

Drivers of hunting in the savannahs of Amapá: implications for conservation

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Abstract Although overhunting is amongst the main threats to biodiversity, wild meat is culturally and nutritionally important for many communities. Conservation initiatives should therefore address the drivers of hunting, rather than its practice alone. Here we gathered information from structured interviews with 68 local households to assess the drivers of hunting in a highly threatened Amazonian savannah complex, the Cerrado of Amapá in Brazil. We used regression models to evaluate the influence of socio-economic parameters and spatial variables on hunting prevalence and frequency. The only identified driver of hunting prevalence was forest cover, whereas five variables had significant effects on hunting frequency. The positive effect of forest cover and the negative effect of hunter's age on hunting frequency suggest that logistical and physical feasibility are important drivers of hunting frequency. Furthermore, we suggest that the negative effect of distance to urban centres may be related to the profitability of hunting. We base this on the negative effect of river length in the vicinity of households and per capita monthly income on hunting frequency, which corroborates the tendency of hunting frequency to decrease when alternatives to wild meat are more readily available. We argue that to reduce unsustainable hunting it is necessary both to raise awareness amongst local communities and involve them in the creation of management plans that conserve biodiversity and meet economic and social needs.

Keywords Amazon, Amazonian savannah, bushmeat, Cerrado of Amapá, commercial hunting, game species, subsistence hunting, wild meat

Introduction

Overexploitation of natural resources and expansion of agriculture are the main threats to biodiversity (Maxwell et al., 2016). Hunting is an important driver of

the growing global biodiversity crisis (Ripple et al., 2016): in the tropics, densities of mammal populations, which are the primary targets, have declined by a mean of 83% in areas subject to hunting (Benítez-López et al., 2017).

The conservation of game species relies not only on the quantification of hunting intensity but also on the understanding of its drivers (Torres et al., 2017). There are several determinants of hunting pressure in a region, including cultural background (Fa et al., 2003) and factors related to food security and subsistence of communities (Brashares et al., 2004; Damania et al., 2005). Ultimately, however, hunting is limited by prey availability (Fa et al., 2003, 2014).

The vertebrates of the Amazon have been hunted for at least 11,200 years, since the arrival of the first Paleoindians in the region (Roosevelt et al., 1996). However, human settlements in the Amazon have changed through time, with an increasing total population size and diversity of settlement types (e.g. Indigenous tribes, settler communities, urban areas). In Brazil, traditional communities are defined by specific characteristics, among which is that they 'occupy and use natural territories and resources as a condition for their cultural, social, religious, ancestral and economic reproduction' (Decree no. 6,040, 7 February 2007). Extraction of natural resources, including subsistence hunting, is thus often a key feature of the livelihood and culture of traditional communities.

Data limitations hinder our ability to determine whether subsistence hunting in the Amazon is sustainable (Fragoso et al., 2016). However, even low levels of hunting can lead to drastic declines of hunted populations in tropical forests (Peres, 1997). Interventions to conserve game species in regions with subsistence hunting should address the local drivers of hunting and aim to diminish the dependency of local communities on wild meat and/or change their hunting profile towards less sensitive, non-threatened species (Bodmer et al., 1997; Damania et al., 2005; Torres et al., 2017).

Here we assessed the socio-economic and spatial drivers of hunting in the south-eastern Cerrado of Amapá, the fourth largest savannah complex in the Amazon (Carvalho & Mustin, 2017). We discuss the link between food security, local knowledge and the conservation of game species. We used the mean number of hunting trips per month to estimate hunting frequency, and the proportion of households with at least one hunter as an estimate of prevalence (related to the number of active hunters in the

