Impacts of rural to urban migration, urbanization, and generational change on consumption of wild animals in the Amazon

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Keywords: rural exodus, wildlife, wildmeat, bushmeat, turtle, tortoise, urban demand, randomized response technique

Running head: Wildlife consumption

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/cobi.13663.

Article impact statement: Amazon urbanite consumption of wildlife is high but decreases with urbanization, over time for rural-urban migrants, and between generations.

Abstract

For the first time in history, more people live in urban areas than in rural areas. This trend is likely to continue, driven largely by rural-urban migration. We investigated how rural-urban migration, combined with urbanization and generational change, affects consumption of wild animals, using one of the most hunted taxa in the Amazon: chelonians (tortoises and freshwater turtles). We surveyed 1,356 households and 2,776 schoolchildren across 10 urban areas of the Brazilian Amazon (six small towns, three large towns, and Manaus, the largest city in the Amazon Basin), using a Randomized Response Technique and anonymous questionnaires. Urban demand for wildmeat (i.e., meat from wildlife) was alarmingly high, with conservative estimates of approximately 1.7 million turtles and tortoises being consumed annually in Amazonas state. However, consumption rates declined with urban area size and between generations (adults versus children). Furthermore, the longer rural-urban migrants lived in urban areas, the lower their consumption rates were. These results suggest that wildlife consumption is a rural-related tradition that decreases with urbanization and over time after people move to urban areas. Current conservation efforts in the Amazon do not address urban demand for wildlife and may be insufficient to ensure the survival of traded species in the face of urbanization and human population growth. Our findings show that conservation interventions must target the urban demand for wildlife, especially by focusing on young people and recent rural-urban migrants.

Introduction

For the first time in history, more people live in urban areas than in rural areas, shifting from ~34% of the human population living in cities in 1960 to >55% in 2018 (United-Nations 2018). This trend is likely to continue, driven largely by rural-urban migration, with far-reaching consequences for biodiversity conservation. Most research to date on the implications of rural-urban migration for biodiversity has focused on what the abandonment of rural agricultural lands may mean for biodiversity (Parry et al. 2010; Queiroz et al. 2014). Some of these studies have predicted positive consequences stemming from forest regeneration (Izquierdo et al. 2011; Queiroz et al. 2014) on abandoned lands, whereas others have predicted negative consequences as a result of increased deforestation rates; e.g., when abandoned lands become vulnerable to exploitation (Parry et al. 2010; Queiroz et al. 2014). How rural-urban migration will affect the demand for wildlife has rarely been addressed, however, even though wildlife trade is a major threat to biodiversity. If rural-urban migrants switch their consumption from wildlife to domesticated animals, the result could be an overall reduction in wildmeat consumption over time. On the other hand, if rural-urban migrants continue to consume wildmeat at the rates they did when living in the countryside, urban areas could become increasingly important markets for wildmeat. Thus, understanding the patterns of urban demand for wildmeat in the face of rural-urban migration is critical to predicting the impact this global demographic shift will have on wild-animal populations and in designing policies to prevent overexploitation of targeted species.

Demand patterns are not static, and people's proclivities toward eating wildmeat could change generationally as a result of urbanization and rural-urban migration. If the children of rural migrants are exposed to different food options in cities, or if their urban peer groups have different taste preferences (Caspi et al. 2012; Higgs 2015), rates of wildmeat consumption could decrease over time. To our knowledge, how the rural-urban population transition affects children's consumption of and preference for the taste of wildmeat, relative to adults, has not been investigated.

Hunting of wildlife to satisfy global demands for live animals and wildlife products (e.g. for pet trade, meat, traditional medicine, and curios) is a major threat to biodiversity globally (Milner-Gulland et al. 2003; Brashares & Gaynor 2017; Benítez-López et al. 2019). This issue is a growing concern in the Amazon as human populations and access to previously remote areas increase (Peres et al. 2016; Di Minin et al. 2019). However, illegal wildlife trade in Amazonia appears primarily regional (van Vliet et al. 2015; El Bizri et al. 2020), increasing the chances that proactive strategies can prevent a dramatic increase in the trade and consequent collapses in wildlife populations in this region.

Here, we assess how rural-urban migration, urbanization, and generational change affect consumption of wildmeat, specifically imperiled tortoises and freshwater turtles (hereafter collectively referred to as "turtles"), in urban areas of the Brazilian Amazon. This region is well suited for a study of demographic changes in wildmeat consumption, with approximately 72% of the human population living in urban areas in 2010, compared with only 49% in 1980 (IBGE 1980, 2010). We focus on turtles because they are prized and consistently consumed throughout the Amazon, often figuring within the top five most consumed and traded species in urban areas (e.g., van Vliet et al. 2014; El Bizri et al. 2020). They are also among the most threatened vertebrates globally (Stanford et al. 2018).

We do not address consumption of wildmeat by rural residents, a topic that has long attracted attention from scientists (Jerozolimski & Peres 2003; Peres & Palacios 2007; Nunes et al. 2019). Instead, we focus on consumption of wildmeat by urban residents. Wildmeat consumption in urban areas is associated with several factors, including wealth, livelihood, and proportion of the population living in rural areas within each municipality (Parry et al. 2014; Chaves et al. 2018; El Bizri et al. 2020). A major gap in research is how demographic shifts, such as rural-urban migration, urbanization, and generational change, affect the demand for wildmeat. We assessed 10 urban sites across Amazonas state, the largest state in Brazil, encompassing ~25% of the Amazon Basin (>1.5 million km2; IBGE 2016). Our goals were to a) compare turtle consumption patterns in urban areas with different population sizes, b) assess how these consumption patterns change as a function of residency time (for rural-urban migrants) and generation time (schoolchildren versus adults), and c) obtain a rough estimate of the magnitude of turtle consumption in urban areas of Amazonas.

Methods

Study sites

Our study sites in Amazonas state, Brazil, included the capital city (Manaus, >2 million residents) and randomly selected urban areas: three large towns (each with 50,000-70,000 residents) and six small towns (each with <10,000 residents; Fig. S1, Table 1). Here, we use the term "urban area size" to refer to Manaus, large towns, and small towns. We followed the definition of "urban" used by Parry et al. (2014) and the Institute for Geography and Statistics of Brazil (IBGE 2010): the administrative center of each municipality, with basic services such as markets, banks, hospital and other health care services. Each urban area has the same name as its municipality.

Household surveys

All research involving people was approved by the Institutional Review Board of leading author's institution (IRB #10617). We conducted surveys of turtle consumption in randomly selected households in Manaus (445 surveys), large towns (312 surveys; ~100 per town) and small towns (599 surveys; ~100 per town; n=1356 surveys) between December 2018 and March 2019 (see supporting information [SI] for detailed sampling design).

