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Contributed Paper

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

Willandia A. Chaves,[1,2,3] Denis Valle,[4] Aline S. Tavares,[3] Thais Q. Morcatty,[5,6] and David S. Wilcove[1,7]

[1]Princeton School of Public and International Affairs, Princeton University, Robertson Hall, Princeton, NJ, 08544, U.S.A.
[2]Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Cheatham Hall, 310 West Campus Drive, Blacksburg, VA, 24061, U.S.A.
[3]Núcleo de Estudos e Pesquisas das Cidades da Amazônia Brasileira, Universidade Federal do Amazonas, Av. Rodrigo Otávio, 6200, Coroado, Manaus AM. Campus Universitário, Setor Norte, ICHL, NEPECAB, Manaus, 69080–900, Brazil
[4]School of Forest Resources and Conservation, University of Florida, McCarty Hall C, PO Box 110339, Gainesville, FL, 32011, U.S.A.
[5]Oxford Wildlife Trade Research Group, Oxford Brookes University, Headington Campus, Oxford, OX30BP, U.K.
[6]RedeFauna - Rede de Pesquisa em Diversidade, Conservação e Uso da fauna da Amazônia, Brazil
[7]Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ, 08544, U.S.A.

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-to-urban migration. We investigated how rural-to-urban migration, urbanization, and generational change affect the consumption of wild animals. We used chelonian (tortoises and freshwater turtles), one of the most hunted taxa in the Amazon, as a model. We surveyed 1356 households and 2776 school children across 10 urban areas of the Brazilian Amazon (6 small towns, 3 large towns, and Manaus, the largest city in the Amazon Basin) with a randomized response technique and anonymous questionnaires. Urban demand for wild meat (i.e., meat from wild animals) was alarmingly high. Approximately 1.7 million turtles and tortoises were consumed in urban areas of Amazonas during 2018. Consumption rates declined as size of the urban area increased and were greater for adults than children. Furthermore, the longer rural-to-urban migrants lived in urban areas, the lower their consumption rates. These results suggest that wild meat consumption is a rural-related tradition that decreases as urbanization increases and over time after people move to urban areas. However, it is unclear whether the observed decline will be fast enough to conserve hunted species, or whether children's consumption rate will remain the same as they become adults. Thus, conservation actions in urban areas are still needed. 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 results suggest that conservation interventions must target the urban demand for wildlife, especially by focusing on young people and recent rural to urban migrants.
Article impact statement: Amazon urbanite consumption of wildlife is high but decreases with urbanization, over time for rural to urban migrants, and between generations.
Impactos de la Migración del Campo a la Ciudad, la Urbanización y del Cambio Generacional sobre el Consumo de Animales Silvestres en el Amazonas

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

Resumen: Por primera vez en la historia, la población urbana es mayor que la rural. Es muy probable que esta tendencia continúe debido a la migración del campo a la ciudad. Investigamos el efecto de la migración del

email *wchaves@vt.edu*
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campo a la ciudad, la urbanización y el cambio generacional sobre el consumo de animales silvestres. Utilizamos como modelo a los quelonios (tortugas acuáticas y terrestres), uno de los taxa más cazados en el Amazonas. Aplicamos encuestas en 1,356 casas y a 2,776 niños en edad escolar en 10 áreas urbanas de la Amazonía brasileña (6 poblados pequeños, 3 poblados grandes y Manaos, la mayor ciudad en la Cuenca del Amazonas) mediante una técnica de respuesta aleatoria y cuestionarios anónimos. La demanda urbana de carne silvestre (i.e., carne de animales silvestres) fue alarmantemente alta. Aproximadamente 1.7 millones de tortugas acuáticas y terrestres fueron consumidas en áreas urbanas del Amazonas durante 2018. Las tasas de consumo declinaron a medida que incrementó la superficie urbana y fueron mayores en adultos que en niños. Más aun, entre más tiempo viviendo en áreas urbanas, las tasas de consumo fueron menores en los migrantes del campo a la ciudad. Estos resultados sugieren que el consumo de carne silvestre es una tradición rural que disminuye a medida que aumenta la urbanización y el tiempo desde que los habitantes se mueven a la ciudad. Sin embargo, no es claro si la declinación observada será lo suficientemente rápida para conservar a las especies cazadas, o si la tasa de consumo de los niños permanecerá igual cuando sean adultos. Por lo tanto, aun se requieren acciones de conservación en áreas urbanas. Los actuales esfuerzos de conservación en el Amazonas no abordan la demanda urbana de carne de monte y pueden ser insuficientes para asegurar la supervivencia de especies comercializadas ante la urbanización y el crecimiento de la población humana. Nuestros resultados sugieren que las intervenciones de conservación deben atender la demanda de fauna silvestre, con énfasis en los jóvenes y los migrantes recientes.