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region). We tested six hypotheses regarding the effect of various socio-economic and spatial variables on hunting prevalence and frequency. (1) Hunting frequency and prevalence are positively associated with forest cover in the vicinity of households, as this variable reflects greater availability of prey and ease of access to hunting areas (Sampaio et al., 2010). (2) Greater distance to urban centres positively affects hunting frequency and prevalence, because alternative sources of food and income are more readily available near urban centres, and the commercial use of wild meat is illegal in Brazil (Dias Junior et al., 2014). (3) Plenitude of rivers surrounding the households has a negative effect on hunting frequency and prevalence because it probably increases access to alternative sources of animal protein (fish), decreasing the dependency on wild meat. (4) Hunting frequency and prevalence are higher in traditional vs settler communities, given the historical and cultural importance of this resource for traditional people. (5) The per capita monthly income and number of residents in the household have negative and positive effects on the frequency of hunting, respectively, because these variables may be associated with the dependency on wild meat for nutrition. (6) Hunting frequency is negatively related to the age of hunters because hunting is a physical activity expected to be more challenging for older hunters.

Study area

The state of Amapá, in the north-east of the Amazon region, has a Köppen's Am climate with a rainy season during December–July (IEPA, 2008; Alvares et al., 2013). The biodiversity of the 10,021 km² savannah region, known as the Cerrado of Amapá (Hilário et al., 2017) is still poorly known but includes endemic plant species and several species of fish, birds and mammals that have restricted distributions and/or are threatened (Mustin et al., 2017). Only c. 9% of the Cerrado of Amapá is legally protected and 0.4% (40.2 km²) is within strictly protected areas (Hilário et al., 2017).

The Cerrado of Amapá is characterized by open woodlands with a dense layer of herbaceous plants and shrubs. Landscape features include gallery forests, patches of *buriti* palms *Mauritia flexuosa*, flooded fields and forest patches within predominantly open formations and plantations (IEPA, 2008; Mustin et al., 2017). Our study area was the south-eastern Cerrado of Amapá (Fig. 1). This is the most densely populated area of the state, containing the largest urban centres, the highest density of roads and expanding soybean plantations (Hilário et al., 2017; Mustin et al., 2017).

Our study focused on the rural communities in the savannah region of two major municipalities, Macapá and Santana. This region comprised > 260,000 ha and a human population of c. 5,050 inhabitants in 1,154 households at the time of the last population census in 2010 (Fig. 1;

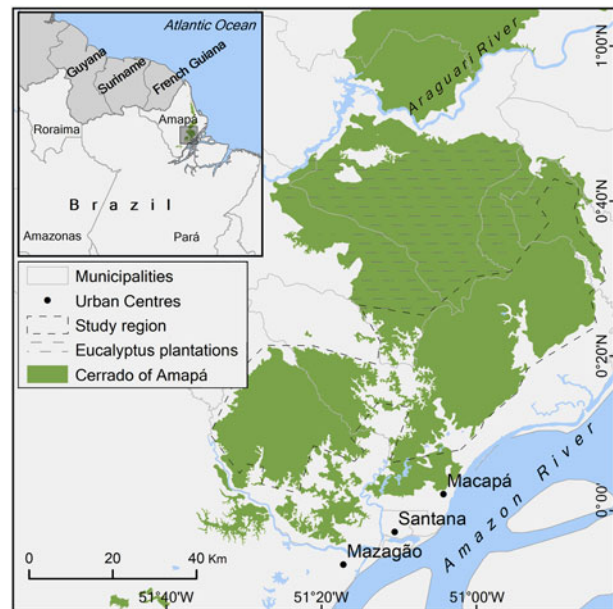


FIG. 1 The south-eastern Cerrado of Amapá, an Amazonian savannah complex in Brazil, showing the study area where we interviewed 68 households to assess hunting activities and socio-economic parameters.

IBGE, 2010). The majority of the traditional communities founded by people of African descent who escaped from slavery in the state of Amapá occurs in this region (Hilário et al., 2017).

