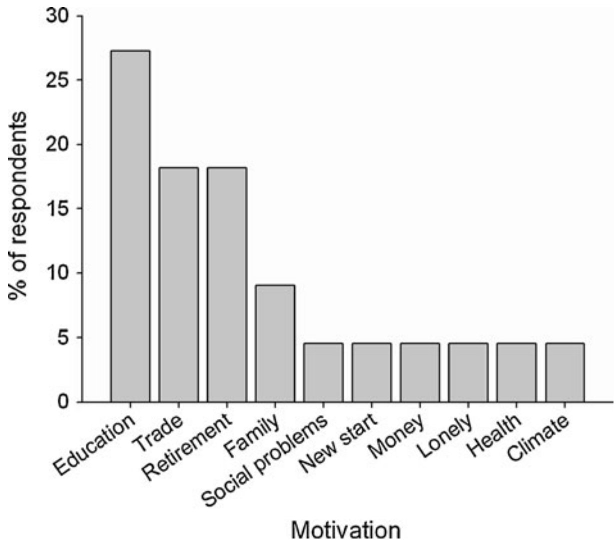

Fig. 13 Primary motive given by households currently planning rural–urban migration

Interview data indicated that rural Amazonians are highly mobile as 72% of the 184 surveyed households had re-located to their current location from elsewhere. The remainder had lived in their current settlement for their entire lives. Nearly a fifth (17 ± 4%) of the respondents were planning on relocating their households within the foreseeable future. Most of these (74% of intended migrants) were planning on moving to their local or other urban center, whereas only seven households (23% of intended migrants) were planning to move to other rural localities, only one of which was an upstream site.

Single isolated households were more likely to migrate; 25% of them were planning to relocate to an urban center, compared to only 8% of households in settlements consisting of at least two houses. Of the isolated households with no neighbors within a 5-km radius, 42% were intending to migrate to an urban center. One-third (32%) of the households living beyond the most distant point of dry-season navigability were going to migrate to an urban center compared to only 7% of those within navigable distance of urban centers. Within 100 km of urban centers, only 6% of all households were planning to relocate to the urban center, compared to 19% and 29% beyond 100 km and 300 km travel distance of their urban center, respectively.

Interviewees reported that depopulation along their sub-tributaries had been severe, and was dramatically summarized by one respondent on the Rio Ituxi, *"this river was once highly populated. Today it has ten times fewer people than before"* (interview no. C180). Respondents perceived advantages to living in remote areas, though these advantages were not seen as sufficient compensation for the higher social and economic costs of living far from urban centers. Equally, interviewees reported significant advantages to living downstream though the limited supply of unclaimed land was seen as a key problem in relocating to rural areas nearer their urban center. As illustrated by one interviewee living 8 km from an urban center, *"the land here is already full"* (C069). Another river-dweller 12 km from the city of Tefé observed, "*Land is scarce here*" (C113). This may explain the predominant intention of rural–urban migration among households planning on re-locating elsewhere, rather than out-migration to rural areas nearer urban centers.

Natural resources

Exploiting natural resource was not an important motive for current migration, as most households planned to migrate to urban areas. However, interviewees across all eight rivers consistently perceived upstream locations to provide highly abundant natural resources, particularly forest game animals and fish. Abundant land, turtles, timber and Brazil-nut tree groves were also mentioned as upstream advantages. Accessing unclaimed land in *terra firme* upland bluffs was an important determinant of previous migrations (Fig. 12). The accessibility of available land upriver was seen as a particular advantage, *"there is lots of virgin* [unfarmed] *land right on the river edge. Here it is already difficult to establish a plot nearby* [to the village]" (H105). Both of the two families planning on migrating to rural areas along another river cited the desire to access unflooded land as the motive. High availability of unflooded land (because of lower population densities and because seasonally flooded *várzea* forest is more prevalent downstream) was perceived as a major advantage to living upstream. One river-dweller who had previously re-located from farther downstream commented that, "*it flooded there in the wet season—the livestock died*" (H058). Respondents also reported that farming on seasonally flooded land was difficult because high waters would kill crops, especially perennials such as banana.

