Rural-urban mobility influences wildmeat access and consumption in the Brazilian Amazon

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Abstract Amazonian research demonstrates substantial urban consumption of wildmeat and documents the existence of trade networks. Yet, we know that rural-urban mobility persists in this now-urbanized region, maintaining the circulation of people, things, and ideas, blurring boundaries between rural and urban lives. Here we examine the relationships between rural-urban mobility and wildmeat access in highly-forested areas of central Brazilian Amazonia. We surveyed 798 households in four towns, and 311 rural households in 63 riverine communities. Rural-urban mobility endured among urban households: 49.7% maintained rural livelihoods, and 57.3% were headed by rural in-migrants. Although many urban consumers purchased wildmeat, gifting was equally important. Urban households with greater rural-urban mobility consumed more wildmeat and were less likely to purchase it. Buying wildmeat was rare in rural areas but emergent in larger communities. Rural consumption was higher in remote areas, non-floodplain communities, and during the high-water season. Urban populations placed intensive pressure on three preferred species (*Cuniculus paca*, *Tapirus terrestris, Tayassu pecari*), whereas rural consumption was relatively diverse. Yet, rural *per capita* wildmeat consumption was four-times higher (21.1kg±6.2 versus 4.9kg±1.0 person/year). We estimate 3,732 tons annual wildmeat consumption across 43 riverine urban centres in central Amazonia, compared to 11,351 tons/year in surrounding rural areas. Due to extreme poverty in these towns and socially-mediated wildmeat acquisition, it is debatable whether urban consumers should, or could, be denied wildmeat access entirely. Nonetheless, the likely continued increase in urban demand – and related risks to sustainable, equitable resource use – necessitates monitoring and management of rural-urban flows of wildmeat.

Keywords Bushmeat, sharing, sustainability, tropical forests, wildlife conservation.

Introduction

Urbanization can increase natural resource use (Güneralp et al., 2017), contradicting previous assumptions that rural depopulation leads to net conservation benefits (e.g. Wright & Muller-Landau, 2006). For instance, in sub-Saharan Africa, population growth and urbanization increased urban demand for wildmeat, with widespread markets and informal trade negatively impacting wildlife (Van Vliet et al., 2019; Luiselli et al., 2020). In Peru, wildmeat trade in a large urban market has increased in parallel with urban population growth since 1973 (Mayor et al., 2021). Wildmeat demand contributes to defaunation around Amazonian towns (Parry & Peres, 2015; Abrahams et al., 2017), which may compromise the wellbeing of forest-dependent rural communities (Nasi et al., 2011). Yet, forest-dwellers circulate between rural and urban spaces and urban wildmeat demand creates income opportunities (van Vliet et al., 2015; Chaves et al., 2019).

Wildmeat and urbanization in Amazonia

Until recently, urban wildmeat consumption in Amazonia was considered negligible (Nasi et al., 2011), reflecting a paucity of relevant urban research. However, emerging evidence shows most households in provincial Amazonian towns eat terrestrial and aquatic wild species (excluding fish), at least occasionally (Parry et al., 2014; Morsello et al., 2015) and estimates of overall annual consumption in Amazonia number in thousands of tons annually (van Vliet et al., 2014; Chaves et al., 2020; El Bizri, et al., 2020).

Most studies attribute urban wildmeat consumption in Amazonia to commercial trade, either explicitly (van Vliet et al., 2015; El Bizri et al., 2020) or implicitly (Chaves et al., 2019). However, there is also evidence of non-market acquisition (wildmeat gifts) (Morsello et al., 2015; Carignano-Torres et al., 2021), which contributes to maintain social relations and meet food needs (WinklerPrins & Souza, 2005; Nunes et al., 2019).

Rural-urban mobility

Amazonia has undergone rapid but spatially heterogeneous urbanization (Guedes et al., 2009), with consequences for rural-urban mobility, i.e. the circulation of people (both rural and urban residents), things, and ideas between urban and rural areas (Nasuti et al., 2015; Dodd, 2020). Rural-urban mobility may affect livelihoods and natural resource use (Eloy et al., 2015). Padoch et al. (2008) observed many rural-urban migrants in Amazonia circulating between both areas, thus retaining rural consumption habits, and stimulating urban markets for forest products. However, rural-urban migrants also acquire forest and agricultural products outside of market exchanges, including wildmeat. Based on redistribution (e.g., gifting) and reciprocity, this 'economy of affection' can equal trade in supplying certain households (WinklerPrins & Souza, 2005; Minzenberg & Wallace, 2011). Indeed, social relations underlie wildmeat consumption in urban and peri-urban locations in the Brazilian Amazon (Morsello et al., 2015; Carignano-Torres et al., 2021).

Urbanization in the forested tropics brings changes to rural areas too, through increased market access, remittances from urban relatives, and households that become 'multi-sited', spreading their time between rural and urban areas (Hecht et al., 2015). Rural-urban movements have intensified through greater affordability of motorized river transport, and the desire to access market goods and services (Dodd, 2020). This rural-urban mobility may change food consumption patterns (Kramer et al., 2009) and increase rural-urban trade (Padoch et al., 2008), thereby altering forest use (Hecht et al., 2015). For instance, urban visitation reduces wildmeat consumption by rural people either by increasing domesticated meat consumption or by stimulating wildmeat trade at the expense of own consumption (Chaves et al., 2017).

Understanding rural-urban wildmeat flows and the scale of consumption in the forested tropics is paramount to enable wildlife management which balances conservation with people's wellbeing, including food security (Cawthorn & Hoffman, 2015). However, we lack evidence about wildmeat access among both Amazonian urban and rural populations, and its linkages to rural-urban mobility, albeit both aspects have been tackled separately (van Vliet et al., 2015; Chaves et al., 2017; El Bizri et al., 2020).

The purpose of this paper is to understand how consumption of terrestrial wildlife species (herein, wildmeat) varies between urban and rural areas, and whether urban consumption is shaped by rural-urban mobility. Based on field surveys in four municipalities in a highly forested region in the central Brazilian Amazon, we examine: (1) differences in patterns of wildmeat consumption between urban and rural areas, based on consumption frequency, species consumed and preferred, besides means of acquiring wildmeat; (2) the association between rural-urban mobility and wildmeat access; (3) rural-urban differences in total wildmeat demand (accounting for *per capita* consumption and number of consumers) in a study region of 43 riverine, geographically isolated municipalities, based on extrapolation from our empirical data.