Most wildmeat consumption in Brazil is illegal (Brasil 1967, 1998). Although hunting for subsistence is allowed, the law is unclear as to what constitutes subsistence hunting, creating legal uncertainties for resource users (Antunes et al. 2019). Furthermore, since wildmeat consumption in urban area is often purchased (Parry et al. 2014; Chaves et al. 2019), which constitutes illegal trade, people are often uncomfortable talking about wildmeat consumption. Thus, we used a randomized response technique, known as unrelated question design (Greenberg et al. 1971; Blair et al. 2015), that enables interviewees to honestly answer our questions without directly implicating themselves in an illegal activity. To each person identified as the head of household (male or female), we presented identical sets of questions regarding consumption that could be construed to refer to a non-sensitive, legal item (a local corn meal dish) or a sensitive, illegal item (turtles). To determine which item our questions were referring to, participants randomly drew a domino from a bag (containing two pieces with one dot and four pieces with two dots). Without showing us the domino they had selected, participants were asked to answer the questions as if we were referring to corn meal if they had selected a domino with one dot and turtles if they had selected a domino with two dots (Fig. S2). We then asked: "do you consume this item in your house?", followed by "how often do you consume this item in your house?", with the options of "weekly", "monthly", and "less often than monthly". We followed this question with: "how many units of this item do you consume in the house per week/month/season?" We used only the frequency (week/month/season) that the household had selected in the previous question. We asked the same questions for high- and low-consumption seasons (see season descriptions below). If the participants responded "no" to whether they consumed the item, we skipped questions about quantity consumed. We randomly selected a subset of the participants to respond only to direct questions about consumption of the corn meal dish. Because we knew the ratio of one-dot to two-dot dominoes in the bag and assessed the consumption of the corn meal dish, we could calculate the consumption rates of turtles.

We obtained information regarding turtle consumption and six socioeconomic factors that we hypothesized were associated with turtle consumption: residency status (defined below), birthplace (i.e., whether the person was born in a large city, like Manaus, or elsewhere, such as a small town, large town, or rural area), the household's Poverty Probability Index (Schreiner 2010; defined below), whether the household had children (individuals under 18 years of age), years since head of household left the rural area (for heads of households who had migrated from rural areas), and season (high and low; defined below). For household heads who openly stated that they consumed turtles, we asked questions about species usually consumed and prices paid the last time they obtained turtles, if purchased.

Residency status: We considered six categories, depending on whether respondents had migrated from rural to urban areas or whether they have always lived in an urban area (Fig. 1).

Poverty Probability Index (PPI): PPI is a well-established poverty measurement that uses 10 questions about characteristics and assets of a household to compute the probability that the household falls under a country's poverty line (Schreiner 2010). We used the index developed for the Brazilian context (see SI for more details). We also considered a quadratic term for PPI to look for a non-linear relationship with wildmeat consumption (Wilkie & Godoy 2001). However, the quadratic term was not significant and did not change our results. Therefore, we removed it from our final analyses.

Season: Consumption of both turtles and corn meal fluctuates seasonally. For turtles, consumption is highest when river levels are low, corresponding to the nesting season. For corn meal, consumption peaks during the period when the corn is not overly ripe, which is also when river levels are low. We defined these seasonal peaks and troughs in turtle and corn consumption as the high and low seasons. We asked participants to report on how long each season lasted (in months) and on their turtle and corn consumption habits during each season.

School surveys of children

To assess differences between generations (children versus adults) with respect to turtle consumption, we surveyed schoolchildren in the same 10 urban areas. We randomly selected 49 middle and high schools (11 in Manaus, 13 in large towns, and 25 in small towns). At each school, we randomly selected four classrooms and asked the schoolchildren to complete an anonymous questionnaire (2,700 students in 146 classrooms; all with parental consent). Schoolchildren varied from 11 to 18 years in age.

We collected three types of response variables: whether a child ate turtle the last time it was offered during a family meal, how often a child consumed turtle when it was offered during a family meal (never, sometimes, almost always, always), and the child's taste preference for turtle relative to other meat types (from 0 [do not like it] to 5 [like it a lot]). In addition, we collected information on whether there were other types of meat available during the meal (e.g. domesticated livestock or fish), whether the children were migrants or non-migrants, grade level (middle or high school), and how many people lived in their household.

Data analyses

Consumption of turtles by households

We used Bayesian statistics to analyze household data. We performed these analyses in JAGS (Plummer et al. 2016) within R Studio (R Core Team 2014). We relied on 25,000 samples from the posterior distribution, after discarding the first 25,000 iterations as the burn-in period. Our analyses focused on two main response variables: recent consumption and consumption quantity.

Recent consumption (RC)

We considered whether households had consumed the item in 2018. Given that RC is a yes-or-no binary variable, we assumed a Bernoulli likelihood. For the direct question (DQ) asked about the non-sensitive food item (NS), we assumed that the response $RC_{ic}^{DQ.NS}$ for individual i in urban area size c is given by a standard logistic regression:

$$RC_{ic}^{DQ.NS} \sim Bernoulli(\theta_{ic}^{NS})$$

$$\theta_{ic}^{NS} = \frac{\exp(\alpha_c^{NS} + x_{ic}^T \beta^{NS})}{1 + \exp(\alpha_c^{NS} + x_{ic}^T \beta^{NS})}$$

where α_c^{NS} is an intercept for urban area size, x_{ic}^T is a vector with covariates, and β^{NS} is a vector of slope parameters for the non-sensitive item.

For the indirect question (IQ) regarding the sensitive food item (SI), we relied on a mixture of logistic regressions, where the weights are known. Specifically, we assumed that the response RC_{ic}^{IQ} for individual i in urban area size c is given by:

$$p(RC_{ic}^{IQ}) = p(RCP_{ic}^{IQ}|SI)p(SI) + p(RCP_{ic}^{IQ}|NS)p(NS)$$

$$= Bernoulli(RC_{ic}^{IQ}|\theta_{ic}^{SI})\pi^{SI} + Bernoulli(RC_{ic}^{IQ}|\theta_{ic}^{NS})(1 - \pi^{SI})$$

$$\theta_{ic}^{SI} = \frac{\exp(\alpha_c^{SI} + x_{ic}^T \beta^{SI})}{1 + \exp(\alpha_c^{SI} + x_{ic}^T \beta^{SI})}$$

where α_c^{SI} is an intercept for urban area size and β^{SI} is a vector of slope parameters for the sensitive item. Furthermore, π^{SI} is the probability that the respondent is providing an answer regarding the sensitive food item (turtles as opposed to corn meal), which is equal to 4/6 because of the frequency of the different domino pieces.

Consumption quantity (CQ)

We asked about the quantity of a given food item (turtles or corn meal) consumed in a week, month, or season. We assumed that CQ follows a negative binomial distribution with an offset for the reference number of days (i.e., week, month, or season). Importantly, we restricted our analysis only to observations for which RC=1 (i.e., only observations from individuals who reported recent consumption).