Many interviewees indicated that exploiting non-timber resources had been important in their re-location to their current settlement. For more than 400 km from an urban center, the primary motivation for previously moving to their current location was access to non-timber resources (particularly the latex of *Hevea* and *Couma* trees) (ESM Fig. 1). However, migrations stimulated by non-timber resource extraction declined after 1980 (ESM Fig. 2). Distant rural areas now appear less attractive for those seeking a new start than during the 1980s and before (ESM Fig. 1). Natural resources are important in retaining many of the 88% of rural households not planning on migrating to urban centers. As one man living 265 km from his local urban center put it, *"here you eat for free"* (H025). Interviewees repeatedly commented that lower abundance of fish and game would be a major cost of living nearer their urban center, as exemplified by one interviewee, *"they're hungry downstream"* (H125).

Transport and trade

Accessing trade was difficult and costly for families in remote areas, and four families cited problems of trade as their motivation for leaving. For downstream rural migration ($n = 4$), two families cited trade as the principal motive, one cited land, and one improved dry season navigability. Enhanced access to urban amenities and trade accounted for 14% (18) of the previous relocation events (Fig. 12) and was especially important for households newly settled within 300 km of urban centers from more remote areas (ESM Fig. 1). Many families had previously re-located from more remote areas of their watershed in order to either access more regular or less costly river trade. Improving accessibility to an urban center was also an important impetus for previous down-river re-locations, as shorter distances allowed direct market trading through a wider spectrum of transport options, faster journey times, and reduced travel costs. Trade access was particularly important for resettlement events in the 1990s (ESM Fig. 2), though this motive was restricted to migrations to areas beyond 500 km from the nearest urban center, in which people had relocated from very remote areas even farther upriver, particularly on the Rio Pauini. Interviewees attributed this headwater exodus to the collapse of rubber prices and bankruptcy of landlords (*patrões*). Under this historical debt peonage system, rubber tappers traded exclusively with a single *patrão*, to whom they were perpetually indebted.

Reduced travel time and transport costs were consistently seen as key advantages to living farther downriver. Interviewees were also consistent in their perception that purchasing essential food and non-food goods was easier for downstream river-dwellers because river traders sold more cheaply, and buying directly in the urban center was also easier. Trade and transport costs emerged from interviewees as the major factors discouraging migration farther upriver. Interviewees were acutely aware of the higher prices charged by river traders for basic goods upstream, and the lower prices paid for produce. As summed up by this interviewee, *"The expense is greater, and the produce* [agricultural and extractive output] *doesn't compensate the expense"* (H064). One interviewee said he would be able to sell perishable cupuaçu fruit pulp (*Theobroma grandiflorum*) if he lived nearer the urban center. Respondents also commented that river traders were unable to reach remote areas in the dry season, and that rapids and low water levels also made it difficult to reach the urban center during this period of the year. One interviewee observed that there was a lack of medical treatment in remote areas, and involved a longer journey to the urban center in case of a medical emergency.

Public services

On the basis of our interviews, access to schools was the primary motivation in current household decisions to migrate to an urban center (Fig. 13), suggesting a change in priorities in the last two decades. Gaining access to education was the principal motive of rural–urban migration for six (27%) of the families planning on leaving. Educational facilities were perceived to play a critical role in settlement viability. *"This community only exists because of the school"*, stated one respondent (C006). Conversely, school closures often led to the exodus of households, as summarized in one settlement, *"The community got smaller when the school closed, lots of people went to the city"* (C134). Even when basic education was available, the desire to complete schooling was thought to encourage rural–urban migration. One man stated that, *"lots of people left to the city because children here only got education to 4th grade."* (C118). In many cases, children left a household to stay with relatives in the urban center and complete their education. One respondent observed that these children rarely return. Although healthcare was not cited as a principal reason for a past or future migration event, many interviewees commented that living downstream was advantageous because of improved healthcare. Malaria was prevalent on all eight rivers, and although malaria was still prevalent in downstream communities, healthcare facilities were generally better and emergency travel to urban centers easier. When asked why the family had previously moved downstream to their current location, an interviewee commented that it was because of the *"difficulty of living far* [from the urban center]. *Many people died of malaria, with no medical assistance"* (H131). River-dwellers also felt that settlements near urban centers received greater attention from local and state politicians, including benefits such as donations of aluminum roofs and outboard motors.