Palabras Clave: carne de monte, carne silvestre, demanda urbana, éxodo rural, fauna silvestre, técnica de respuesta aleatoria, tortuga acuática, tortuga terrestre

Introduction

For the first time in history, more people live in urban areas than in rural areas; approximately 34% of the human population lived in cities in 1960, whereas >55% lived in cities in 2018 (United-Nations 2018). This trend is likely to continue, driven largely by rural-to-urban migration, and to have far-reaching consequences for biodiversity conservation. Most research to date on the implications of rural-to-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 predict positive consequences stemming from forest regeneration (Izquierdo et al. 2011; Queiroz et al. 2014) on abandoned lands, whereas others predict 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-to-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-to-urban migrants switch their consumption from wildlife to domesticated animals, the result could be an overall reduction in wild meat consumption over time. However, if rural-to-urban migrants continue to consume wild meat at the rates they did when living in the countryside, urban areas could become increasingly important markets for wild meat. Thus, understanding the patterns of urban demand for wild meat in the face of rural-to-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 for eating wild meat could change generationally as a result of urbanization and rural-to-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 wild meat consumption could decrease over time. To our knowledge, how the rural-to-urban population transition affects children's consumption of and preference for the taste of wild meat, 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 & Bennett 2003, 2015; Brashares & Gaynor 2017; Benítez-López et al. 2019). This problem 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.

We assessed how rural-to-urban migration, urbanization, and generational change affect the consumption of wild meat, 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 wild meat consumption because approximately 72% of the human population lived in urban areas in 2010, compared with only 49% in 1980 (IBGE 1980, 2010). We focused on turtles because they are prized and consistently consumed throughout the Amazon, often figuring within the 5 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 did not address the consumption of wild meat by rural residents, a topic that has long attracted attention from scientists (Jerozolimski & Peres 2003; Peres & Palacios 2007; Nunes et al. 2019). Instead, we focused on the consumption of wild meat by urban residents. Wild meat 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-to-urban migration, urbanization, and generational change, affect the demand for wild meat. We assessed 10 urban sites across Amazonas state, the largest state in Brazil, encompassing approximately 25% of the Amazon Basin (>1.5 million km^2 [IBGE 2016]). Our goals were to compare turtle consumption patterns among urban areas of different human population sizes, assess how these consumption patterns change as a function of residency time (for rural-to-urban migrants) and generation time (children vs. adults), and 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: 3 large towns (50,000–70,000 residents) and 6 small towns (<10,000 residents) (Table 1 & Appendix S1). We used the phrase *urban area size* to refer to the size of surveyed areas: 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 Princeton University (approval number 10617). We conducted surveys of turtle consumption in randomly selected households in Manaus (445 households), large towns (312 households, approximately 100/town), and small towns (599 households, approximately 100/town) (1356 total surveys) from December 2018 to March 2019 (see Appendix S2 for detailed sampling design).

Table 1. Data[a] on study sites in Amazonas states, Brazil, where surveys on wild meat consumption were conducted.