Study area

Our field research was carried out in the municipalities of Caapiranga, Maués, Jutaí, and Ipixuna in Amazonas State, Brazil (Fig. 1). Each municipality constitutes a town unconnected to the road network, surrounded by an extensive mostly-intact forested area (>90% of municipal forest cover remaining) in which riverine communities are located. There are also some non-riverine rural settlements around each town (connected by rough roads), but these were not investigated. The study towns are distant from one another,

relatively isolated, and vary in: watershed location; urban population (from estimated 13,300 to 65,000 people) (IBGE, 2020); fluvial distance to the state capital, Manaus (162-2,566 km) (Parry et al., 2018) (Table 1), which underpins variable access to larger markets and services (private and public). These municipalities have low development outcomes (HDI = 0.49 to 0.59) and maintain significant rural populations (from 41.4% to 57.3% of the municipal population in 2010).

The four study towns grew substantially (mean = 47.2%, range: 22% to 65% population growth) between 2000 and the last census in 2010, despite their total municipal populations growing less, or even declining (mean = 21.6%, range: -19.8 to 50.8%) (IBGE, 2000, 2010). This rapid growth of small cities is typical in Latin America (Baeumler et al., 2021) and is raising the proportion of Amazonia's population living in urban areas (i.e. urbanization). Growth in our study towns reflects ongoing rural-urban migration (Parry et al., 2010), and 'natural' population growth due to the relatively young age structures.

The municipalities' main economic activities are harvesting non-timber forest products, small-scale fishing, and agriculture. Also important are public sector employment in urban areas and government cash transfers.

Rural populations are mainly distributed in riverine communities of various sizes, including along remote sub-tributaries. These river-dwellers are peasants of mixed ancestry (indigenous, African, and European backgrounds), who live inside and outside Sustainable Use Reserves (human-inhabited protected areas). Although study areas house also Amerindian societies, they were not investigated.

To estimate total wildmeat demand in urban and rural areas in the region, we included data on population size of all 43 river-dependent municipalities in Amazonas

State (Chacón-Montalván et al., 2021), constituting 77.1% of the state's area and 65.8% of the population outside of Manaus (our calculations).

Methods

Sampling design

In each municipality, we aimed to randomly sample 200 households from the urban centre (total 800), and 80 households from 16 surrounding rural communities (5 households per community, totaling 320 households from 64 communities). The sampling in each municipality was split across two hydrological seasons, with no repeated sampling (i.e., per-season aim in each municipality was 100 urban households and 40 rural households from 8 rural communities), as this affects availability and access to wildmeat (van Vliet, et al., 2015; Endo et al., 2016; Chaves et al., 2017). Low-water season sampling spanned 08-12/2015, whereas high-water season spanned 03-07/2016. In each municipality, we concentrated a season's sampling into 4-to-5 weeks during the low- and high-water peaks, planned around spatial differences in hydrological seasonality (Extended Data Fig. 4 in Chacón-Montalván et al., 2021).

The final sample included 198 to 201 urban households per municipality (total 798) and 311 rural households from 63 communities. The rural under-sample reflects 9 fewer rural households (and 1 fewer community) in Jutaí due to logistical issues. Sampled rural communities (or 'settlement' in places with fewer households) (range: 3 to 42 households) were chosen to capture: gradient in travel distance from the nearest town (range: 7 to 249 km), locations in/out of Sustainable Use Reserves, and habitat diversity (floodplain/non-floodplain; affecting wildlife assemblages and abundance, besides hunting activity) (Endo et al., 2016; Pereira et al., 2019) (Fig. 1). Urban households were selected by proximity to randomized geographic coordinates, whereas rural households

from a list in sampled communities (Supplementary Material 1). Household members included all people considered residents during the interview, even if only part-time (when someone spent time also in rural areas or working elsewhere). We did not sample multi-sited households in both their urban and rural locations.

Data collection

We adopted a survey to collect data on household rural-urban mobility, wildmeat consumption, and socioeconomic and demographic characteristics, through face-to-face interviews (Supplementary Appendices 1-4). Using the same method, we collected community-level information with rural community leaders (Table 2, Supplementary Table 1). The interview protocol was elaborated and conducted in Brazilian Portuguese, the native language of all interviewees and interviewers. We pre-tested the interview protocol (May/June 2015) in urban and rural areas of a similar municipality in Amazonas (Autazes). P.C.T and L.P. coordinated the survey, conducted together with nine other researchers and assistants.

Measures of mobility

We measured households' rural-urban mobility using four binary indicators for urban households and two for rural households (Table 2). Mobility here constitutes rural-urban movements (i.e. circulation) (Dodd, 2020), household economic strategies (Nasuti et al., 2015), and geographic origin and identity of household heads (Castree et al., 2013).

Measures of wildlife consumption, preference and potential reporting bias

To measure wildmeat consumption, we asked about the number of meals in which it was consumed in the previous 30 days. We also asked when wildmeat was last consumed in the household and recorded: the date of that event (to establish whether it

was consumed in the previous 12 months); whether it was purchased, gifted, or hunted by a household member (Table 2); which species was/were eaten, the quantity (in kilograms, the whole animal or pieces), and divided across how many meals. With this information, we estimated wildmeat consumed per meal in the household and per person (for each household) (Supplementary Material 1).

To evaluate meat preferences, we asked the interviewee (male or female household head) to rank the three most preferred types of meat. If the interviewee cited wildmeat, we asked which species he/she preferred.

While in Brazil commercial hunting and wildmeat trade are illegal, subsistence hunting has an uncertain legal status, being allowed for traditional communities or subsistence hunters in a 'state of necessity', although still subject to arbitrary law interpretation (Antunes et al., 2019). Despite this, wildmeat hunting and consumption are ubiquitous in Amazonia and trade occurs in some food markets ('under the counter'), restaurants (clandestinely), and elsewhere through social networks (van Vliet, et al., 2015; Chaves et al., 2019; El Bizri, et al., 2020; El Bizri, 2020). Wildmeat consumption in small and medium towns in Amazonas state is unlikely to be underreported by direct questioning. Once households declared consumption, they unlikely underreported the quantity consumed (Chaves et al., In press). The study researchers were often offered wildmeat in both rural and urban areas (personal observation). Similarly, numerous Amazonian studies using direct questioning have documented high rates of wildmeat consumption (Chaves et al., 2019; El Bizri, et al., 2020; El Bizri, et al., 2020) and people's opinions about wildmeat purchases are not negative (Chaves et al., 2019).