Methods

Sampling design

We conducted structured interviews with representatives of 72 households (6% of the total) in the study region (Fig. 1) during February–March 2018. Using the sample size calculation for random sampling without replacement (Cochran, 1977), the most conservative optimal sample sizes (with a predicted proportion of households with hunters of 50%) were estimated to be 64 and 288 households, with an absolute error (δ) of 0.1 and 0.05, for a 90% and a 95% confidence interval (CI), respectively. Therefore, our sample size may furnish reliable estimates for hunting frequency within a 90% CI. For the prevalence of hunting our sample size may provide estimates close to a 95% CI as we used information on 223 households regarding the presence or absence of active hunters. SMS and BRCR had met 36 of the 72 interviewees during a separate study in October 2017 (S.M. Silvestre, B.R. Calle-Rendón, J.J. Toledo, R.R. Hilário, unpubl. data). At that time, those households were selected because they were located near forest patches related to that investigation. Considering the openness with which the interviewees talked about hunting in the region, despite

this frequently constituting an illegal activity, we deemed it unnecessary to use an indirect research approach such as the quantitative randomised response technique (Conteh et al., 2015).

We hired local assistants to facilitate the communication between researchers and local people. They helped explain the objectives of the research to the participants and confirmed that it did not constitute surveillance, thereby establishing a trusting relationship. Local assistants were selected based on two main characteristics: expertise in hunting and their good reputation within the local communities. Local assistants also indicated 36 additional hunters/households to be interviewed. We evaluated the reliability of the interviews based on the interviewees' behaviour, and discarded four of them because of contradictory responses and signs of scepticism or mistrust from the interviewees.

Interviews

We conducted interviews with the head of the family or with one of the hunters. Before each interview we informed participants about the study objectives, that their participation was voluntary and that information provided would be used anonymously and strictly for scientific purposes. After verbal consent was given, we conducted the interviews using an informal approach, in the form of a conversation between two researchers, one local assistant and the interviewee. During this conversation, the researchers sought the answers to six questions: (1) age of the interviewee, (2) monthly household income, (3) number of people (including children) in the household, (4) type of community (traditional or settlers), (5) number of households amongst the four nearest houses with at least one hunter, and (6) hunting frequency (days per month) of the interviewee (or the hunter of the household).

Variables

We estimated the total proportion of households with at least one hunter based on the information provided by interviewees regarding the presence of hunters in the four nearest neighbouring households. Some of the households visited had fewer than four neighbours; in those cases we based the estimate on the number of neighbours present. Because we asked local assistants to indicate other hunters to be interviewed, we did not include the interviewee households themselves in the calculation of hunting prevalence, to avoid sampling biases.

When the interviewee provided different estimates of hunting days per month (hunting frequency) for the rainy and dry seasons, we computed the weighted average of the estimates based on a rainy season of 8 months (IEPA, 2008).

Frequencies were rounded to the nearest integer and used as count data.

We converted monthly income data to per capita monthly income, dividing the total monthly household income by the number of household residents. Spatial variables were extracted from Landsat 8 satellite imagery (scenes: 225/60 from 2015 and 226/59 and 226/60 from 2016). We calculated forest cover and the length of rivers within a 1, 2 and 5 km buffer radius around each household.

To estimate the forest cover we categorized the satellite images as forest or non-forest, based on the normalized difference vegetation index (scientific output; threshold = 0.7). We computed the total length of rivers within the three buffers around each household, based on the drainage shapefile of the state (IBGE, 2015).

We calculated the travel distances via roads from households to the nearest urban centre (defined as having a population > 10,000) using satellite imagery from *Google Earth Pro 7.3.2.5491* (Google, Mountain View, USA). Urban centres in the study region were the state capital Macapá (474,706 inhabitants) and the cities of Santana (115,471 inhabitants) and Mazagão (20,387 inhabitants; IBGE, 2017). All spatial variables were extracted using *ArcGIS 10.5* (Esri, Redlands, USA).

Data analyses

We used *R 3.4.3* for all analyses (R Core Team, 2017). We used simple regression models to test the relationship between our response variables, forest cover and total river length in three buffers sizes (1, 2 and 5 km radius), to select the scale in which the relationship is strongest (e.g. Fahrig, 2013). Based on the significance levels and AICc (Akaike information criterion corrected for small sample size) values, we chose the buffers with a 5 km radius for both forest cover and river length.