Urban area size	*Municipality*	*No. of urban houses*	*Total no. of people*	*No. of urban people*	*No. of rural people*	*Urban people (%)*	*River basin*	*Distance to Manaus (km)[b]*
City	Manaus	458,300	2,145,444	2,123,990	21,454	99	Negro/Amazon	0
Small town	Beruri	1488	15,479	7740	7739	50	Purus	239
Small town	Canutama	1401	12,694	6601	6093	52	Purus	613
Small town	Pauini	1767	17,996	9178	8818	51	Purus	924
Small town	Novo Airão	2072	14,723	9570	5153	65	Negro	117
Small town	SIRN[c]	1206	18,104	6880	11,224	38	Negro	631
Small town	Tonantins	1431	17,044	8863	8181	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] *Census by the Institute for Geography and Statistics of Brazil (2010, 2016). Rural areas include the people outside of the urban areas but that are in the same municipality.*
[b] *Approximate distance based on urban center location of each municipality.*
[c] *Santa Isabel do Rio Negro.*

Most wild meat 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, because wild meat 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 wild meat 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 answer questions honestly 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 nonsensitive, 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 2 pieces with 1 dot and 4 pieces with 2 dots). Without showing us the domino they selected, participants were asked to answer the questions as if we were referring to corn meal if they had selected a domino with 1 dot and turtles if they had selected a domino with 2 dots (Appendix S3). We then asked, "do you consume this item in your house?" This question was followed by "how often do you consume this item in your house?" Options were "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, or season?" We used only the frequency (week, month, and season) that the household had selected in the previous question. We asked the same questions for high- and low-consumption seasons (seasons described below). If 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 1-dot to 2-dot dominoes in the bag and assessed the consumption of the corn meal dish, we were able to calculate the consumption rates of turtles.

We obtained information regarding turtle consumption and 6 socioeconomic factors that we hypothesized were associated with turtle consumption: residency status (depended on whether respondents migrated from rural to urban areas or whether they always lived in an urban area) (Fig. 1); birthplace (i.e., whether the person was born in a large city, such as Manaus, or elsewhere, such as a small town, large town, or rural area); household's poverty probability index (PPI) (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). In addition, we assessed household heads' taste preference for turtles relative to other meat types (from 1, do not like it, to 5, like it a lot). 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.

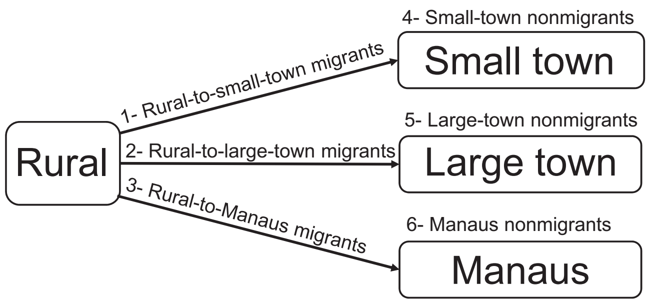

Figure 1. Migration status of Amazonas heads of households participating in the study. Participants in categories 4, 5, and 6 never lived in rural areas (nonmigrants). Residents who migrated from one urban area to another are considered nonmigrants.

The PPI is a well-established poverty measurement. Answers to 10 questions about characteristics and assets of a household are used to compute the probability that the household falls under a country's poverty line (Schreiner 2010). We used the index developed for Brazil (details in Appendix S2). We also considered a quadratic term for PPI to look for a nonlinear relationship with wild meat 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.

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 when the corn is not overly ripe, which is also when river levels are low. We refer to 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. Survey questionnaires are available from https://doi.org/10.7294/JK6J-2Q18.

School Surveys of Children

To assess differences between generations (children vs. adults) with respect to turtle consumption, we surveyed school children 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 4 classrooms and asked the children to complete an anonymous questionnaire (2700 students in

146 classrooms; all with parental consent). Age range of children was 11–18 years.

We collected 3 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, and always), and the child's taste preference for turtle relative to other meat types (from 1, 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 nonmigrants, grade level (middle or high school), and how many people lived in their household. Survey questionnaire is available from https://doi.org/10.7294/JK6J-2Q18.

Analyses of 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. We focused on 2 main response variables: recent consumption (RC) and consumption quantity (CQ).

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

$$\mathrm{RC}_{ic}^{\mathrm{DQ.NS}} \sim \mathrm{Bernoulli}\left(\theta_{ic}^{\mathrm{NS}}\right) \text{ and} \tag{1}$$

$$\theta_{ic}^{\mathrm{NS}} = \frac{\exp\left(\alpha_c^{\mathrm{NS}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{NS}}\right)}{1 + \exp\left(\alpha_c^{\mathrm{NS}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{NS}}\right)}, \tag{2}$$

where α_c^{NS} is an intercept for urban area size, $\mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}$ is a vector with covariates, and $\beta^{\mathbf{NS}}$ is a vector of slope parameters for the nonsensitive item.