For the direct questions (DQ) about consumption of the non-sensitive item (NS), we relied on a negative-binomial regression. Specifically, we assumed that the response $CQ_{ic}^{DQ.NS}$ for individual i in urban area size c is given by:

$$CQ_{ic}^{DQ.NS} \sim NB\left(\mu_{ic}^{NS}, n\right)$$

where $\mu_{ic}^{NS} = E\left[CQ_{ic}^{DQ.NS}\right]$ is given by:

$$\mu_{ic}^{NS} = \exp(\alpha_c^{NS} + x_{ic}^T \beta^{NS})\, D_{ic}^{DQ.NS}$$

Here, α_c^{NS} is an intercept for urban area size, x_{ic}^T is a vector with covariates, and β^{NS} is a vector of slope parameters for the non-sensitive item, and $D_{ic}^{DQ.NS}$ is the reference number of days.

For the indirect questions (IQ), we relied on a mixture of negative-binomial regressions, where the weights are known. Specifically, we assumed the response CQ_{ic}^{IQ} for individual i in urban area size c is given by:

$$p\left(CQ_{ic}^{IQ}\right) = p\left(CQ_{ic}^{IQ} | SI\right) p(SI) + p\left(CQ_{ic}^{IQ} | NS\right) p(NS)$$

$$= NB\left(CQ_{ic}^{IQ} | \mu_{ic}^{SI}, n\right) \pi^{SI} + NB\left(CQ_{ic}^{IQ} | \mu_{ic}^{NS}, n\right)(1 - \pi^{SI})$$

$$\mu_{ic}^{SI} = \exp(\alpha_c^{SI} + x_{ic}^T \beta^{SI})\, D_{ic}^{IQ}$$

where α_c^{SI} is an intercept for urban area size, β^{SI} is a vector of slope parameters for the sensitive item, and D_{ic}^{IQ} is the reference number of days. Furthermore, π^{SI} is the probability that the respondent is providing an answer regarding the sensitive item, which is equal to 4/6 because of the frequency of the domino pieces.

Models to assess factors associated with consumption

Using the models for recent consumption and consumption quantity, we assessed: (1) demographic and socioeconomic factors associated with consumption, for which our covariates included residency status (six categories; Fig. 1), birthplace (large city versus elsewhere), number of people in the household, whether the household had children, and PPI; (2) how consumption changes as function of time, for which we included years since the head of household left the rural area while accounting for residency status (only migrants; Fig. 1), number of people in the household, whether the household had children, and PPI. In all these analyses, an additional binary covariate consisted of the consumption season (high and low seasons were set to 1 and 0, respectively). All continuous variables were standardized (mean of zero and standard deviation of one), and there was no collinearity among the variables.

Models to estimate the number of turtles consumed

We estimated the total number of turtles consumed in each season and urban area size (Manaus, small town, large town) in 2018. To do so, we used similar models to the ones described above for recent consumption and consumption quantities. However, we removed all covariates and allowed intercepts to vary for each urban area size and season combination. Specifically, we used logistic regression model to estimate the proportion of participants who consumed turtles for each urban area size c and for each season s (θ_{cs}^{SI}). We used negative binomial model to estimate the average number of turtles consumed/household/day for each urban area size and season (μ_{cs}^{SI}), considering only participants who consumed turtles in each season. To obtain an estimate of number of turtles consumed for each urban area size c, season s and household i (Y_{ics}), we relied on the law of iterated expectations:

$$E[Y_{ics}] = E[Y_{ics}|Z_{ics} = 1]p(Z_{ics} = 1) + E[Y_{ics}|Z_{ics} = 0]p(Z_{ics} = 0)$$

$$= \mu_{cs}^{SI} \times \theta_{cs}^{SI} + 0 \times (1 - \theta_{cs}^{SI}) = \mu_{cs}^{SI} \times \theta_{cs}^{SI}$$

where Z_{ics} is whether the household consumes turtles. We used the median duration of high and low seasons for turtles reported by participants (D_{hi} and D_{lo}) to determine annual consumption per household, given by $D_{hi} \times E[Y_{ic,hi}] + D_{lo} \times E[Y_{ic,lo}]$. Notice that this annual consumption per household already accounts for the fact that a proportion of the households do not consume turtles. Finally, we made extrapolations of annual consumption for each town/city by multiplying the average annual consumption per household in each urban area size by the total number of households in each city/town.

Consumption of turtles by children

We used a logistic regression model to assess the probability of consuming turtle meat the last time it was offered as part of a meal. We used ordinal logistic regression to (1) assess how often children consumed turtle meat when it was available in a meal, (2) assess children's taste preference for turtle relative to other types of meat, and (3) compare the preferences of children versus heads of households for turtle meat, using the function polr within the R package MASS (Venables & Ripley 2002). All analyses were performed in R Studio (R-Core-Team 2014).

Results

Patterns of rural-urban migration

The proportion of households containing rural-urban migrants was greater in small towns than in large towns, and greater in large towns than in Manaus. In small towns, 65.30% of the households (n = 397/608) were rural-urban migrants. In large towns, this percentage dropped to 54.34 (169/311). In the city of Manaus, only 33.78% (151/447) of the households were rural-urban migrants.

Consumption of turtles by households

PPI and season were strongly associated with the odds of consuming turtles. The poorer people were, the less likely they were to consume turtles, with odds of consuming turtles 72% lower when PPI increased by one standard deviation (equivalent of 26.8% change in PPI; Table S1). The odds of consuming turtles in the high season were 30 times higher than in the low season. The remaining variables included in the model were not significant (Table S1).

Rural-to-small town migrants consumed more turtles than all other groups (rural-to-Manaus migrants, rural-to-large town migrants, Manaus non-migrants, large town non-migrants, and small-town non-migrants; Fig. 2). Households with children consumed 48% fewer turtles than households without children. In addition, households consumed more turtles during the high season than during the low season. The remaining variables included in the model were not significant (Table S2).

For rural-urban migrants, the odds of consuming turtles were 59% lower as years the head of that household had spent living in an urban area increased by one standard deviation (equivalent to 16.6 change in years). Among migrants who consumed turtles, the number of turtles consumed per household was 70% lower as the years the head of that household spent living in an urban area increased by one standard deviation (Tables S3 and S4). Overall, changing priors did not change outcomes.

We recorded seven species of freshwater turtles and two tortoises consumed in our study sites; seven of them are threatened with extinction (Table 2). Prices reported by 207 households for a turtle averaged USD$ 13.71± SE 1.09 in small towns, USD$ 46.18±5.69 in large towns, and USD$ 49.04±8.21 in Manaus (using the conversion rate 1.00 USD = 4.15 Brazilian reais; Table S5).