Data analysis

Objective 1: To compare differences in consumption rates and means of acquiring wildmeat between rural and urban areas, we calculated descriptive statistics. We estimated mean *per capita* consumption in rural and urban areas in each municipality per month and year including all sampled households (even those where wildmeat was not consumed, meaning consumption equals zero). We calculated monthly *per capita* consumption for each household based on the quantity consumed per meal per person, multiplied by the number of meals consumed in that given household in the previous 30 days.

We assessed species consumption profiles in each urban and rural area in the previous 12 months, using Principal Component Analysis (PCA) in the *vegan* package. We considered the number of times each species was consumed relative to the total number of declared events in each municipality and area (urban or rural).

Objective 2: To investigate how wildmeat access is associated with rural-urban mobility, we modelled (i) consumption frequency – i.e. the number of wildmeat meals consumed in the previous 30 days (using a negative binomial distribution to account for excess zeros); (ii) types of acquisition – i.e. the probability of acquiring wildmeat through different means (purchase=1; hunted/gift=0), based on when it was last acquired (using binomial distribution model). For both analyses, we excluded households that declared no consumption in the previous 12 months, therefore including 73.4% (n=586) of sampled urban households, and 98.7% (n=307) of sampled rural households. We ran separate models for urban and rural samples and controlled for household- and community-level characteristics (Table 2, Supplementary Material 1). We used generalized linear models (GLM) for urban households and generalized linear mixed-effects models (GLMM) for rural households, using community identity as random variable 'nesting' households within the same community to account for spatial dependency. We treated municipality

as a fixed effect factor for both rural and urban models. We tested for correlation between independent variables and found no strong correlations that would justify their exclusion, although community size and urban visits bore some association with remoteness (Supplementary Table 2).

Objective 3: We estimated the total amount of wildmeat consumed in urban and rural areas of our study region based on our estimate of mean monthly and yearly consumption of wildmeat (kg) per household and per person (Supplementary Material 1). We then extrapolated it to include the other 39 non-road-connected municipalities in Amazonas (Fig. 1) using 2020 municipal population estimates (IBGE, 2020) and estimating the size of urban and rural sub-populations. Two demographic scenarios were assumed: (i) no change in the urbanization rate (proportion of municipal population residing in urban area) after 2010; (ii) that post-2010, a municipality's decadal change in urbanization rate was equal to that observed between the censuses of 2000 and 2010 (IBGE, 2000, 2010) (e.g. an increase from 60 to 65% in 2000-10 would mean a further increase to 70% from 2010-20). We indicate the lower and higher bounds of our region-wide estimates based on the lowest and highest *per capita* values calculated from the four fieldwork municipalities.

All analyses were implemented in *R 4.0.2* (R Development Core Team, 2020).

Results

Rural-urban mobility

We found considerable rural-urban mobility among town residents, even in the largest town, Maués. In most households in towns (57.3%), at least one of the household heads was a rural in-migrant, and in many households (42.7% overall, or 44.2% of migrant

households) someone visited rural areas at least monthly or practiced rural livelihoods (49.7% overall, increasing to 56.2% of migrant households) (rural-centric activities including agriculture, forest resource' extraction or fishing). Dual residence (being 'multi-sited') was maintained by 24.5% of rural in-migrants. Likewise, for rural residents, rural-urban circulation was common: 67.5% travelled to the nearest town (mean=84 km) at least monthly, whereas visiting weekly was rare (8.4%). Dual residence was maintained by 14.8% of rural residents (Fig. 2).

Objective 1: Rural and urban wildmeat consumption

Wildmeat was eaten less often in towns than in rural communities. Some consumption of wildmeat was ubiquitous in rural areas, whereas in towns 26.6% of households had not eaten any wildmeat in the previous 12 months (Table 3). Within our sample, *per capita* annual consumption across municipalities was 14.7-28.8 kg in rural (mean=21.1±6.2) and 1.3-6.4 kg in urban areas (mean=4.9±1). Wildmeat consumption was lower in towns because it was eaten less often (urban mean=1.3±0.2; rural mean=4.7±0.8 meals per month) and these meals were smaller (urban mean=1.1±0.2 kg wildmeat; rural mean =1.8±0.5 kg) (Supplementary Table 3).

Wildmeat consumption in urban areas was characterized and concentrated on three species: lowland paca (*Cuniculus paca*; eaten in 30.9% of events), tapir (*Tapirus terrestris*; 21.7%), and white-lipped peccary (*Tayassu pecari*; 20.5%), also the most often declared as preferred (Fig. 3, Fig. 4). Nonetheless, consumption in each town varied from 10 to 12 species and 26.7% of events were from either brocket deer (*Mazama* spp.), curassow (no id.), agouti (*Dasyprocta* sp.), collared peccary (*Pecary tajacu*) or tortoise (*Chelonoidis* sp.). In rural areas, consumption varied from 12 to 18 terrestrial species with a more even distribution of the percentage of consumption events across species. Lowland

paca, tapir and white-lipped peccary accounted for 39.2% of events (16.0%, 6.2% and 17.0%, respectively), instead of nearly 75% found in towns. Howler monkeys (*Alouatta* spp.) were consumed almost as frequently as lowland paca in rural areas (13.4% and 16.0% of events, respectively), particularly due to widespread rural consumption in Jutaí, whereas howlers were rarely consumed in towns (2% of events) and brocket deer, curassow (no id.), agouti, collared peccary and tortoise accounted together for 39.9% of events (Supplementary Fig. 1).

Purchase and gifting had similar importance for wildmeat acquisition in towns (44% and 42.6% of households, respectively). In rural areas, only 7.5% of households purchased wildmeat. Hunting by a household member still occurs among urban populations (11-15% of households). Nonetheless, means of acquiring wildmeat varied by municipality (Fig. 5) and species. In remoter municipalities of Ipixuna and Jutaí, purchase centred on tapir and white-lipped peccary, whereas paca was the most purchased species in Maués (Supplementary Fig. 2, Supplementary Fig. 3).

Objective 2: Rural-urban mobility and wildmeat access

In towns, consumption of wildmeat meals was 57% higher among rural in-migrants (incidence rate ratio [IRR]=1.57; 95% CI=1.15-2.12), and 42% higher for those with rural livelihoods (IRR=1.42; 95% CI=1.06-1.89). Consumption frequency was unrelated to rural visitation by town-dwellers when accounting for other variables (Supplementary Table 5).