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

$$\begin{aligned} p\left(\mathrm{RC}_{ic}^{\mathrm{IQ}}\right) &= p\left(\mathrm{RCP}_{ic}^{\mathrm{IQ}}|\mathrm{SI}\right)\mathrm{p}\left(\mathrm{SI}\right) + p\left(\mathrm{RCP}_{ic}^{\mathrm{IQ}}|\mathrm{NS}\right)p\left(\mathrm{NS}\right) \\ &= \mathrm{Bernoulli}\left(\mathrm{RC}_{ic}^{\mathrm{IQ}}|\theta_{ic}^{\mathrm{SI}}\right)\pi^{\mathrm{SI}} \\ &\quad + \mathrm{Bernoulli}\left(\mathrm{RC}_{ic}^{\mathrm{IQ}}|\theta_{ic}^{\mathrm{NS}}\right)\left(1-\pi^{\mathrm{SI}}\right) \text{ and} \end{aligned} \tag{3}$$

$$\theta_{ic}^{\mathrm{SI}} = \frac{\exp\left(\alpha_c^{\mathrm{SI}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{SI}}\right)}{1 + \exp\left(\alpha_c^{\mathrm{SI}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{SI}}\right)}, \tag{4}$$

where α_c^{SI} is an intercept for urban area size and $\beta^{\mathbf{SI}}$ 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.

We also asked about the quantity (CQ) 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 the consumption of the nonsensitive (NS) item, we relied on a negative-binomial (NB) regression. Specifically, we assumed that the response $\mathrm{CQ}_{ic}^{\mathrm{DQ.NS}}$ for individual i in urban area size c is given by:

$$\mathrm{CQ}_{ic}^{\mathrm{DQ.NS}} \sim \mathrm{NB}\left(\mu_{ic}^{\mathrm{NS}}, n\right), \tag{5}$$

where $\mu_{ic}^{\mathrm{NS}} = \mathrm{E}[\mathrm{CQ}_{ic}^{\mathrm{DQ.NS}}]$ is given by

$$\mu_{ic}^{\mathrm{NS}} = \exp\left(\alpha_c^{\mathrm{NS}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{NS}}\right) D_{ic}^{\mathrm{DQ.NS}}. \tag{6}$$

Here, α_c^{NS} is an intercept for urban area size, $\mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}$ is a vector with covariates, $\beta^{\mathbf{NS}}$ is a vector of slope parameters for the nonsensitive item, and $\mathrm{D}_{ic}^{\mathrm{DQ.NS}}$ is the reference number of days.

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

$$\begin{aligned} p\left(\mathrm{CQ}_{ic}^{\mathrm{IQ}}\right) &= p\left(\mathrm{CQ}_{ic}^{\mathrm{IQ}}|\mathrm{SI}\right)p\left(\mathrm{SI}\right) + p\left(\mathrm{CQ}_{ic}^{\mathrm{IQ}}|\mathrm{NS}\right)p\left(\mathrm{NS}\right) \\ &= \mathrm{NB}\left(\mathrm{CQ}_{ic}^{\mathrm{IQ}}|\mu_{ic}^{\mathrm{SI}}, n\right)\pi^{\mathrm{SI}} + \mathrm{NB}\left(\mathrm{CQ}_{ic}^{\mathrm{IQ}}|\mu_{ic}^{\mathrm{NS}}, n\right) \\ &\quad \left(1-\pi^{\mathrm{SI}}\right) \text{ and} \end{aligned} \tag{7}$$

$$\mu_{ic}^{\mathrm{SI}} = \exp\left(\alpha_c^{\mathrm{SI}} + \mathbf{x}_{\mathbf{ic}}^{\mathbf{T}}\beta^{\mathbf{SI}}\right) D_{ic}^{\mathrm{IQ}}, \tag{8}$$

where α_c^{SI} is an intercept for urban area size, $\beta^{\mathbf{SI}}$ is a vector of slope parameters for the sensitive item (SI), 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.