Prevalence of consumption and number of turtles consumed by households

The proportion of households that consumed turtles in 2018 varied by urban area size and by season (Fig. 3A; Table S6). Turtle consumption in the large town of Manacapuru was remarkably higher than in other towns, so we estimated consumption patterns for this town separately from the others. The percentage of households consuming turtles declined with increase in urban area size (excluding Manacapuru). Estimates of consumption that combine Manacapuru with the other two large towns are available in SI.

Among households that consumed turtles in 2018, the number of individuals consumed per day also varied by urban area size and by season (Fig. 3B; Table S6). By combining the proportion of households that consumed turtles with the number of turtles consumed per day, we obtained estimates of the number of turtles consumed per household in 2018 for each urban area size. The median length of the high season for Manaus and Manacapuru was one month (11 months for low season), whereas the median length of the high season for the other towns was two months (10 months for low season). We used these medians to estimate the number of turtles consumed/household/year (Fig. 3C; Table S6).

Estimated total consumption of turtles by households across Amazonas

To be conservative, we used the estimate of consumption per household for large towns other than Manacapuru to make extrapolations to the rest of the state (Table S7). Based on these extrapolations, the number of turtles consumed in 2018 in urban areas across Amazonas state was ~1.7 million (95% Credible Interval [CI] 1.0; 3.3). Manaus accounted for >40% of that consumption (~792 thousands per year [CI 507,000; 1.7 million]), and Manacapuru accounted for approximately ~15% (~267,000 per year [CI 119,000; 535,000). The combined consumption of the remaining 60 towns was ~709,000 turtles (CI 455,000; 1.12 million). We also provide less conservative estimates by assigning consumption per household from each urban area size (Manaus, large towns and small towns) to each town of similar size instead of using only consumption rates for large towns. For less conservative estimates, see Table S7.

Consumption of turtles by schoolchildren

Urban area size (small towns, large towns, or Manaus), birthplace (Manaus versus elsewhere), and whether children were rural-urban migrants were important predictors of turtle consumption and taste preference among schoolchildren. Compared with children who lived in small towns, children who lived in large towns and Manaus were, respectively, 61% (odds ratio [OR]=0.39, $p<0.0001$) and 64% (OR=0.36, $p<0.0001$) less likely to consume turtle meat the last time it was offered to them as a part of a meal (Fig. 4A); 68% (OR=0.32, $p<0.0001$) and 79% (OR=0.21, $p<0.0001$) less likely to consume turtle meat whenever it was offered to them (Fig. 4B); and they expressed 56% (OR=0.44, $p<0.0001$) and 71% (OR=0.29, $p<0.0001$) lower preference for turtles relative to other types of meat (e.g., domesticated meat) than did their small-town peers (Fig. 4C).

Rural-urban migrant children were more likely to consume turtles and had a higher taste preference for turtle meat than did non-migrant children. Compared with children who had never lived in a rural area, children who were rural-urban migrants were 71% (OR=1.71, $p<0.0001$) more likely to consume turtle meat the last time it was available to them, 67% (OR=1.67, $p<0.0001$) more likely to eat turtles whenever they had the opportunity, and they expressed a 74% (OR=1.74, $p<0.0001$) higher preference for the taste of turtles.

Children who had other options for meat (e.g. domesticated animals) the last time turtles were available in a meal were 48% (OR=0.52, $p=0.01$) less likely to consume turtles than children without an alternative (Table S8). We did not detect an effect of school grade (middle versus high school) and number of people on the odds of consuming turtles. Importantly, when comparing children and household heads, schoolchildren exhibited a 19% lower taste preference for turtles (OR=0.81, $p<0.0001$; Table S9).

Discussion

Effect of rural-urban migration and urbanization on turtle consumption

The worldwide phenomenon of people leaving rural areas for towns and cities is certain to have major impacts on biodiversity. However, almost all research to date on this topic has focused on issues related to land-use change. Largely ignored has been the question of how consumption of wildlife will change as countries become increasingly urbanized. Focusing on the consumption of threatened turtles in the Brazilian Amazon, we show that rural-urban migration, the size of the urban area into which people move, and generation (adults versus children) all affect the rate at which people consume wild animals.

The consumption decline observed with increase in urban area size could be driven by the higher price of turtles in large cities compared with small towns. There may also be higher levels of law enforcement in large cities than in small towns. A third contributing factor could be the greater rural influence in small towns, as measured by the proportion of residents who came from rural areas or the frequency with which people visit rural areas. Rural-urban boundaries in small towns may be blurrier, with residents living within the town but continue traveling to and using goods from rural areas (Padoch et al. 2008). Furthermore, the high incidence of turtle consumption in small towns may create a more receptive social environment for this behavior (Rimal & Real 2005). At the same time, consumption of turtles among rural-urban migrants decreased over time across all urban settings, which may indicate reduced access to rural areas over time, and therefore turtles, and increased access to meat from domesticated animals (Chaves et al. 2019).

Generational differences in turtle consumption

Over time, the generational change we detected could lead to a per capita decrease in turtle consumptions and, ultimately, alleviate pressure on turtles, if children make similar dietary decisions as they grow older. In addition, the generational change in turtle consumption and preference among children could influence attitudes among adults, an intergenerational phenomenon noted elsewhere (Marchini & Macdonald 2020). Current and future turtle consumption by children is likely to be associated with social eating norms (defined as what is perceived as appropriate to consume by members of a social group; Higgs 2015) and food environments (defined as the physical and social environmental aspects that affect food choices and behaviors, such as accessibility, affordability, and acceptability; Caspi et al. 2012). The difference in consumption among urban areas suggests that both social eating norms and the food environment are more conducive to turtle consumption in small towns than in large towns.

Magnitude of consumption and targeted interventions

Our estimate of 1.7 million turtles consumed in urban areas of Amazonas in 2018 supports previous findings of high urban demand for wildlife in the Amazon (Parry et al. 2014; van Vliet et al. 2015; Chaves et al. 2018; Chaves et al. 2019; El Bizri et al. 2020). Household consumption rates were lower in Manaus than in other urban areas, but Manaus contains over 50% of the state's population, which makes the aggregate turtle consumption there significant. Manacapuru, although smaller, had an anomalously high rate of turtle consumption, accounting for approximately 15% of total consumption in Amazonas. This town is strategically located along the Amazon River (Fig. S1), downstream from several important tributaries and may be a stopping point for boats heading to Manaus. Manacapuru's location, combined with road access and reduced levels of law enforcement compared with Manaus, may explain why it is a consumption hotspot.

Our results can help to inform cost-effective conservation interventions. First, demand-side interventions (e.g. programs aimed at reducing consumption) prioritizing recent migrants may have a higher return on investment than programs focusing on the general population. Second, unless Manacapuru is a singular phenomenon, there are certain towns that are hotspots of wildmeat consumption. Targeting conservation efforts in these places should have disproportionately positive outcomes. As a starting point, focusing such efforts on towns strategically located at the intersections of major rivers or other transportation corridors may be warranted. Third, efforts to raise awareness of the plight of Amazonian turtles among schoolchildren while fostering children's connection with nature may have long-term payoffs if such efforts maintain or increase the generational difference that already exists regarding wildmeat and cause today's children to forego eating turtles even more as they become adults.