In rural areas, consumption of wildmeat meals was 90% higher in the high-water season (IRR=1.90, 95% CI=1.23-2.89). Consumption was twice as high among non-floodplain communities, compared to floodplain (*várzea*) communities (increasing 107%; IRR=2.07, 95% CI=1.08-4.01). Living 100 km farther from town increased wildmeat

consumption frequency by one meal a month (95% CI=0.5-10) (Supplementary Table 6). Accounting for rural remoteness, urban visitation by rural people was unrelated to wildmeat consumption frequency. Although we cannot completely exclude an effect of urban visits, it is likely that variation in rural consumption of wildlife reflects aspects of rural remoteness (e.g. lower human population density and more forest) more strongly than those of urban market access, since remoteness and urban visits were not strongly correlated.

In towns, purchasing wildmeat correlated with higher income. For a R$100 increase in monthly *per capita* income (~USD$19 at the time), the odds of purchasing wildmeat increased by 13% (odds-ratio=1.13; 95% CI=1.04-1.24). In contrast, having a rural livelihood (compared to not) decreased the odds of purchasing wildmeat by 33% (odds-ratio=0.67; 95% CI=0.46-0.96). Purchase differed between towns; it was less likely in Caapiranga, with 53% lower odds compared to Ipixuna (odds-ratio=0.47; 95% CI=0.29-0.76).

In rural areas, living in a larger community increased the odds of a household purchasing wildmeat. An increase in 10 households increased the odds by 97% (odds-ratio=1.97; 95% CI=1.01-4.08) (Supplementary Table 7).

Objective 3: Estimated wildmeat consumption in non-road-connected municipalities

Considering the study region and static municipal urbanization rates (scenario i), we estimate overall wildmeat consumption (including purchase, gifts or hunted) is over three-times higher in rural areas (total 12,057 tons/year) compared to urban areas (total 3,614 tons/year). These estimates account for our empirical estimates of *per capita* rural and urban consumption, official estimates of municipal population growth 2010-2020, and

the municipality-specific urbanization rates (% urban) in 2010. Nonetheless, these estimates have broad confidence intervals (rural range: 9,103-15,635 tons; urban range: 2,893-4,336 tons), given the observed municipality-scale variation in *per capita* consumption. Assuming on-going urbanization (continuation of observed municipal urbanization trends from 2000-2010 (i.e. scenario ii), the study region's overall rural population would be 14% lower and the urban 11% higher compared to scenario (i). Yet rural consumption would still be more than twice that of urban consumption (rural total: 10,362 tons, range: 7,823-13,437 tons, versus urban total: 4,009 tons, range: 3,209-4,810 tons).

Discussion

Here we discuss five main results of our study. They highlight one important similarity and four important rural-urban differences in wildmeat consumption and access.

First, the importance of gifting in both areas emphasizes the crucial role of social relations in accessing wildmeat. Although wildmeat sharing practices have been investigated in indigenous and non-indigenous rural communities in Amazonia (e.g. Nunes et al. 2019), the scale of its importance is rarely accessed. Although purchase was common in urban areas, even for its highest rate (access to tapir in Ipixuna), ~30% of meals with this species were sourced through gifts. While some studies found social relations are important in accessing wildmeat in towns (Morsello et al., 2015), most studies attribute it to trade (Chaves et al., 2019; El Bizri et al., 2020).

Second, trade was in fact important in towns while rare in rural areas. Studies in other Amazonian towns have reported high rates of urban wildmeat purchases (70%-86%) (Chaves et al., 2019; El Bizri et al., 2020). Our 43% estimate may reflect under-reporting if interviewees felt purchasing wildmeat was 'riskier' than other acquisition

forms. However, we believe under-reporting was not high, as we still found a high purchase rate (~40-50%) even in the largest town, Maués (47%). Additionally, direct questioning does not seem to underestimate consumption in Amazonas towns (Chaves et al., In press) as urban residents apparently lack a negative opinion about purchasing wildmeat (Chaves et al., 2019). In rural areas, wildmeat was seldom purchased, being instead accessed through direct harvesting or social relations. Although our sample overrepresented small communities, we still observed a higher probability of wildmeat purchase in larger communities. Nascent trade in these larger communities may reflect less food-sharing due to less reciprocal cooperation (Ringen et al., 2019). Trade might therefore become more important in rural locations, given that rural communities near to towns are growing rapidly (Parry et al., 2010).

Third, rural-urban mobility is enduring in central Amazonia, influencing town-dwellers' both wildmeat consumption and acquisition, while appearing less important in shaping rural consumption. In towns, poor and migrant households tended to access wildmeat through rural connections and social practices (gift-giving), while purchasing was more likely among wealthier urban households. Wildmeat consumption frequency in towns was also mediated by rural connections and practices. It was consumed more often by rural-urban migrants and those with rural livelihoods, showing how rural-urban mobility (including identity) explains wildmeat consumption in urban Amazonia. This supports the notion that wildmeat consumption is a rural tradition, not restricted to Amazonia (Chausson et al., 2019, in the Republic of Congo). Migrants' wildmeat food practices fade after decades in towns (Chaves et al., 2020; Lemos et al., 2021) or in younger generations (Chausson et al., 2019; Luiselli et al., 2020). In rural areas, remote households consumed more wildmeat, perhaps due to better access to primary forests (therefore game availability) *sensu* Parry et al. (2010) than to little access to markets,

given that rural consumption was unrelated to urban visitation. Lower wildlife consumption in communities nearer towns may, conversely, could reflect wildlife depletion (Parry & Peres, 2015; Abrahams et al., 2017), instead of easier access to, and consumption of, domesticated meat. Nonetheless, a study in another Amazonian municipality found that rural people spending more time in town ate less wildmeat (Chaves et al., 2017).

Fourth, urban consumption concentrated on three preferred species whereas rural populations consumed a greater number of species more evenly. Tapir and white-lipped peccary are "Vulnerable" (IUCN, 2020) and both our urban and rural interviewees perceived them as becoming harder to acquire (Supplementary Table 4). Preferential urban consumption of these species has been reported elsewhere in Amazonia (Parry et al., 2014; van Vliet et al., 2015; van Vliet et al., 2015; El Bizri et al., 2020). These species were also the most often purchased here, perhaps reflecting taste preference, reinforcing evidence associating wealth with consumption of preferred species (van Vliet et al., 2011), and hunter preferences for large-bodied species (van Vliet et al., 2014).