We first applied a binomial generalized linear model to assess the influence of the independent variables (forest cover, river length, distance to the nearest urban centre and type of community) on the number of hunters. However, because the model showed overdispersion, we changed it to a quasi-generalized linear model (Zuur et al., 2009). The number of neighbours considered for each proportion estimate was the weight argument. The optimal model was selected through a backwards stepwise selection, based on the lowest QAICc (quasi-AICc) and best fit of the data (Zuur et al., 2009). We used the *R* package *MuMIn* to calculate the QAICc (Barton, 2018).

We used zero-inflated negative binomial models to assess the influence of the independent variables (hunter age, per capita monthly income, number of residents, forest cover, river length, distance to the nearest urban centre and type of community) on hunting frequency. This model was used

to address overdispersion caused by the high frequency of zeros in the data (Zuur et al., 2009). The optimal model was selected based on the lowest AICc and best fit of the data, as indicated by the *model.avg* function in the *R* package *MuMIn* (Barton, 2018). The zero-inflated negative binomial models were created using the *R* package *pscl* (Jackman, 2017).

We tested the residuals of all models for spatial autocorrelation using variograms, created using the *R* packages *gstat* (Pebesma, 2004) and *sp* (Pebesma & Bivand, 2005; Bivand et al., 2013). The variograms showed no spatial autocorrelation in the model residuals. We calculated the variance inflation factors, using the *R* package *car* (Fox & Weisberg, 2011), to detect problems with multicollinearity. None of the variables had variance inflation factors > 3, so we kept all variables in the analyses (Zuur et al., 2009).

Results

With interviewees indicating the presence of hunters in neighbouring households, we obtained information about 223 households, of which 111 (49.8%) had at least one hunter. This proportion was different from the mean because not all interviewees had four neighbours (Table 1).

The optimal quasi-generalized linear model selected to explain the drivers of hunting prevalence included only forest cover, which had a positive effect on the proportion of households with hunters ($t = 2.60$; $P = 0.0117$; Fig. 2a).

The optimal zero-inflated negative binomial model selected to predict hunting frequency included five independent variables (Table 2). Forest cover was the only variable positively associated with hunting frequency (Fig. 2b). Hunting frequency decreased with increasing river length (Fig. 2c), distance to the nearest urban centre (Fig. 2d), log per capita monthly income (Fig. 2e), and hunter's age (Fig. 2f).

Our results corroborated the hypothesized positive effect of forest cover on hunting frequency and prevalence, as well as the negative influence of length of rivers, hunter's age and income per capita on hunting frequency. However, we did not find evidence to support any significant effects of distance to urban centre, length of rivers or type of community on hunter prevalence, nor of type of community and number of residents in the household on hunting frequency. Furthermore, and contrary to our hypothesis, we found evidence of a negative effect of distance to urban centres on hunting frequency.

Discussion

Spatial and socio-economic drivers of hunting

Forest cover is positively associated with the presence and abundance of game species (Sampaio et al., 2010). It has

TABLE 1 Summary of the variables used on the regression models to assess the socio-economic and spatial drivers hunting prevalence and frequency in the south-eastern region of the Cerrado of Amapá, in the state of Amapá, Brazil.

Variable	Mean \pm SD	Range
Hunting trips per month	2.16 \pm 3.63	0–16.7
Proportion of households with hunters	0.53 \pm 0.37	0–1
Age of hunters (years)	43.82 \pm 14.90	19–77
Forest cover (km ²)	19.50 \pm 10.59	3.4–42
Total river length (km)	48.34 \pm 11.70	22.1–72.8
Per capita monthly income (USD) ¹	152.37 \pm 137.77	13.5–711.7
Number of household residents	4.46 \pm 2.52	1–14
Distance to urban centre (km)	40.51 \pm 24.67	1.5–80.6
Number of neighbours considered ²	3.38 \pm 0.99	0–4

¹Conversion rate: BRL 1.00 = USD 0.27.