Implications for biodiversity in an urbanizing world

Several strategies to conserve chelonian populations *in situ* are currently in place in the Amazon (Tavares de Freitas et al. 2020). None of these efforts, however, addresses urban demand. For instance, the Brazilian Amazon has community engagement programs aimed at both protecting nesting beaches for river turtles and artificially increasing hatchling survivorship, with positive outcomes for some species and regions (Campos-Silva et al. 2018; Eisemberg et al. 2019). Other notably consumed species, such as *Chelonoidis denticulatus*, *Chelonoidis carbonarius*, and *P. dumerilianus*, are not included in any conservation program. Conservation efforts aimed at reducing overall demand for turtles in urban areas are still needed.

While this demographic shift from rural to urban areas presents challenges to conservation, it creates opportunities. Urban residents typically have access to domesticated meat largely unavailable to rural residents. In addition, people in urban areas are more densely packed, making targeted interventions easier. Also, since poverty was associated with a lower probability of consuming turtles (a pattern consistent with other research showing an increase in consumption of wildmeat as a function of increases in wealth or income; Wilkie & Godoy 2001; Godoy et al. 2010), interventions in urban areas to reduce turtle consumption are unlikely to exacerbate food insecurity or substantially threaten people's food sovereignty. If availability of wild meat declines, people in urban areas can switch to domesticated alternatives, whereas people in rural communities may be unable to do so due to a lack of alternatives or means to access alternatives (Milner-Gulland et al. 2003). Therefore, reducing demand in urban centers and guaranteeing that harvest levels are sustainable are likely effective strategies to safeguard livelihoods in both urban and rural areas.

If people migrating to urban areas continue to consume wildmeat, the aggregate urban demand for it could still have significant impacts on wildlife populations. Our study is the first large-scale contribution to understanding how the ongoing global shift in human populations from rural areas to urban areas affects wildmeat consumption. Whether the observed decline in wildmeat consumption between generations and with time spent in urban areas will significantly reduce the absolute consumption remains to be seen.

Acknowledgments

We thank research assistants for data collection, T. Schor for the technical and logistical support, and S. Perz and K. Silvius for feedback on earlier versions of this manuscript. We thank D.S.W lab members for their helpful insights and suggestions. The High Meadows Foundation funded this research. The Federal University of Amazonas, the State University of Amazonas, and Chico Mendes Institute for Biodiversity Conservation provided logistical support. The Wildlife Conservation Society Graduate Scholarship Program, the Christensen Conservation Leaders Scholarship, and the Wildlife Conservation Network Scholarship Program through the Sidney Byers Scholarship award supported T. Q. M.

References

Antunes AP, et al. 2019. A conspiracy of silence: Subsistence hunting rights in the Brazilian Amazon. Land Use Policy **84**:1-11.

Benítez-López A, Santini L, Schipper AM, Busana M, Huijbregts MAJ. 2019. Intact but empty forests? Patterns of hunting-induced mammal defaunation in the tropics. PLOS Biology **17**:e3000247.

Blair G, Imai K, Zhou Y-Y. 2015. Design and Analysis of the Randomized Response Technique. Journal of the American Statistical Association **110**:1304-1319.

Brashares JS, Gaynor KM. 2017. Eating ecosystems. Science **356**:136-137.

Brasil. 1967. Lei no. 5197, de 3 de janeiro de 1967. Dispõe sobre a proteção à fauna e dá outras providências. Diário Oficial da União, Brasília, 5 jan. 1967. Diário Oficial da União.

Brasil. 1998. Lei no. 9605, de 12 de fevereiro de 1998. Dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente, e dá outras providências. Diário Oficial da União, Brasília, 13 fev. 1998.

Campos-Silva J, Hawes J, Andrade P, Peres C. 2018. Unintended multispecies co-benefits of an Amazonian community-based conservation programme - Nature Sustainability. 1:650-656.

Caspi CE, Sorensen G, Subramanian SV, Kawachi I. 2012. The local food environment and diet: a systematic review. Health Place **18**:1172-1187.

Chaves WA, Monroe MC, Sieving KE. 2019. Wild Meat Trade and Consumption in the Central Amazon, Brazil. Human Ecology **47**:733-746.

Chaves WA, Valle DR, Monroe MC, Wilkie DS, Sieving KE, Sadowsky B. 2018. Changing Wild Meat Consumption: An Experiment in the Central Amazon, Brazil. Conservation Letters **11**:e12391.

Di Minin E, et al. 2019. Identifying global centers of unsustainable commercial harvesting of species. Science Advances **5**:eaau2879.

Eisemberg CC, Vogt RC, Balestra RAM, Reynolds SJ, Christian KA. 2019. Don't put all your eggs in one basket – Lessons learned from the largest-scale and longest-term wildlife conservation program in the Amazon Basin. Biological Conservation **238**:108182.

El Bizri HR, et al. 2020. Urban wild meat consumption and trade in central Amazonia. Conserv Biol **34**:438-448.

Godoy R, Undurraga EA, Wilkie D, Reyes-García V, Huanca T, Leonard WR, McDade T, Tanner S, Vadez V, Team TBS. 2010. The effect of wealth and real income on wildlife consumption among native Amazonians in Bolivia: estimates of annual trends with longitudinal household data (2002–2006). Animal Conservation **13**:265-274.

Greenberg BG, Kuebler RR, Abernathy JR, Horvitz DG. 1971. Application of the Randomized Response Technique in Obtaining Quantitative Data. Journal of the American Statistical Association **66**:243-250.

Higgs S. 2015. Social norms and their influence on eating behaviours. Appetite **86**:38-44.

IBGE. 1980. Instituto Brasileiro de Geografia e Estatística. Biblioteca, Brasília, Brasil. https://www.ibge.gov.br/estatisticas/multidominio/ciencia-tecnologia-e-inovacao/25089-censo-1991-6.html?edicao=25091&t=publicacoes. Acessed 09 December 2019.

IBGE. 2010. Instituto Brasileiro de Geografia e Estatística. Cidades@, Brasília, Brasil. http://www.cidades.ibge.gov.br/xtras/home.php. Acessed 09 December 2019.

IBGE. 2016. Instituto Brasileiro de Geografia e Estatística. Cidades@, Brasília, Brasil. https://cidades.ibge.gov.br. Acessed 09 December 2019.

Izquierdo AE, Grau HR, Aide TM. 2011. Implications of rural-urban migration for conservation of the Atlantic Forest and urban growth in Misiones, Argentina (1970-2030). Ambio **40**:298-309.