Finally, despite the persistence socially-constructed linkages with rural locations in towns, wildmeat was eaten less often and in lower quantities compared to rural communities, consistent with evidence from Africa and Amazonia (Nasi et al., 2011; van Vliet et al., 2014; Nunes et al., 2019; El Bizri et al., 2020), resulting in higher overall consumption in rural areas, as discussed below.

Overall wildmeat consumption in non-road-connected municipalities

Overall, we show forest wildlife provides large meat quantities to rural and urban inhabitants in our largely-intact study region. Our field-estimates of urban consumption fall within those modelled by El-Bizri et al. (2020) for three out of four municipalities. Instead, consumption in Maués was our lowest record (1.3kg *per capita*/ year) and below

their study predictions, though consistent with findings that consumption rates decline as a town's population increases (Chaves et al., 2020). Overall, our rural consumption estimate of 21.1kg/person/year was well below the 54.8kg in Nunes et al. (2019). This discrepancy is likely explained by their assessment of indigenous communities, often more reliant on wildmeat, and estimates based on hunting offtake figures rather than actual household consumption (since usually not all households have hunters). In our study, one-quarter of rural households lacked a hunter. In summary, we find strong evidence that *per capita* and aggregate urban consumption of wildmeat in central Amazonia is currently much lower than rural consumption, albeit we did not attempt to extrapolate our empirical findings to larger or road-connected cities.

Despite growing conservation interest in Amazonian urban wildmeat consumption, rural consumption far exceeds it here. This carries important policy implications for biodiversity conservation and livelihoods. A logical first step to protect game populations while sustaining local livelihoods is to incentivize sustainable management in rural locations. Such management is challenging and requires strong formal and informal institutional arrangements (Coad et al., 2019), albeit there are evidences of sustainable hunting in some indigenous and traditional forest-dwellers' territories (Ohl-Schacherer et al., 2007; Shaffer et al., 2018). Implementing management plans outside protected areas is particularly challenging because of insecure land tenure. Multi-sited households, linked to rural-urban mobility, bring additional challenges to natural resources management, such as altering institutional arrangements in rural areas, as residents are away periodically (Eloy et al., 2015). Additionally, subsistence hunting has ambiguous legal status in Brazil, even for traditional and rural peoples, which adds challenges to hunting management (Antunes et al., 2019).

What might explain much lower consumption of wildmeat in urban areas? Wildmeat trade illegality may prevent large flows to towns, despite weak enforcement. Moreover, domesticated meat, especially frozen chicken, is relatively cheap and substitutes wildmeat, even among poor urban households. Beef is also locally available and affordable in one town, Ipixuna (unpublished data). Finally, consuming wildmeat is a rural-related practice, which tends to fade in towns with time and generational changes (Chaves et al., 2020; Lemos et al., 2021).

Conclusions

We show urban consumption is intimately related to sharing networks and rural-urban mobility. This suggests limitations in the conventional typology of urban wildmeat consumption as being, necessarily, tightly linked to vendors and markets (Fig. 3 in Ingram et al., 2021). Accounting for rural-urban mobility and the persistence of rural livelihoods may help achieve sustainability goals by, for example, including urban stakeholders in discussions around management of natural resources (Padoch et al., 2008; Hecht et al., 2015; Eloy et al., 2015). If the current illegality of urban consumption was actually enforced in Brazilian Amazonia, food insecurity would be greatest for rural-urban migrants, who tend to maintain rural livelihoods and social networks. Nonetheless, policy interventions to restrict urban trade in wildmeat may spare migrants from the greatest risk, given they purchase wildmeat less often. This is particularly important since consumer preferences for vulnerable species (*Tayassu pecari* and *Tapirus terrestris*), often accessed through market exchanges, likely explain why they can be depleted >100km from central Amazonian towns (Parry & Peres, 2015; Abrahams et al., 2017). Despite claims of high demand in towns (Chaves et al., 2020; El Bizri, et al., 2020) and although it may still increase due to urban growth, we show that currently, conservation

interventions are still more urgent in rural locations. Thus, monitoring rural-urban flows of vulnerable species and sustainably manage rural hunting is warranted where strong institutional arrangements allow.

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Conflicts of interest None.

Ethical standards This research was carried out following the rules and guidelines of the Brazilian National Health Council (Resolution 466/12) and the British Sociological Association. The research and survey instrument (interview protocol) were evaluated and approved by Brazil's National Health Research Ethics Committee (CONEP/CNS; protocol 45383215.5.0000.0005) and Lancaster University's Research Ethics Committee (S2014/126). Written free and informed consent was obtained from all interviewees after explaining the research aims and protocols, and before administering interviews. This included a statement ensuring that information participants provided would only be known to project researchers, and names and personal data would remain confidential.

One copy, signed by the study coordinator, remained with the participant. In rural areas, we first approached the leader of each riverine community and held a community meeting, explaining our research aims and protocols. Only after receiving the community's verbal approval for conducting the research, we proceeded to sample households.