²Used to calculate the proportion of neighbouring households with at least one hunter (maximum 4).

been suggested as the main driver of hunting probability in some regions (Torres et al., 2017). Hunting and the consumption of wild meat are an important aspect of the livelihoods of many rural communities, particularly in Amazonia (Nasi et al., 2008). As expected a large proportion (c. 50%) of households in the study sample had at least one resident hunter. Forest cover was the only driver of hunter prevalence in our optimal model, corroborating our hypothesis that greater availability of forest would increase the prevalence of hunters.

In contrast, we found hunting frequency was influenced by five independent variables. Forest cover was again positively associated, but the age of the hunters was the main factor affecting hunting frequency in our sample. The negative effect of this variable is probably a reflection of the physical requirements of hunting trips, which may be more challenging for older hunters. Along with the positive effect of forest cover, it is the physical and logistic feasibility that primarily regulates hunting frequency.

Distance to urban centres, per capita monthly income and length of rivers, which could be associated with factors such as market demand for wild meat or accessibility/availability of alternative food sources, had greater influence on the frequency of hunting than on the number of hunters.

The overall effects of forest cover, per capita monthly income and length of rivers on hunting frequency corroborated our hypothesis that decreasing dependency on wild meat for nutrition would decrease hunting frequency. The effect of distance to urban centres, however, was contrary to our expectations. We predicted that greater distance to urban centres would have a positive effect on hunting frequency because communities that are more isolated are probably more dependent on wild meat for subsistence as domesticated meat is less available, and because we expected subsistence hunting (rather than commercial hunting) to