Social issues

Rural–urban migration was more likely for settlements receiving fewer visits from the urban center by a priest or government agency (27% migrating with 0–2 visits per year, compared to an average of 11% for settlements receiving ≥ 3 visits per year). Upstream settlements received fewer of these visits; a mean of 16 per year $<$ 100 km from urban centers but only 3 visits per year beyond 300 km. Four households were leaving in order to retire in an urban center. Other motivations included joining family, health problems, and loneliness. The single family planning upstream migration cited the desire for independence and freedom from a landlord (*patrão*) as their motive. Coming to join a relative or a new marital partner, and personal problems (typically the breakdown of previous marriage, which we include as social relations) accounted for 30% of the reasons triggering relocations to current households for those who had moved from elsewhere at any time (Fig 12).

Employment

Seeking employment as a farm laborer was an important motivation to resettle to the current location, particularly for those individuals or households leaving urban centers (urban–rural migration). However, of the 150 interviewees that had moved to their current location from elsewhere, only 24% came from an urban center. Urban exodus accounted for 27% of all relocation events before 1979, declined to 10% during the 1980s and 1990s, and then increased to 34% after 2000 (ESM Fig. 1). Seeking wage labor (normally on a cattle ranch) became more important post 2000. Cattle ranching also forced river-dwellers off their land in some cases. One family on the Rio Ituxi, for example, had been forced by ranchers from their land under a false promise of R$1,500 ($\sim$ US$775) in compensation. Unemployment in urban centers had also played a role in driving urban–rural migration in the past. One river-dweller that had relocated from the local urban center stated that, *"life in the city was difficult. You need a good job there"* (H018).

Summary

The drivers of migration have changed in recent decades. Many families once drawn to remote rural areas to extract non-timber resources are now leaving for urban centers, often in order to access education. Migrating to downstream areas is appealing though a scarcity of unclaimed land was perceived to be a major constraint. Although remote areas upstream are still viewed as abundant sources of land and resources, transport costs and trading difficulties are seen as major barriers, not to mention lack of public services.

Statistical model for drivers of settlement growth

Our qualitative findings were tested using an empirical model of settlement growth. Of the 74 settlements with no access to education, 10 declined in size since 1991, 24 stayed the same, and 40 became larger, but 30 of these grew by only one household. Over the same period, however, hundreds of additional settlements along the rivers we surveyed had been completely abandoned (Parry et al. 2010), most of which lacked a school. The median growth of settlements deprived of education facilities was only one house, compared to four houses for the 84 settlements with at least some access to education. Of these, 16 declined in size, eight stayed the same, and 60 grew by at least one house. Model results indicated an overall trend of settlement expansion over the 1991–2007 period, though this excluded abandoned settlements (Table 6). There was an increase of 21.1% in the size of urban centers (distance 0). There was only a weak river effect—the change in intercept (urban centre size) is predicted to be between 12.2 and 30.2% for 95% of rivers (C $\pm$ 2 SD). Settlements farther from urban centers were smaller (Fig. 2), and this effect of distance became increasingly acute (at a 90% confidence level) between 1991 and 2007. In 2007 the effect of distance on settlement size was 3% more negative per 100 km upriver than in 1991. The effect of navigability on settlement size was approximately 10% more negative in 2007 than in 1991, although this change was not significant. The addition of a school or health agent was associated with positive settlement growth

Table 6 Drivers of rural settlement growth (1991 to 2007) along seven Amazonian sub-tributaries, using proportional change in number of households [log(1991hh + 1) − log(2007hh + 1)] as our measure of change in size

Category	Driver	β	F	p
Constant		0.212	2.012	<0.025
Physical	Travel distance to urban center	−0.0003	−1.387	<0.10
	Navigability	−0.095	−1.215	<0.15
Social	Education (Δ from 1991 to 2007)	0.119	2.027	<0.025
	Health (Δ from 1991 to 2007)	0.116	1.948	<0.05
	Variance of river-specific effects (M^2)	0.0020		
	Variance of residuals (σ^2)	0.1061		

$N = 157$

over this period, which is in agreement with our qualitative findings. The model results indicate that the addition of either a school or a health agent exerted an increase of 12% on settlement size.