We used the models for recent consumption and consumption quantity to conduct 2 types of analyses. In the first analysis, we assessed demographic and socioeconomic factors associated with consumption, for which our covariates included residency status (6 categories) (Fig. 1), birthplace (large city vs. elsewhere), number of people in the household, whether the household had children, and PPI. In the second analysis, we assessed how consumption changed as a 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 (1, high season; 0, low season). All continuous variables were standardized (mean = 0 and SD = 1), and there was no collinearity among the variables.

We also 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 models similar 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 a 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 a negative binomial model to estimate the average number of turtles consumed per household per day for each urban area size and season (μ_{cs}^{SI}) based only on participants who consumed turtles in each season. To obtain an estimate of number of turtles consumed for each urban area c, season s, and household i (Y_{ics}), we relied on the law of iterated expectations:

$$E\ [Y_{ics}] = E\left[Y_{ics}|\ Z_{ics} = 1\right] p\left(Z_{ics} = 1\right) + E\left[Y_{ics}|\ Z_{ics} = 0\right] p\left(Z_{ics} = 0\right) = \mu_{cs}^{SI} \times \theta_{cs}^{SI} + 0 \times \left(1 - \theta_{cs}^{SI}\right) = \mu_{cs}^{SI} \times \theta_{cs}^{SI}, \quad (9)$$

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 $D_{hi} \times E[Y_{ic,hi}] + D_{lo} \times E[Y_{ic,lo}]$. 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 and city by multiplying the average annual consumption per household in each urban area size by the total number of households in each town or city.

Analyses of 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 assess how often children consumed turtle meat when it was available in a meal; to assess children's taste preference for turtle relative to other types of meat; and to compare the preferences of children versus heads of households for turtle meat. To do so, we used the function polr in the R package MASS (Venables & Ripley 2002). All analyses were performed in R Studio (R-Core-Team 2014).

Results

Patterns of Rural-to-Urban Migration

The proportion of households containing rural-to-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-to-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-to-urban migrants.

Consumption of Turtles by Households

The 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 1 SD (equivalent of 26.8% change in PPI [Appendix S4]). 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 (Appendix S4).

Rural-to-small-town migrants consumed more turtles than any other groups (rural-to-Manaus migrants, rural-to-large town migrants, Manaus nonmigrants, large-town nonmigrants, and small-town nonmigrants) (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 (Appendix S5).

For rural-to-urban migrants, the odds of consuming turtles were 59% lower as the years the head of that household had spent living in an urban area increased by 1 SD (equivalent to 16.6 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 1 SD (Appendices S6 & S7). Overall, changing priors did not change outcomes.

Seven species of freshwater turtles and 2 tortoises were reported as consumed in our study sites; 7 of them are threatened with extinction (Table 2). Prices reported by 207 households for a turtle averaged US$13.71 (SE 1.09) in small towns, US$46.18 (5.69) in large towns, and