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Figures

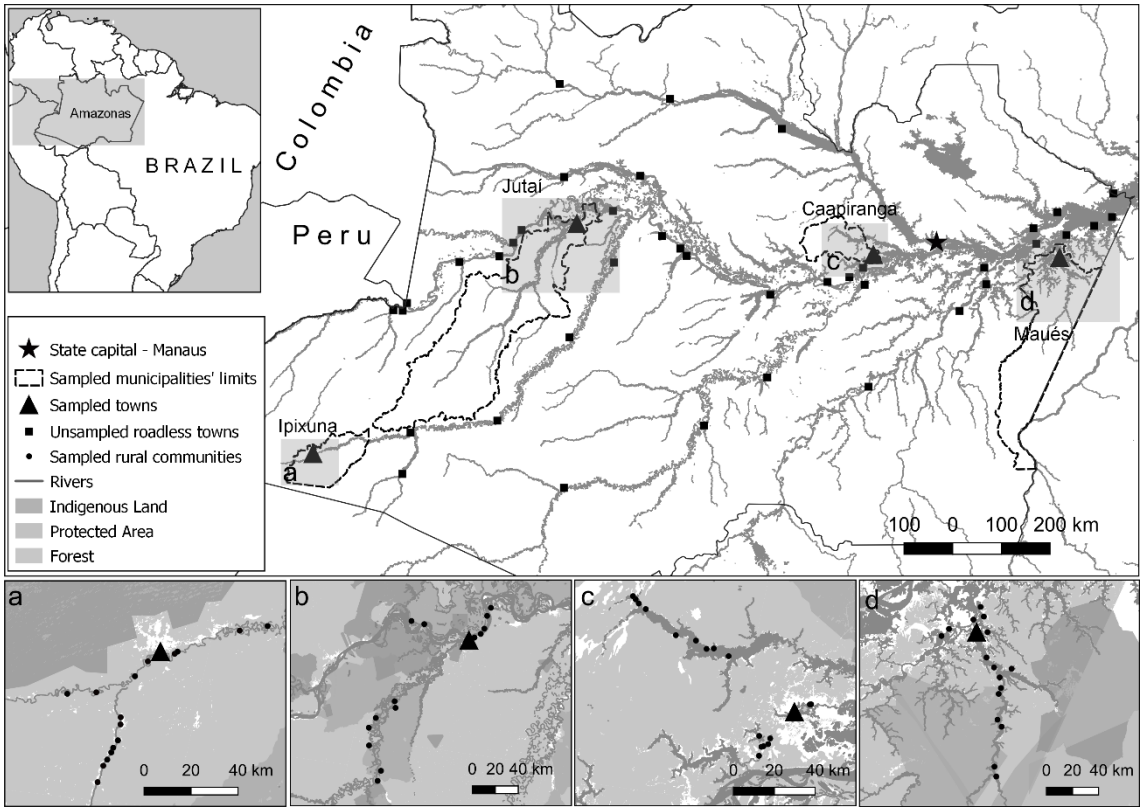


FIG. 1. Study area in Amazonas State in Brazil, including the 4 study municipalities and the other 39 non-road-connected towns (unsampled) in the state. Inset maps show the distribution of the 63 rural riverine communities surveyed (~16 in each municipality).

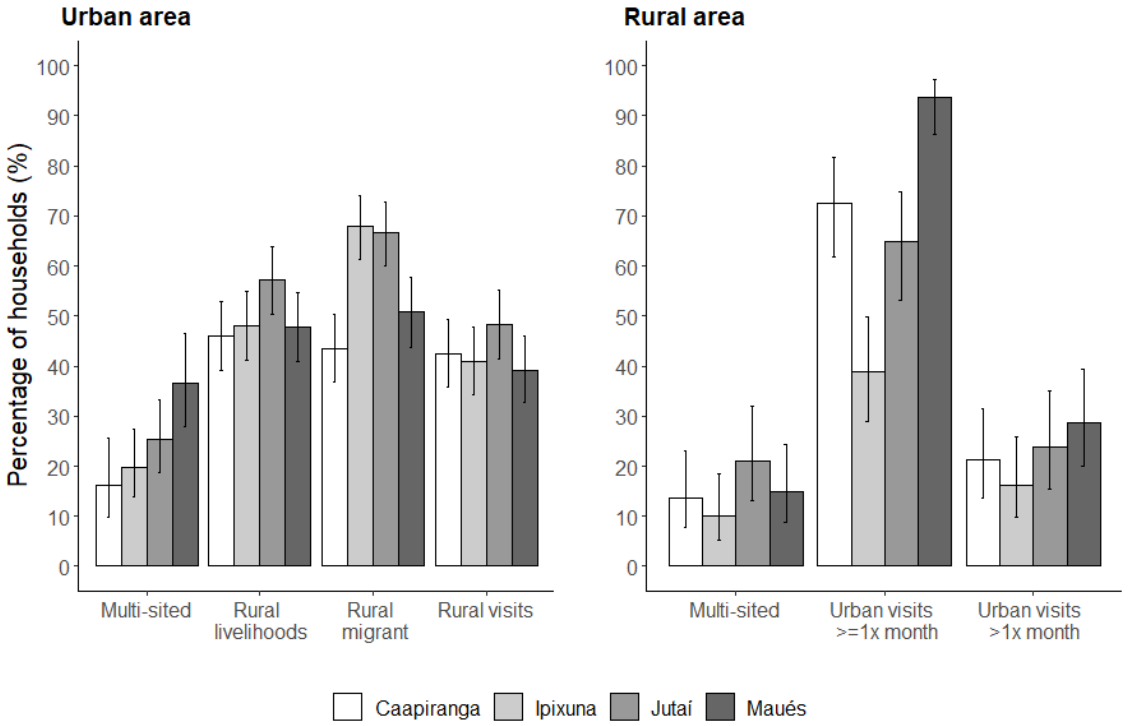


FIG 2. Summary statistics of household rural-urban mobility for households surveyed in four municipalities in Amazonas State, Brazil. Error bars represent 95%CI for the observed percentages, estimated using Wilson score interval (confidence interval for binomial proportion).