Random utility model of current migration intent

A quarter (24%) of households with no school access were planning rural–urban migration, compared to 11% of families with school access. Rural–urban migration was less likely for families with a health agent (16%) than without (22%). Around a fifth (21%) of households with immediate access to abundant hunted game (<250 m to signs of tapir *Tapirus terrestris*) planned rural–urban migration, compared to only 5% of households in highly depleted areas (>10 km encounter distance); 15% of households receiving no government subsidy planned to leave, compared to 12% of families that did receive a subsidy. Households receiving at least one private salary were relatively likely to be planning rural–urban migration (36%), compared to 15% of households receiving a public salary and 12% of families receiving no salary. Households with some form of land tenure were more likely to be planning migration (19%) compared to those without (13%). However, on federal or state lands (National Forest, for example), only 8% of households planned rural–urban migration. Our results demonstrate strong collinearity between these variables, settlement size, and distance from urban centers. Our multivariate random utility model showed that only a deficit in educational provision between a settlement and its nearest local urban center was a significant predictor of rural–urban migration intent (Table 7). In contrast, none of the household characteristics or the other

Table 7 Results of a random utility model used to assess the effects of settlement utility (versus urban area) and household characteristics on rural–urban migration intention along Amazonian sub-tributaries

Driver	Effect	SE	*z*	*p*
Constant	−6.00	5.49	−1.093	ns
Household characteristics				
Land tenure (T/F)	0.322	0.823	0.392	ns
Poor (T/F)	0.011	0.804	0.014	ns
Public salary (T/F)	−0.981	1.231	−0.797	ns
Private salary (T/F)	0.469	1.991	0.235	ns
Government subsidy (T/F)	−0.613	0.961	−0.638	ns
Children (T/F)	0.349	0.974	0.359	ns
Settlement utilities				
Distance to urban center (km)	0.000	0.003	0.044	ns
Health facilities (categ.)	−0.654	0.657	−0.995	ns
Educational facilities (categ.)	1.001	0.453	2.209	0.0272
Tapir depletion zone (km)	0.014	0.151	0.091	ns
Sugar price (R$)	0.670	0.839	0.799	ns

Variable types are indicated in parentheses: Binary variables by true/false (T/F), categorical variables (categ.) or continuous (km, R$)

biophysical, social, and economic utilities describing each settlement locality was found to be significant predictors of migration intent.

Discussion

Summary

We show that remote areas of currently road-less watersheds in the Amazonian pre-frontier have been largely abandoned due to severe lack of public services and the economic costs inherent in living far from urban centers (Chomitz 2004, 2007). Remote areas are valued for their abundance of land and natural resources, but in the contemporary post-rubber era these advantages are not perceived to compensate for the disadvantages of inhabiting headwater regions. This is consistent with the wider pattern of rural depopulation in tropical regions, as forest dwellers seek better economic and social opportunities in urban areas (Zelinsky 1971; Rudel et al. 2005, de Jong et al. 2006). We explore the economic and social drivers of rural exodus in the Amazon and consider why rural populations near to urban centers are growing. We then examine the implications of our findings for governmental initiatives that aim to assist rural communities in Brazil, particularly the anti-poverty subsidy *Bolsa Família* (Family Grant) and *Bolsa Floresta* (Forest Grant), a form of payment for ecosystem services (PES).

Costs of living upstream

Upstream settlements in the eight subtributaries we surveyed were generally small (often a single isolated household) and lacked basic services such as healthcare, education, electricity, and communication. Further from urban centers, there was reduced uptake of government subsidies and severe difficulties in exchanging agricultural and extractive produce with essential external goods (such as salt, sugar and petrol). Ultimately, these spatial gradients reflect the physical constraints of supplying goods and services far up Amazonian sub-tributaries. Upriver travel is costly, time-consuming and restricted during dry seasons (McGrath 1989). Using a livelihoods interpretation of our results it appears that households' wealth of natural capital (natural resources) in remote areas of Amazonia is not sufficient to counter the lack of human capital (education and health), physical capital (assets and communication), financial capital (particularly through employment or subsidy) and possibly social capital (social resources) (Ellis 2000; de Sherbinin et al. 2008).