Izquierdo AE, Grau HR, Aide TM. 2011. Implications of rural-urban migration for conservation of the Atlantic Forest and urban growth in Misiones, Argentina (1970-2030). Ambio **40**:298-309.

Jerozolimski A, Peres CA. 2003. Bringing home the biggest bacon: a cross-site analysis of the structure of hunter-kill profiles in Neotropical forests. Biological Conservation **111**:415-425.

Marchini S, Macdonald DW. 2020. Can school children influence adults' behavior toward jaguars? Evidence of intergenerational learning in education for conservation. Ambio **49**:912-925.

Milner-Gulland EJ, Bennett EL. 2003. Wild meat: the bigger picture. Trends in Ecology & Evolution **18**:351-357.

Nunes AV, Peres CA, Constantino PDL, Santos BA, Fischer E. 2019. Irreplaceable socioeconomic value of wild meat extraction to local food security in rural Amazonia. Biological Conservation **236**:171-179.

Padoch C, Brondizio E, Costa S, Pinedo-Vasquez M, Sears RR, Siqueira A. 2008. Urban Forest and Rural Cities: Multi-sited Households, Consumption Patterns, and Forest Resources in Amazonia. Ecology and Society **13**.

Parry L, Barlow J, Pereira H. 2014. Wildlife Harvest and Consumption in Amazonia's Urbanized Wilderness. Conservation Letters **7**:565-574.

Parry L, Peres C, Day B, Amaral S. 2010. Rural–Urban Migration brings Conservation Threats and Opportunities to Amazonian Watersheds. Conservation Letters **3**.

Accepted Article

Peres CA, Emilio T, Schietti J, Desmoulière SJM, Levi T. 2016. Dispersal limitation induces long-term biomass collapse in overhunted Amazonian forests. Proceedings of the National Academy of Sciences **113**:892-897.

Peres CA, Palacios E. 2007. Basin-Wide Effects of Game Harvest on Vertebrate Population Densities in Amazonian Forests: Implications for Animal-Mediated Seed Dispersal. Biotropica **39**:304-315.

Plummer M, Stukalov A, Denwood M. 2016. Package 'rjags': bayesian graphical models using MCMC.

Queiroz C, Beilin R, Folke C, Lindborg R. 2014. Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. Frontiers in Ecology and the Environment **12**:288-296.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rimal RN, Real K. 2005. How Behaviors are Influenced by Perceived Norms:A Test of the Theory of Normative Social Behavior. Communication Research **32**:389-414.

Rhodin, AGJ, Iverson JB, Bour R, Fritz U, Georges AH, Shaffer HB, Dijk 2017 PPV. Turtles of the World: Annotated Checklist and Atlas of Taxonomy, Sononymy, Distribution, and Conservation Status (8th Ed.). Chelonian Research Foundation and Turtle Conservancy, New York, NY.

Schreiner M. 2010. A Poverty Probability Index (PPI®) for Brazil (2008), http://www.povertyindex.org/country/brazil. Acessed 19 December 2019.

Stanford CB, et al. 2018. Turtles in Trouble: The World’s 25+ Most Endangered Tortoises and Freshwater Turtles. Turtle Conservation Coalition, Ojai, CA.

Freitas CT, Lopes PFM, Campos-Silva JV, Noble MM, Dyball R, Peres CA. 2020. Co-management of culturally important species: A tool to promote biodiversity conservation and human well-being. People and Nature **2**:61-81.

United-Nations. 2018. 2018 Revision of World Urbanization Prospects. United Nations, Population Division.

Vliet N, Mesa M, Cruz-Antia D, Aquino L, Moreno J, Nasi R. 2014. The uncovered volumes of bushmeat commercialized in the Amazonian trifrontier between Colombia, Peru & Brazil. Ethnobiology and Conservation **3**:2014.

van Vliet N, Quiceno MP, Cruz D, Jonhson Neves de Aquino L, Yagüe B, Schor T, Hernandez S, Nasi R. 2015. Bushmeat networks link the forest to urban areas in the trifrontier region between Brazil, Colombia, and Peru. Ecology and Society **20**.

Venables, WN, Ripley BD. 2002. Modern applied statistics with S. Springer, New York, NY.

Wilkie DS, Godoy RA. 2001. Income and Price Elasticities of Bushmeat Demand in Lowland Amerindian Societies. Conservation Biology **15**:761-769.

Table 1 – Study sites in Amazonas states, Brazilian Amazon. Population data based on census by the Institute for Geography and Statistics of Brazil (IBGE 2010; 2016). The table contains information on population from urban areas (the towns/city) and rural areas (which includes the people outside of the urban areas but that are in the same municipality).

Urban area size	**Munici pality**	**# houses (urban)**	**# people (total)**	**# people (urban)**	**# people (rural)**	**% people (urban)**	**River basin**	**Distance to Manaus[a]**
City	Manaus	458,300	2,145,444	2,123,990	21,454	99	Negro/ Amazon	0
Small town	Beruri	1,488	15,479	7,740	7,740	50	Purus	239
Small town	Canutama	1,401	12,694	6,601	6,093	52	Purus	613
Small town	Pauini	1,767	17,996	9,178	8,818	51	Purus	924
Small town	SIRN[b]	1,206	18,104	6,880	11,224	65	Negro	117
Small town	Novo Airão	2,079	14,723	9,570	5,153	38	Negro	631
Small town	Tonantins	1,431	17,044	8,863	8,181	52	Amazon	862
Large town	Manacapuru	13,071	85,109	59,576	25,533	70	Amazon	68
Large town	Parintins	14,336	102,011	70,388	31,623	69	Amazon	369
Large town	Tefé	10,014	61,405	49,124	12,281	80	Amazon	521

[a] Approximate distance in km based on urban center location of each municipality
[b] Santa Isabel do Rio Negro

Table 2 – Species listed as consumed among participants who openly stated that there was consumption of turtles in their household.