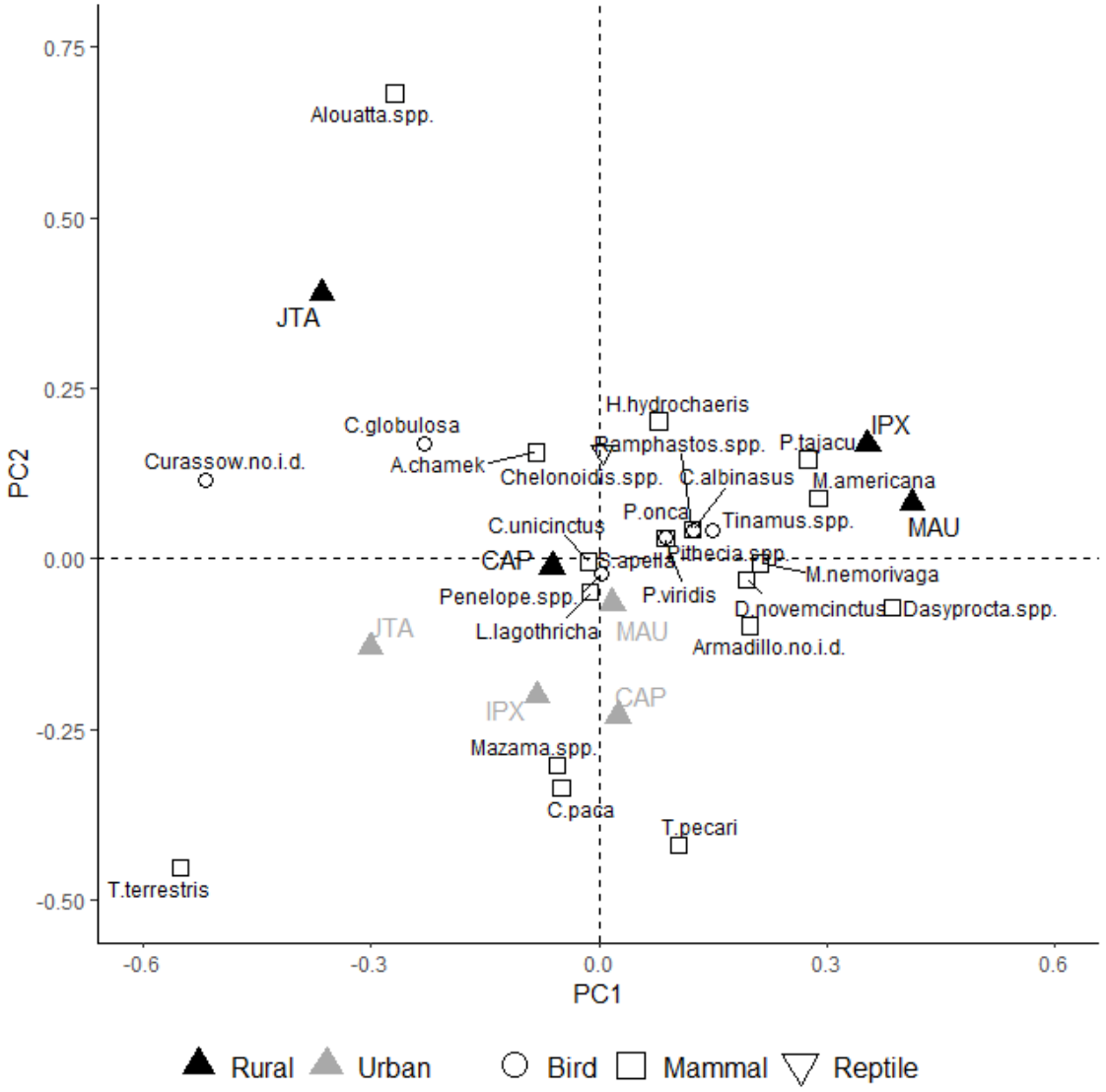


FIG. 3. Ordination of species composition based on the last species consumed in the households the previous 12 months. Species occurrence was pooled by municipality and area (urban or rural). Species are represented by shapes according to taxonomic classes. Municipalities are represented by triangles (CAAP-Caapiranga; IPX-Ipixuna; JTA-Jutaí; MAU-Maués) and areas by different colours.

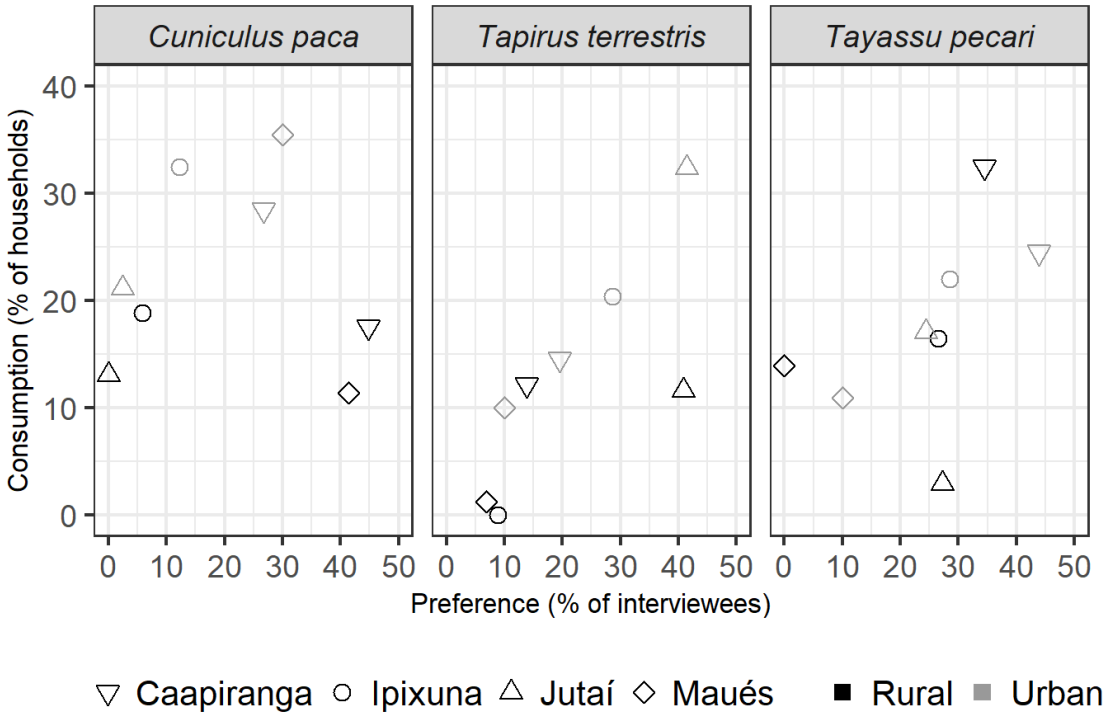
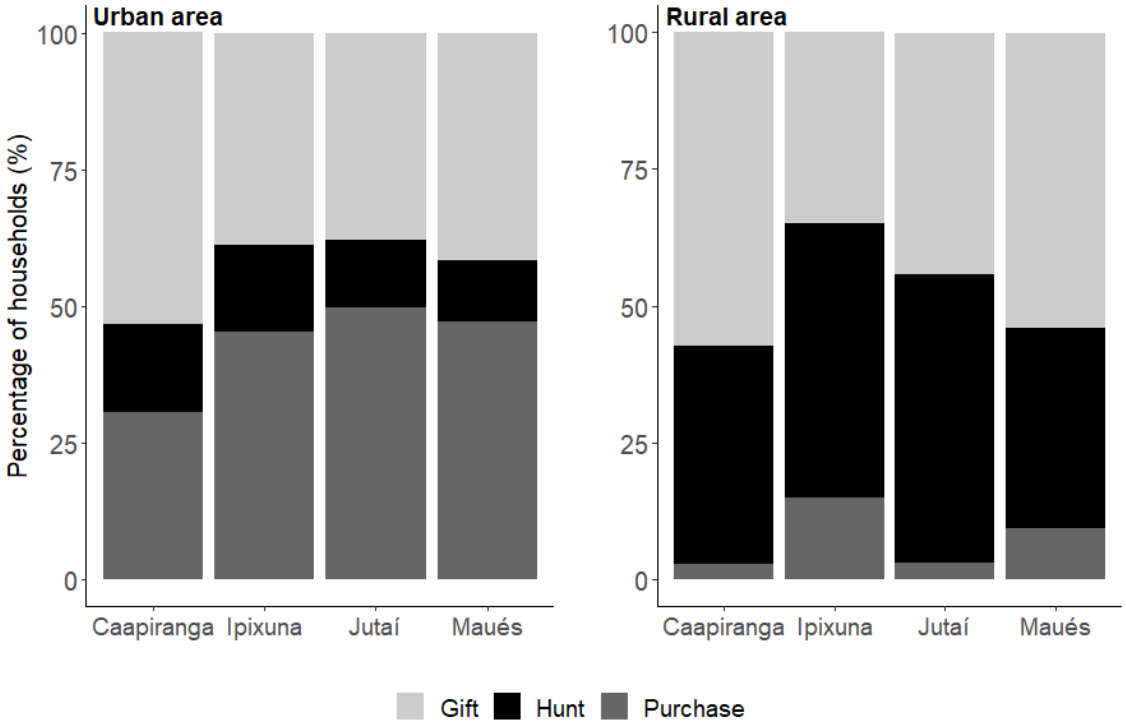