Demand for education

We predicted the provision of public services to be the primary driver of settlement growth, or the lack thereof to be the primary motive for rural–urban migration. The extensive interviews we conducted across Amazonas state support this prediction and indicate that river-dwelling *ribeirinhos* will remain in remote areas if public education and healthcare are available. However, our results demonstrate that road-less headwater regions in the Amazon generally lack school access and are virtually uninhabited due to a second wave of out-migration driven by demand for education. Random utility model results support our prediction that availability of education services is the primary factor in deciding when and where to relocate a household. This is consistent with previous studies that identified access to education as an important motive for rural–urban migration (Henkel 1994; Boyle 2004; Alencar 2005; Pantoja 2005). The results of our settlement growth model indicate that those settlements gaining educational access between 1991 and 2007 grew faster over this 16-yr period. An absence of a school was associated with reduced settlement growth, implying out-migration. Determining causality is difficult, however. The construction of a school or deployment of a teacher could either attract families from other settlements or dissuade rural–urban migration. Alternatively, local authorities may have established schools in settlements that were already growing for other reasons, and hence education provision could follow settlement growth rather than initiate it. Nevertheless, our evidence suggests that school provision at least encouraged *further* settlement growth. Completing secondary education in Latin America provides a child with a fair chance of escaping poverty (Aldaz-Carroll and Moran 2001). It is therefore unsurprising that parents in settlements without a school wished to relocate their family to an urban area, even if employment is problematic at least in the short term given the typically severe mismatch between background qualification and urban income opportunities.

Influence of rubber decline

The local-scale push and pull factors we focused on in this study are also mediated by important contextual factors, including institutional factors (e.g. policies, trading systems and land tenure arrangements) and economic factors (e.g. national and global demand for produce) (de Sherbinin et al. 2008). For example, Amazonian settlement patterns are strongly influenced by local agrarian (Brondízio 2005) and extractive histories (Stoian and Henkemans 2000). Many of our interviewees had relocated to their current settlement from more remote areas following the decline of rubber prices and the associated system of debt-peonage. That these headwaters were thoroughly populated (from approximately 1850 to the 1970s) due to the once high value of the wild-harvested goods traded on international markets (Dean 1987), underscores the importance of global markets in driving migration and rural settlement (Oglethorpe et al. 2007; Jensen 2009). Our findings confirm reports that out-migration to rainforest cities in Amazonian countries in the 1980s was prompted by the collapse in rubber prices (World Bank 2003), combined with a desire for access to education and other urban amenities (Stoian 2000). Harvesting of Brazil nuts remains an important part of the rural extractive economy in many regions of the Amazon though seasonal extraction by urban-based collectors is common in remote areas (Stoian 2000; Parry et al. 2010).

Social drivers of migration

In addition to the lack of public services, decisions to leave remote rural areas could be affected by the age cohort of households, social networks, or household wealth. We observed that average household size, age, and sex structure altered with remoteness from urban centers. Households beyond 300 km of urban centers were characterized by few children, a relatively large number of working men and few adult women, particularly older women. It is not clear whether these changes are due to migration patterns (which could be influenced by female bias to rural–urban migration or a male bias to forest extractivism (Pantoja 2005)) or other demographic phenomena such as relationships between remoteness from urban centers and fertility, morbidity and mortality (de Sherbinin et al. 2008). The age cohort in rural households determines colonization and land-use patterns in road-based areas of the Brazilian Amazon (Perz et al. 2006). Neoclassical migration models suggest that rural–urban migration is also a response to expected income differentials between rural and urban areas (Harris and Todaro 1970). However, in contrast with other studies that found that migrant selectivity is predictable on the basis of wealth and age (de Jong et al. 1996; Carr 2008, 2009), household characteristics and wealth were not significant predictors of migration intent. Households in more remote rural areas were not much poorer than rural people near urban centers, as measured by ownership of valuable goods. Browder and Godfrey (1997) found that intra-regional migration in the Amazon was not associated with significant changes in the socio-economic position of migrants, suggesting that other factors (e.g. access to education, healthcare, and subsidies) are important, rather than solely seeking monetary gain in cities. However, our failure to identify demographic and wealth as drivers of rural–urban migration could also be due to our sample sizes and because we only collected data at the scale of household, rather than individuals. Understanding migrant selectivity requires individual, rather than solely household analysis. For example, some people do not migrate due to emotional attachments to home, family, friends, and community (Lee 1966).