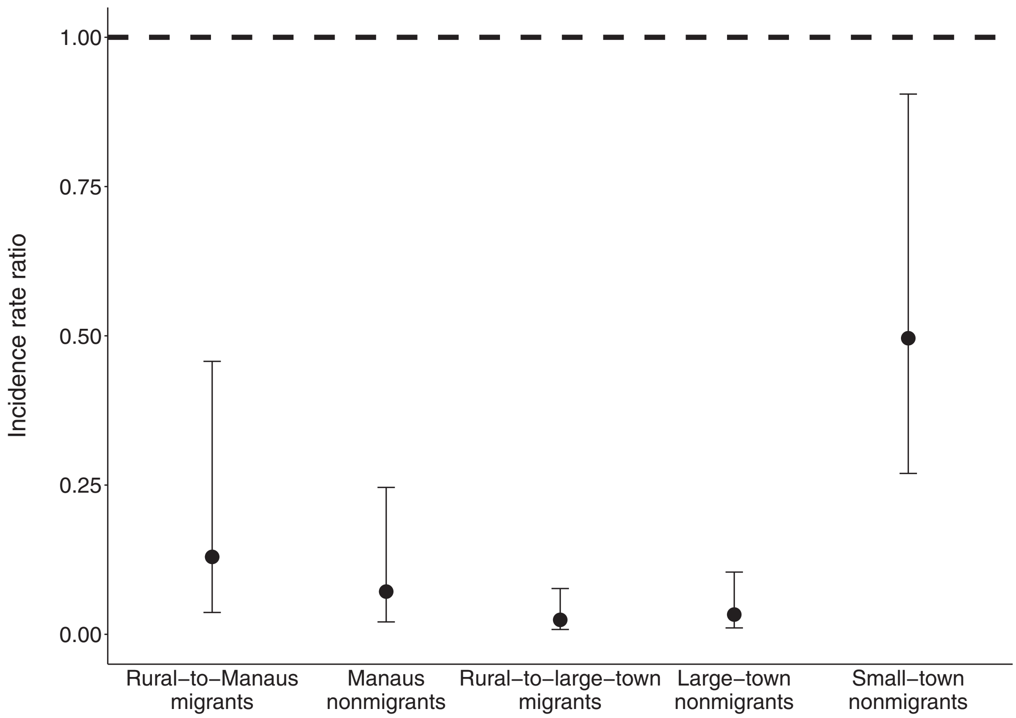

Figure 2. Incidence rate ratio of turtles consumed by Amazonas households (migrants and nonmigrants) compared with the baseline group of rural-to-small-town migrants (dashed line, 95% CI).

US$49.04 (8.21) in Manaus (conversion rate of US$1.00 = 4.15 Brazilian reais) (Appendix S8).

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 season (Fig. 3a & Appendix S9). 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 as urban area size increased (excluding Manacapuru). Estimates of consumption that combined Manacapuru with the other 2 large towns are available in Appendix S2.

Among households that consumed turtles in 2018, the number of individuals consumed per day also varied by urban area size and season (Fig. 3b & Appendix S9). 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 1 month (11 months for low season), whereas the median length of the high season for the other towns was 2 months (10 months for low season). We used these medians to estimate the number of turtles consumed per household per year (Fig. 3c & Appendix S9).

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 (Appendix S10). Based on these extrapolations, the number of turtles consumed in 2018 in urban areas across Amazonas state was approximately 1.7 million (95% credible interval [CI] 1.0, 3.3). Manaus accounted for >40% of that consumption (approximately 792 thousands per year [95% CI 507,000, 1.7 million]), and Manacapuru accounted for approximately 15% (approximately 267,000 per year [95% CI 119,000, 535,000). The combined consumption of the remaining 60 towns was approximately 709,000 turtles (95% CI 455,000, 1.12 million). We also provided 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 Appendix S10.

Consumption of Turtles by School Children

Urban area size, birthplace (Manaus vs. elsewhere), and whether children were rural-to-urban migrants were important predictors of turtle consumption and taste preference among school children. Compared with children who lived in small towns, children who lived in large

Table 2. Species listed as consumed among survey respondents who openly stated there was consumption of turtles in their household.

Scientific name	Common name	Conservation status[a]	No. of households reporting consumption: small towns	large towns	Manaus	Total consumed per species
Chelonoidis spp."/>	Tortoise	near threatened or vulnerable	154	19	12	185
Chelus fimbriata	Matamata	least concern	11	1	0	12
Rhinoclemmys punctularia	spot-legged wood turtle	vulnerable	6	0	0	6
Peltocephalus dumerilianus	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] *Conservation status from International Union for Conservation of Nature Tortoise and Freshwater Turtle Specialist Group 2011 (Rhodin et al. 2017).*
[b] Chelonoidis carbonarius *and* Chelonoidis denticulatus.