Scientific name	Common name	Conservation Status[b]	# of households that reported consuming			Total per species
			Small towns	Large towns	Manaus	
Chelonoidis spp. [a]	Tortoise	Near Threatened/ Vulnerable	154	19	12	185
Chelus fimbriana	Matamata	Least Concern	11	1	0	12
Rhinoclemmys puctularia	Spot-legged wood turtle	Vulnerable	6	0	0	6
Peltocephalus dumer-ilianus	Big-headed Amazon river turtle	Vulnerable	127	107	4	238
Podocnemis erythrocephala	Red-headed Amazon river turtle	Vulnerable	98	83		181
Podocnemis expansa	South American river turtle	Critically Endangered	272	63	29	364
Podocnemis sextuberculata	Six-turbercled Amazon river turtle	Vulnerable	254	68	5	327
Podocnemis unifilis	Yellow-spotted river turtle	Endangered	378	159	42	579

[a] Two species: *Chelonoidis carbonarius and Chelonoidis denticulatus*
[b] Status classification from IUCN Tortoise and Freshwater Turtle Specialist Group 2011 (Rhodin et al. 2017)

Figure-legend page

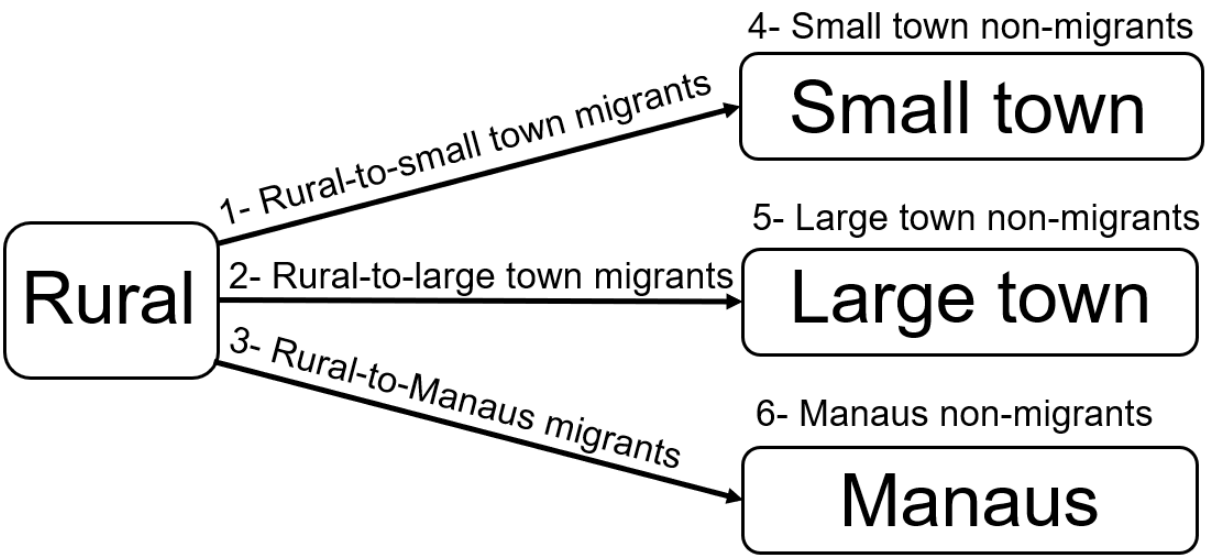

Fig. 1 – Residency status of heads households. Residents in categories 4, 5, and 6 never lived in rural areas (non-migrants). Residents who migrated from one urban area to another are all considered non-migrants for the purpose of this study.

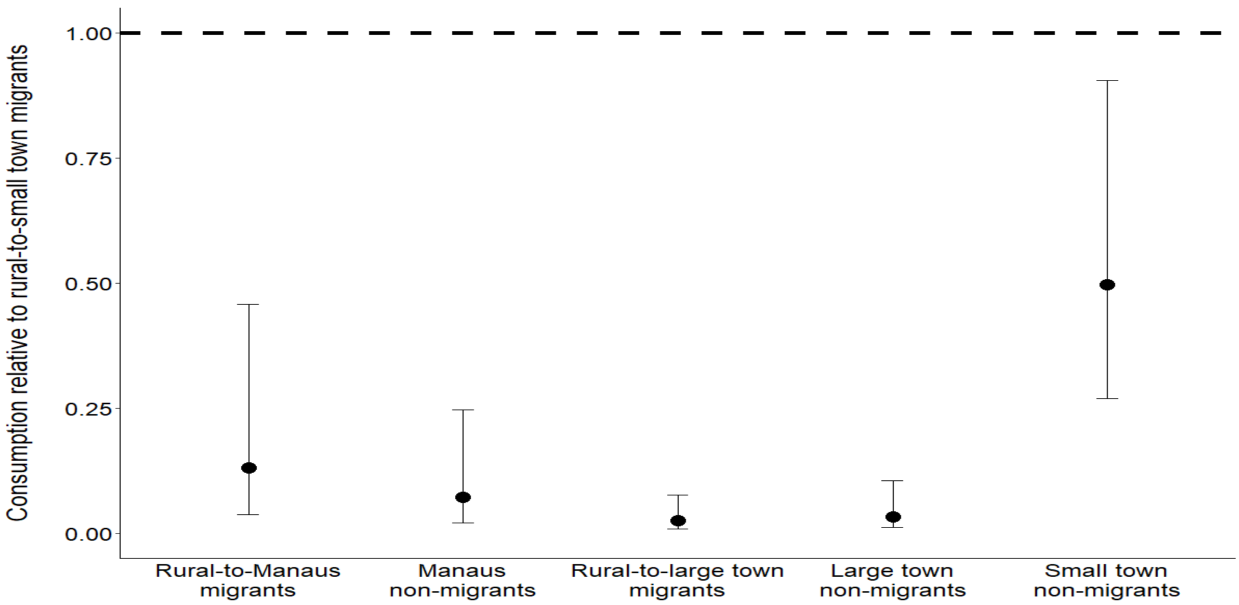

Fig. 2 – Consumption of turtles among households that consume turtles. Residency status categories (rural-to-Manaus migrants; Manaus residents who never lived in rural area; rural-to-large town migrants; large town residents who never lived in rural area; and small-town residents who never lived in rural areas) are compared with rural-to-small town migrants (dashed line). Error bars are 95% credible intervals.