FIG. 4. Wildlife consumption and preference in urban and rural households in each municipality. Symbols plotted represent the percentage of households that had consumed each species the last time wildmeat was consumed in the household, in the previous 12 months and the percentage of interviewees (one per household) that declared the species as his/her favourite wildmeat type in each municipality.



715 FIG. 5. Means of acquiring wildmeat for the last time wildmeat was consumed in the household, in urban and rural areas of the four study municipalities. Hunt refers to access via a household member going hunting.

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Tables

TABLE 1 Municipalities' characteristics.

	Municipality				Description
	Caapiranga	Ipixuna	Jutaí	Maués	
Forest cover	89.7	96.9	92.7	90.7	Percentage of remaining forest cover (INPE, 2019)*
Area (km^2)	9,472	12,220	69,961	40,256	Municipality area
Travel distance (km)	162	2,566	947	342	Travel distance from the state capital, Manaus, to the urban centre of the municipality (Parry et al. 2018)
Population	13,081	29,689	14,317	63,905	Estimated population size for 2020 (IBGE, 2020)
Urban population (%)	46.8	42.7	58.6	49.5	Urban population in the last available national population census (IBGE, 2010)
Urban population change (%)	64.5	64.8	37.3	22.3	Urban population change between the two last available national population censuses (IBGE, 2000, 2010)
Rural population change (%)	2.7	41.8	-49.5	40.0	Rural population change between the two last available national population censuses (IBGE, 2000, 2010)

*INPE, Instituto Nacional de Pesquisas Espaciais. Projeto PRODES - Monitoramento Da Floresta Amazônica Brasileira Por Satélite (2019). http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes

TABLE 2 Household- and community-level characteristics and variables of the study population.

	Mean (SD/percentage)		Type of variable	Description
Mobility variables	Rural	Urban		
Migrant	-	57.3%	binary	Whether any of the urban household heads had migrated from a rural location to the urban centre.
Multi-sited household	14.8%	20.9%	binary	Whether the family in the household maintains dual residence – both in the rural and urban areas.
Rural visits	-	42.7%	binary	Whether anyone in the household visits any rural location at least once monthly.
Rural livelihoods	-	49.6%	binary	Whether urban household economic strategies relied on rural-urban mobility. Specifically, if anyone in the household performs agriculture, forest resources' extraction or fishing in a rural location.
Urban visits	67.5%	-	binary	Whether anyone in the rural household visits the urban area at least once monthly.
Wildmeat consumption variables				
Wildmeat consumption frequency [median (IQR)]	2 (6)	0 (2)	count	Number of meals containing wildmeat eaten in the household in the previous 30 days
Form of acquisition	6.7 %	43%	binary	Whether the wildmeat last acquired in the household was purchased (=1) or hunted or a gift (=0).
Rural community characteristics				
Community size	15.6 (9.1)	-	continuous	Number of households in the community.
Habitat type (floodplain)	51.4%	-	binary	Classified as floodplain or non-floodplain according to the community's leader.

Travel distance to town (km)	84.4 (69.6)	-	continuous	Fluvial distance in kilometres from the rural community to the urban centre of the municipality (considering the school or community centre location, because some communities are spread over few kilometres). Measured using a handheld GPS and, when not available, using ArcGIS 10.3.
Control variables				
Monthly monetary income [median (IQR)]*,**	133.9 (200.3)	327.3 (451.9)	continuous	*Per capita* monetary income earned from salaries, daily work, rent and other forms of remuneration and state transfer (e.g. retirement pension, conditional cash transfers) by all household members, in the previous 30 days.
Season (low water)***	48.5%	49.9%	categorical	Whether the household was surveyed in the low-water season or the high-water season.

*IQR – interquartile range. **a conversion rate of $1 = 3.70 Brazilian Reais. ***percentages indicate households interviewed in the low-water season

TABLE 3 Wildmeat consumption showing the percentage of households where wildmeat was declared to have been consumed and the mean number of meals consumed containing wildmeat.

		Wildmeat consumption			
		(% of households that consumed)		Mean consumption frequency in the previous 30 days (SD)	
Municipality	Area	Previous 1 year	Previous 30 days	All households	Consuming households only
Caapiranga	Urban	72.7	41.9	1.6 (4.0)	3.9 (5.4)
	Rural	93.8	60.0	3.9 (6.2)	6.5 (6.9)
Ipixuna	Urban	86.0	45.0	1.4 (3.5)	3.1 (4.6)
	Rural	100.0	72.5	4.7 (5.9)	6.4 (6.0)
Jutaí	Urban	80.6	39.8	1.5 (3.1)	3.7 (4.1)
	Rural	95.8	70.4	4.5 (6.7)	6.3 (7.3)
Maués	Urban	54.3	15.6	0.5 (2.0)	3.4 (3.9)
	Rural	95.0	72.5	5.7 (9.7)	7.9 (10.6)
All	Urban	73.4	35.6	1.3 (3.2)	3.6 (4.6)
	Rural	96.1	68.8	4.7 (7.3)	6.8 (7.9)