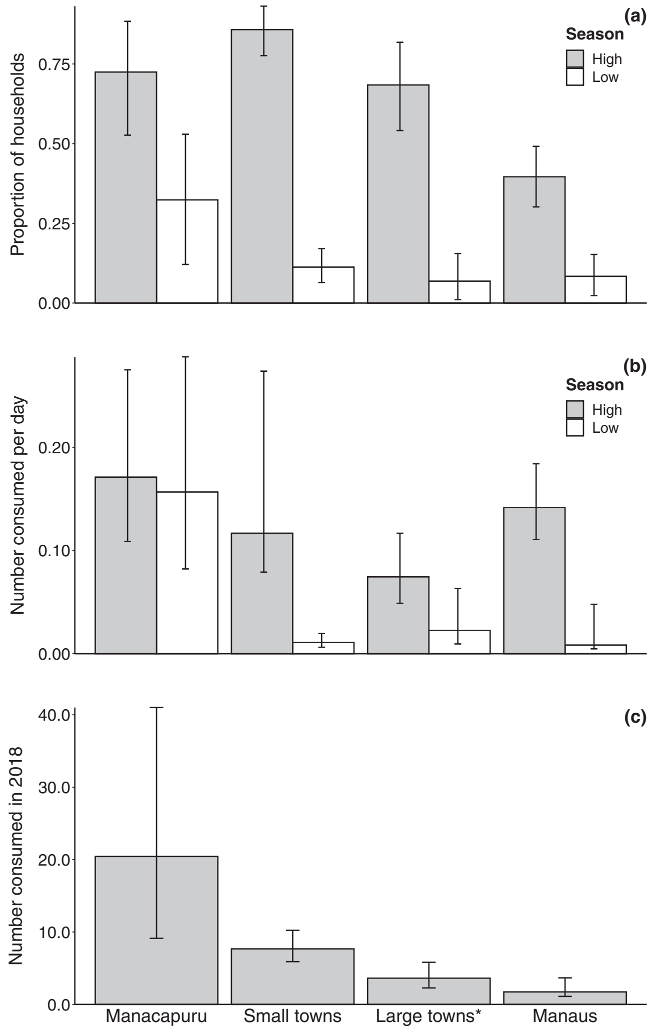

Figure 3. For sampled households in Amazonas urban areas, (a) proportion in which turtles are consumed, (b) number of turtles consumed among households that consume turtles, and (c) number of turtles consumed per household in 2018 (∗, not including Manacapuru; error bars, 95% CI).

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 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-to-urban migrant children were more likely to consume turtles and had a higher taste preference for turtle meat than did nonmigrant children. Compared with children who had never lived in a rural area,