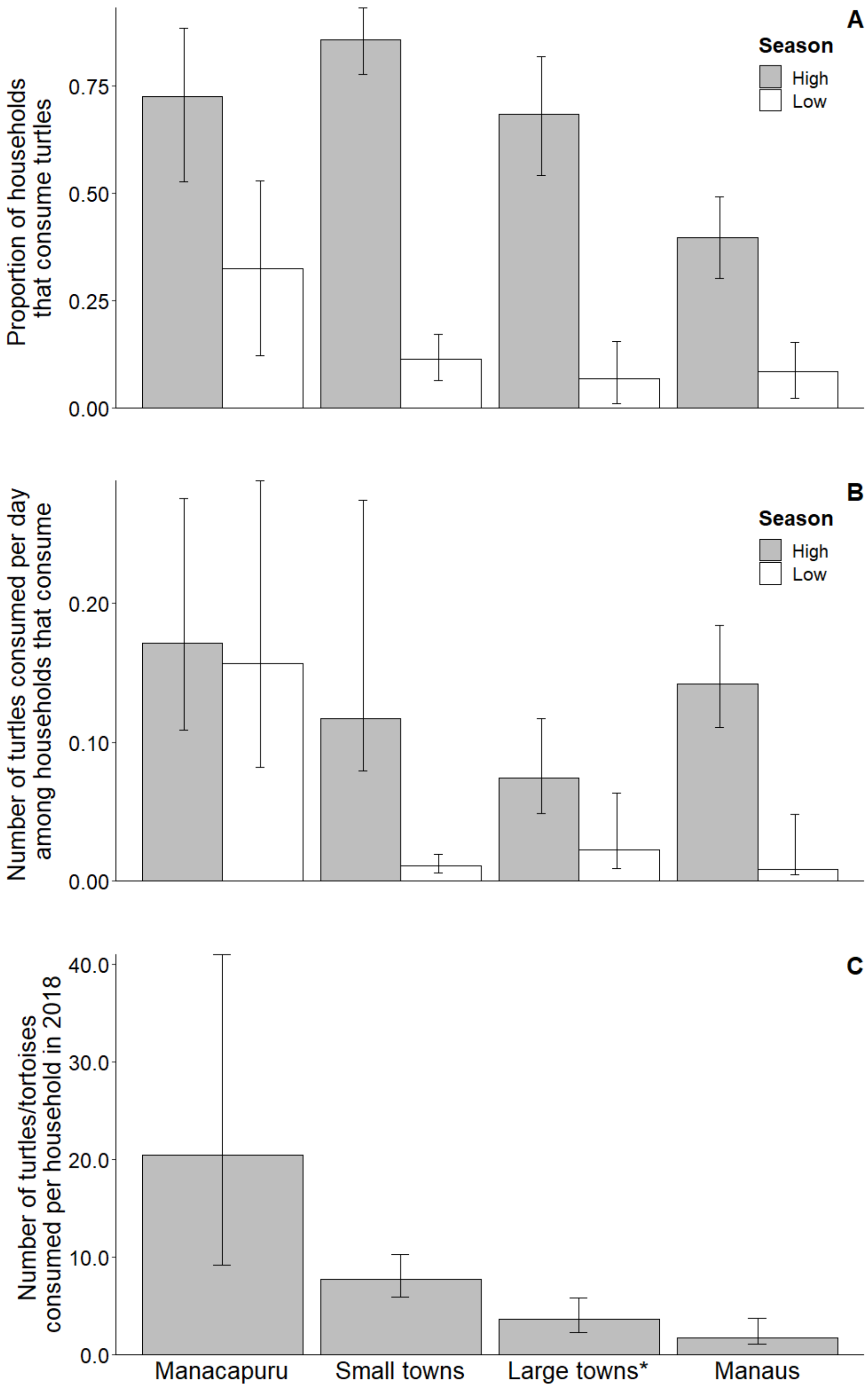

Fig. 3 – Proportion of consumption by all households sampled (**A**), number of turtles consumed among households who consume (**B**), and number of turtles consumed per household per year (**C**). * Large towns other than Manacapuru. Error bars are 95% credible intervals.

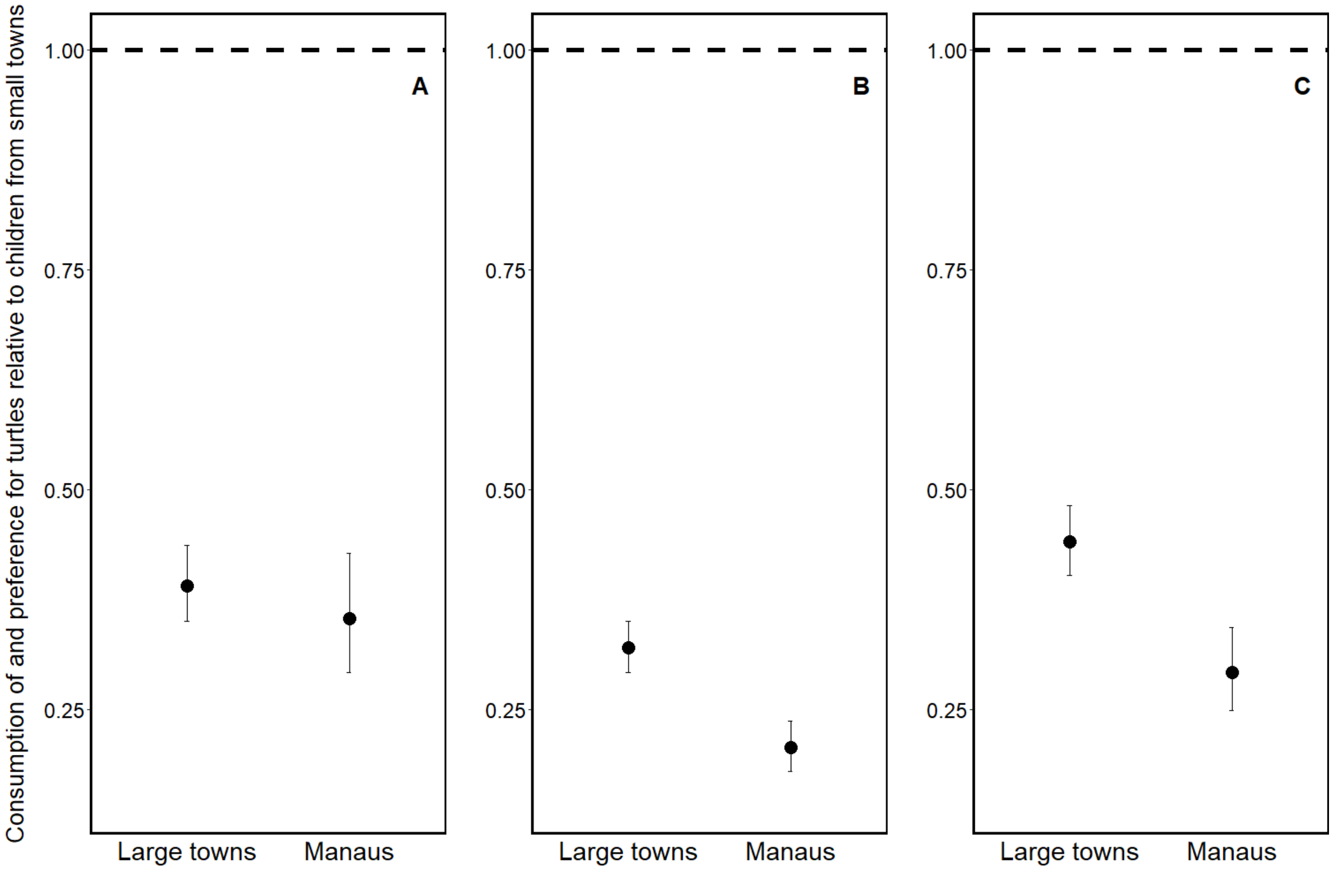

Fig. 4 – Consumption of and preference for turtles. Schoolchildren from large towns and Manaus are compared with schoolchildren from small towns (dashed lines). Probability of consumption the last time turtle/tortoise was available (**A**); probability of consumption when turtles/tortoises are available in a meal (**B**); taste preference for turtles/tortoises (**C**). Error bars are SE.