We did not find conclusive evidence of either household structure or wealth as drivers of migration. As recommended by Massey (1990), we adopted an approach that integrated economic and social factors within a community framework in which structural factors are inherent in the context within which migration decisions are made (Wolpert 1965). However, rural–urban migration in the Amazon is inevitably complex to untangle, given that push–pull factors affecting migration decisions operate at different levels of social organization (e.g. state/regional; community; household and individual) (Kleiner et al. 1986). Social networks (embeddedness of individuals or communities with social networks of relations) are argued to have an important and overlooked role in understanding migration (Curran 2002). In addition, access to information is known to influence migration (Massey et al. 1993) and inhabitants of the remote rural settlements we visited typically lacked access to important means of communication such as local FM radio broadcasts, public telephones or mobile phone networks. Migrant social networks effectively diminish the selectivity of migration over time (Curran 2002), which may be important given that the majority of our interviewees already had relatives living in their local urban center.

Population growth near to urban centers

In the vicinity of urban centers in Amazonas, rural populations are growing and households are less likely to migrate to urban centers (Parry et al. 2010). This probably reflects the higher provision of public services in settlements near urban centers, which is associated with larger settlements and improved urban access. Trading was also less costly near to urban centers, and many households near urban centers were able to bypass the middlemen, thereby avoiding typically unfavorable barter exchange with river traders. A further explanation for rural population growth near urban centers may be that increased food demand from rapidly growing urban centers leads to high demand for local agricultural produce (Lynch 2005). Toasted manioc (*farinha* and derivatives), a staple carbohydrate in the Amazon, is consumed in vast quantities by rural and urban populations alike though is costly to transport, and farmers close to urban centers can reduce their *farinha* transport costs, as well as sell perishable fruits. Shorter journey times to urban centers also allows these producers to return to markets more frequently, which serves the dual purpose of selling smaller quantities of produce more quickly, and achieving better integration and contacts with buyers. In essence, rural populations near urban centers are able to exploit the advantages of both urban services and rural resources (Stoian 2005; Padoch et al. 2008).

Rural exodus and public policy

The social consequences of rural–urban migration are debatable. Ellis (2005) argues that access to healthcare and amenities ensures that migration to urban areas leads to enhanced human welfare. Conversely, there is also concern over rapid unplanned urbanization that leads to unemployment, low levels of welfare and slum development in peripheral areas of urban centers for unqualified immigrants from the countryside (Wratten 1995; Bezemer and Headey 2008). Deforestation (and in some cases agricultural intensification) in the Brazilian Amazon has driven rural–urban migration from road-based colonization areas and the expansion of urban areas with resulting socio-economic inequality, poverty, violence, and unemployment (O'Dwyer 2005; Castro 2009). Ultimately, choosing whether to stabilize remote rural populations and reduce migration, encouraging ongoing rural–urban migration, or do nothing will depend on the vision of Brazilian society. Whether further urbanization is encouraged or not, large-scale change is coming to the Amazon. In continuation of decades of schemes promoting the exploitation of Amazonian resources (Foresta 1992), the Brazilian government is pushing ahead with the *Avança Brasil* (Advance Brazil) program, which includes doubling the coverage of paved highways in Amazonia (Fearnside 2002). Protected areas are an effective method of reducing deforestation (Nepstad et al. 2006), though the political will for designating strictly protected reserves in developing counties is limited. Inhabited sustainable use reserves are politically more attractive although the potential to demarcate inhabited reserves in strategically important locations ahead of the Arc of Deforestation will only be possible while sub-tributaries remain populated.