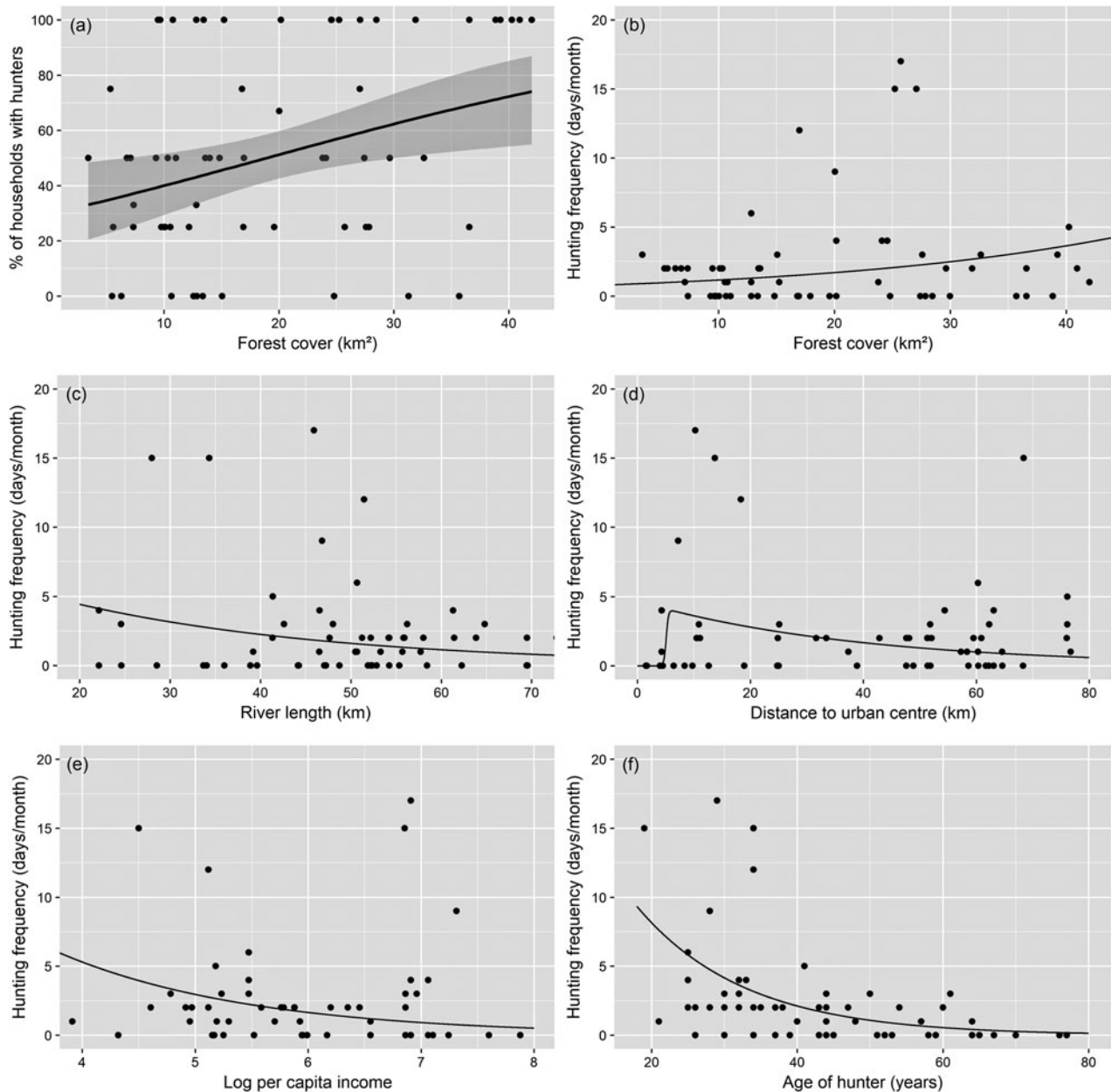


FIG. 2 Socio-economic and spatial drivers of hunting in the south-eastern Cerrado of Amapá, Amapá, Brazil. (a) Relationship between proportion of households with hunters and forest cover within a 5 km radius buffer, as described by a quasi-generalized linear model, with binomial distribution, and the 95% confidence interval in dark grey. Relationships between estimated mean number of hunting trips per month and (b) forest cover within 5 km buffer, (c) river length within 5 km buffer, (d) distance to the nearest urban centre, (e) log per capita monthly income, and (f) age of hunter, as described by a zero-inflated negative binomial model.

be the prevalent type of hunting in the study region. The dependence of isolated communities on wild meat for subsistence is supported by the observed negative effects of river length and per capita monthly income on hunting frequency. However, the fact that hunting occurs more frequently near urban areas suggests that commercial hunting may be more prevalent than we expected.

Urban populations can create a high demand for wild meat and play a key role in the overexploitation of game species (Milner-Gulland & Bennett, 2003). Higher levels

of hunting near urban centres are expected when this proximity increases the demand for wild meat as a result of greater human population density or the intensification of commercial hunting (Damania et al., 2005; Pangau-Adam et al., 2012; Torres et al., 2017). We therefore suggest that the observed higher frequency of hunting near urban centres is related to the role of wild meat as a source of income in the region.

In contrast, presence of rivers is an unambiguous measure of the availability of an alternative source of animal

TABLE 2 Count model coefficients of the zero-inflated negative binomial model assessing the drivers of hunting frequency in the Cerrado of Amapá, Amapá, Brazil.

Variable	Estimate \pm SE	Z	P ($>$ z)
Age of hunters	-0.0674 \pm 0.0106	-6.35	< 0.0001
Forest cover	0.0379 \pm 0.0133	2.84	0.0045
River availability	-0.0338 \pm 0.0114	-2.96	0.0030
Distance to urban centre	-0.0257 \pm 0.0066	-3.87	0.0001
Log per capita monthly income	-0.5847 \pm 0.1784	-3.28	0.0010

protein and is intrinsically related to the dependency of the local human population on wild meat for nutrition (Saffirio & Scaglione, 1982). Fish is one of the main sources of animal protein for rural communities in the Amazon (e.g. Passos et al., 2008). As we predicted, hunting frequency was lower when there were a greater number of rivers in the vicinity of households.