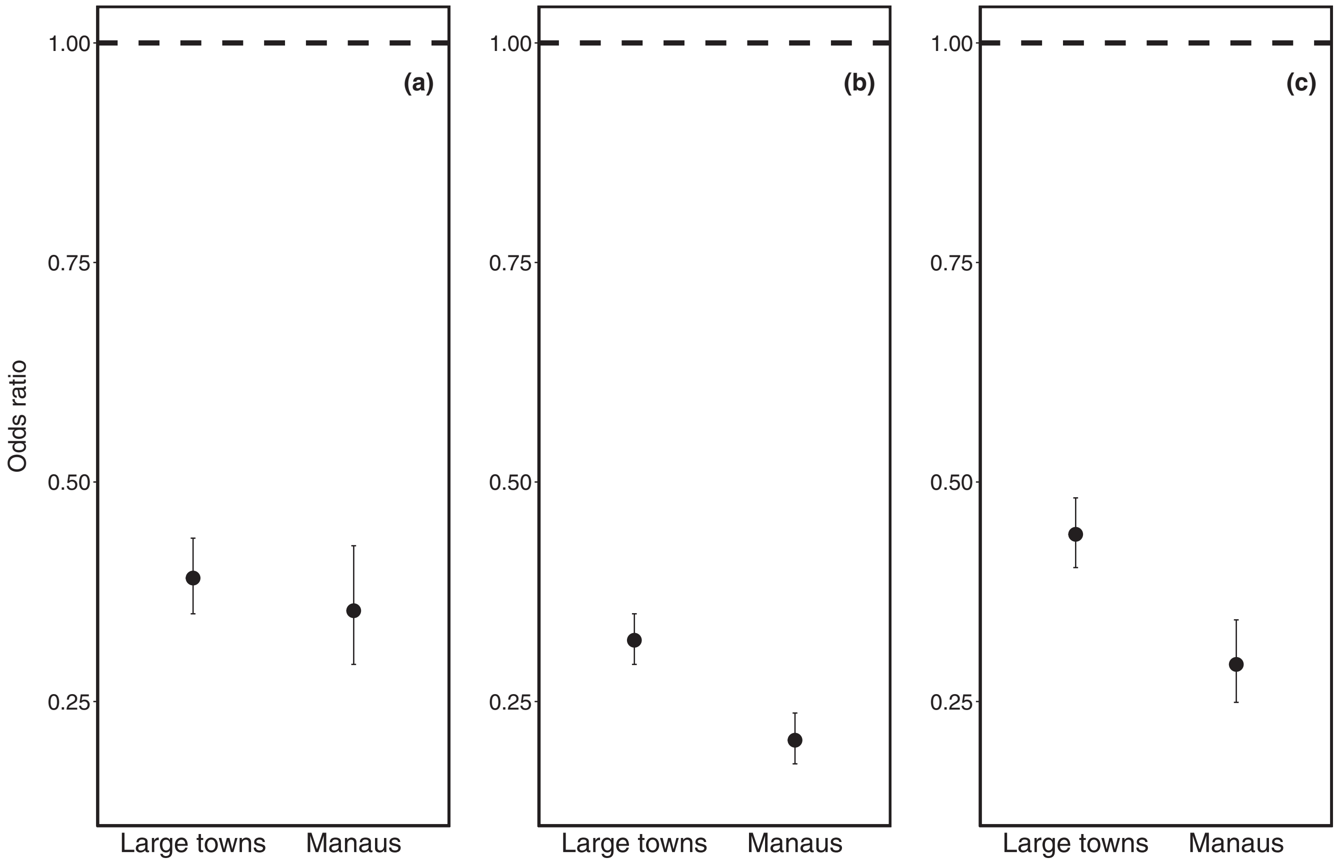

Figure 4. Odds ratio of children's consumption of and preference for turtles in large towns and Manaus compared with the baseline group of children from small towns (dashed lines): (a) consumption the last time a turtle or tortoise was available; (b) consumption when turtles and tortoises are served at a meal; and (c) taste preference for turtles or tortoises (error bars, SE).

children who were rural-to-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 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 (Appendix S11). We did not detect an effect of school grade (middle vs. high school) and number of people in the household on the odds of consuming turtles. Importantly, when comparing children and household heads, school children exhibited a 19% lower taste preference for turtles (OR = 0.81, $p<0.0001$) (Appendix S12).

Discussion

Effect of Rural-to-Urban Migration and Urbanization on Turtle Consumption

Almost all research to date on the worldwide phenomenon of people leaving rural areas for urban areas has focused on issues related to land-use change. Largely ignored has been the question of how consumption of wild animals will change as countries become increasingly urbanized. Focusing on the consumption of threatened turtles in the Brazilian Amazon, we found that rural-to-urban migration, the size of the urban area into which people move, and generation (adults vs. children) all affect the rate at which people consume wild animals.

The consumption decline observed with increase in urban area size may 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 a greater rural influence in small towns than in cities, 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; residents living within the town may 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-to-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 wild meat 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 (Appendix 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 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 wild-meat 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 children and to foster their connection with nature may have long-term payoffs if such efforts maintain or increase the generational difference that already exists regarding wild meat consumption 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 (Freitas et al. 2020). None of these efforts, however, address urban demand. For instance, the Brazilian Amazon has community-engagement programs aimed at both protecting nesting beaches for river turtles and artificially increasing hatchling survival, with positive outcomes for some species and regions (Campos-Silva et al. 2018; Eisemberg et al. 2019). Other notably consumed species that may be unsustainably harvested and highly traded in urban centers, such as *Chelonoidis denticulatus*, *Chelonoidis carbonarius*, and *P. dumerilianus*, are not included in any conservation program (see Morcatty & Valsechhi 2015). Conservation efforts aimed at reducing overall demand for turtles in urban areas are still needed.

Although 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, because poverty was associated with a lower probability of consuming turtles (a pattern consistent with other research showing an increase in consumption of wild meat 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 & Bennett 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 wild meat, 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 wild meat consumption. Whether the observed decline in wild meat consumption between generations and with time spent in urban areas will significantly reduce the absolute consumption remains to be seen.

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Supporting Information

Additional information is available online in the Supporting Information section at the end of the online article. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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