Stabilizing rural populations

What could stabilize populations in remote areas? Our results show that school provision could be an important policy tool with which to curb rural–urban migration. However, this recommendation is made with two important caveats. First, it may not be possible to effectively supply competent teachers to remote areas in which human settlements are small and sparsely scattered, and transport is costly, further impeded during dry seasons. Accordingly, the 'remote forest and poverty syndrome' is problematic for development and standard approaches are unfeasible or extremely costly (Chomitz et al. 1998; Chomitz 2007). Second, increasing the provision and quality of rural education may, in the short term, keep some families from seeking access to schools in urban centers, but this may be a temporary respite because education increases the chances of urban employment (Rhoda 1983) or further education, thereby spurring future rural out-migration for those seeking secondary and tertiary education. An important initiative to support rural populations in the Upper Solimões region of Amazonas has been the formation of rural education poles in which 8th grade education and beyond is supplied in a few rural locations in a municipality (Alencar 2005). This initiative is credited with the provision of rural jobs such as boat drivers and school assistants, and is believed to have helped prevent further rural–urban migration (Alencar 2005). The provision of a community health agent was associated with increased settlement growth and increased healthcare provision might reduce the incentive for rural–urban migration. We observed the delivery of federal disease eradication programs (typically insecticide against disease vectors) in even the most remote settlements. However, the provision of artesian wells, which are crucial to ensure clean potable water in the dry season, and sanitation infrastructure was generally lacking.

Delivering subsidies

Our results raise important concerns regarding the efficacy of governmental initiatives to protect Amazonian forests and improve human welfare. Many rural families in Amazonia are deserving of federal subsidy aimed at reducing poverty. Importantly, in addition to demonstrating the severely restricted supply of public services to remote rural settlements, we show that river-dwellers in remote areas rarely visit urban centers, presumably because these journeys are too costly. This has important implications for both the delivery and impact of government-led cash transfer initiatives. Public salaries and subsidies are increasingly important for rural communities in the Brazilian Amazon (Steward 2007). Current efforts to pursue forest conservation and development in the Amazon also focus on regular subsidy to forest-dwelling families, in the form of a monthly payment for ecosystem services (e.g. *Bolsa Floresta* in sustainable use reserves in Amazonas), on the proviso that any forest clearance will be limited (Viana and Campos 2007; Hall 2008b). Our results suggest that these subsidies could have undesired consequences in large reserves if monthly payment has to be collected in person from an urban center. While the value of the subsidy is fixed, its collection costs (in terms of time, fuel, and foregone opportunities) are closely related to travel distance so that over time households in more remote areas will likely be tempted to move within the reserve to an area closer to their urban center.

We also suggest that the *Bolsa Família* poverty alleviation scheme could encourage out-migration from remote rural areas, as only one in ten rural households beyond 100 km of urban areas were receiving the subsidy. This program provides a monthly payment to 11.1 million poor families in Brazil and has been credited with reducing extreme poverty and hunger (Hall 2008a). However, payment is equal for urban and rural households (median payment to the receiving families we surveyed was R$95/US$50 per month) so the net gain after deducting travel costs is negligible for families living in remote settlements. The widespread desire to claim this subsidy while reducing the collection costs could therefore encourage migration to urban areas, especially given that unclaimed land in peri-urban areas is generally scarce. However, although many families we interviewed were still waiting to receive *Bolsa Família* payments, this was never cited as the principal reason for rural–urban migration. Across Brazil, 60% of all eligible families currently fail to receive *Bolsa Família* (Soares et al. 2007). Our results suggest that many of these disadvantaged families occupy remote rural areas.

Current strategies to support traditional populations in the Amazon are focused on providing land tenure, mainly through demarcation of inhabited watersheds as sustainable use reserves. This can reduce out-migration by ensuring legitimate land claims (Bravo-Ureta et al. 1996). Sustainable use reserves in the Amazon have also served as testing grounds for PES (e.g. Viana and Campos 2007). However, demarcation of indigenous reserves in Amazonia has also increased rural–urban migration in cases where non-indigenous (yet traditional) riverine communities have been forced to leave (Alencar 2005).

Spatial constraints to non-timber economies

Within inhabited Amazonian reserves, there are ongoing efforts to augment income streams based on non-timber resource extraction. Historically, rubber-tapping and Brazil nut collection provided income in the dry and wet seasons, respectively. Declining rubber prices (World Bank 2003) created an income gap that governmental and nongovernmental organizations have attempted to fill by encouraging the extraction of oils and resins (e.g. *Copaifera* spp), for example. River-dwellers in remote areas presumably have an advantage in the collection of natural resources prone to depletion because resource abundance in headwaters is likely to be relatively high. Although 40 vegetable oils were exported from the Brazilian Amazon during the early twentieth century (Clay and Clement 1993), market demand for forest oils is currently low, and the production of harvestable forest fruits is normally low outside seasonally flooded forest (Phillips 1993). Remote rural producers are also constrained by fruit perishability and transport difficulties (Shanley et al. 2002). Consequently, the supply of ‘forest products’ can become dominated by agroforestry and mono-dominant stands near large urban centers (Wunder 1999), such as the concentration of açaí (*Euterpe oleracea*) palm fruit production near the city of Belém (Brondízio and Siqueira 1997; Wunder 1999). Furthermore, rural populations in remote areas often lack market access (Massey et al. 1993) or information on appropriate extraction techniques for non-timber forest products (L. Parry, personal observation). Many of the commercially valuable wild goods that river dwellers may consider selling—including several timber species, forest mammals, and river turtles—cannot be traded legally. For example, rural Amazonians no longer gain income from the once widespread sale of mammal skins (e.g. jaguar *Panthera onca*; Smith 1978).

Future research

This paper attempts to understand the relative importance of a broad range of determinants of rural–urban migration in currently road-less areas of the Brazilian Amazon. However, this research raises as many questions as it answers. Longitudinal studies along rural–urban gradients are essential to understanding the dynamics of settlement growth and migration between tropical forest cities and rural areas, especially given that a stated intention to move does not always materialize (Lu 1999). Greater sampling effort within settlements (for example using a proportional sampling effort relative to settlement size) would be a useful means of understanding the trade-offs in natural and other forms of capital and consequently also reveal whether there are predictable patterns to identify individuals and household types most likely to migrate (e.g. Bravo-Ureta et al. 1996).

Further research in urban centers is necessary in order to determine the well-being of newly resettled rural immigrants and how incomes in urban centers compare to their previous direct and indirect revenues (de Jong et al. 1996). Relative utility depends on greater well-being in cities, as the expected stream of income is critical to most migration decisions (Todaro 1969; Stark 1991). Very few of the rural people we surveyed were born outside of the state of Amazonas. In Amazonian states that recently experienced high rates of colonization from immigrants arriving from other regions (e.g. Rondonia and Mato Grosso (Perz et al. 2005)), it would be informative to explicitly examine the geographic origins of interviewees. In these states rural settlement is generally based around road-networks, rather than rivers. The resulting differences in livelihoods, social structure, and land-use patterns are therefore likely to determine different patterns of migration and warrant further comparison. Further insight for river-based systems could be gained from investigating linkages between life-cycles and migration patterns, which are key determinants of farm-scale land-use decisions, for example (Perz 2002). Finally, separately interviewing all adults in rural households would advance understanding of the rural exodus from Amazonian headwaters beyond the scale of the household to the level of the individual.

Conclusions

Rural–urban migration in tropical forest regions is driven by a suite of biophysical, social, and economic factors, which we assessed using an inter-disciplinary approach along rural–urban gradients in eight watersheds of the Brazilian Amazon. Access to education emerged as a crucial factor in determining the difference between the growth or abandonment of riverine settlements and out-migration to local urban centers. However, heterogeneity in migration decisions among the 184 riverine households we surveyed highlights the complexity of spatial decision-making. We observed stark gradients in public service provision and trading conditions with increasing fluvial distance from urban centers, combined with increasing isolation and transport difficulties. Understanding the drivers of rural exodus can be used to predict the effects of direct payments for ecosystem services and anti-poverty subsidies on the stability of rural populations in the Amazon and elsewhere. This work is also relevant to predicting future environmental change, which requires not only an understanding of land management, but also the reasons for people to be there in the first place (Carr 2009).

Acknowledgments We are grateful to the Brazilian Government for permission to conduct this research (Portaria Ministério No. 908, 04/12/2006). We are indebted to the rural Amazonians who kindly participated in this study, as well as the support and advice gained from local municipal secretariats and others during fieldwork. Funding came from Natural Environment Research Council (NERC), UK and Center for International Forestry Research (CIFOR). We thank the many people who provided input to this research, particularly E. Brondízio, S. Rosendo, N. Grist, A. Southern, B. Fisher, P. Shanley, and M. Hopkins. K. Abernethy, R. Ellis and R. Rajão provided useful comments on an earlier version of this manuscript. The manuscript benefited greatly from the comments of three anonymous reviewers and L. Hunter.

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