Implications for conservation

Increasing cattle farming or wages paid to local workers could decrease illegal hunting in some regions (Moro et al., 2013). The availability of an alternative to wild meat may thus reduce hunting in the Cerrado of Amapá. However, given that pasture expansion is the predominant driver of deforestation in the Amazon (Barona et al., 2010), support for the local production of chickens or small-scale fish farming could be effective strategies to reduce hunting, while also avoiding an increase in local deforestation. In contrast, we expect that reduced fishery resources would increase hunting activity. Soybean plantations in the region increased by $>$ 200% during 2013–2016 (Hilário et al., 2017) and Brazil is the country with the third highest annual consumption of pesticides worldwide (FAO, 2019) and pesticides used on soybean plantations could negatively affect local fish communities (Ullah et al., 2018). Soybean expansion in the region could therefore indirectly contribute to an increase in hunting frequency.

Trade in wild meat plays a key role in the impact of hunting on global biodiversity (Benítez-López et al., 2017). Investments in hunting equipment may be covered by the sale of wild meat and hunting quotas tend to increase when economic profit is generated (Altherr, 2007). Most types of hunting, and wild meat trade, are prohibited in Brazil (Law no. 5,197, 3 January 1967). However, subsistence hunting may be legal in some circumstances, including where it is necessary to provide food for the hunter and their family, and in traditional communities within their territories (Law no. 6,001, 19 December 1973; Law no. 9,605, 12 February, 1998). This means that in legal terms there are two potential solutions: the maintenance of the prohibition with stricter enforcement, or the regulation of professional hunting, aiming to sustainably manage this resource.

Rigorous law enforcement alone is often not able to prevent illegal hunting in large areas. It may also affect hunters differentially based on their wealth, deterring mostly poorer hunters who are probably more dependent on wild meat for subsistence (Moro et al., 2013). Wide support from community leaders for a ban on wild meat trade may be attained by education programmes, which could raise awareness of the threats of overexploitation to the native fauna and the livelihoods of local communities, and the benefits that the change could yield (Nasi et al., 2008). In this context, encouraging the formation of local councils dedicated to the participatory creation of management plans could be a powerful tool to empower local communities towards making more sustainable decisions regarding the use of local wildlife. The implementation of those actions relies on further research that should focus on four main topics: (1) quantifying hunting pressure in local rural communities, (2) assessing the status of the main targeted game species in the region, (3) assessing the potential for sustainable economic activities in the region and (4) quantifying hunting pressure originating in the urban centres, including hunting prevalence and frequency and the trade of wild meat.

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Author contributions Study design: SMS, BRCC, RRH; fieldwork: SMS, BRCC; data analysis: SMS, RRH; writing: all authors.

Conflicts of interest None.

Ethical standards The research abided by the *Oryx* guidelines on ethical standards. All methods complied with the Brazilian legal requirements for research involving human subjects and were approved by the ethics committee of Universidade Federal do Amapá.

References

- ALTHERR, S. (2007) *Going to Pot: the Neotropical Bushmeat Crisis and its Impact on Primate Populations*. Care for the Wild and Pro Wildlife, Kingsfold, UK.
- ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., DE MORAES, G., LEONARDO, J. & SPAROVEK, G. (2013) Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22, 711–728.
- BARONA, E., RAMANKUTTY, N., HYMAN, G. & COOMES, O.T. (2010) The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters*, 5, 024002.
- BARTON, K. (2018) *MuMIn: Multi-Model Inference*. R package version 1.40.4. cran.r-project.org/web/packages/MuMIn/MuMIn.pdf [accessed 4 July 2019].
- BENÍTEZ-LÓPEZ, A., ALKEMADE, R., SCHIPPER, A.M., INGRAM, D.J., VERWEIJ, P.A., EIKELBOOM, J.A.J. & HUIJBREGTS, M.A.J. (2017) The impact of hunting on tropical mammal and bird populations. *Science*, 356, 180–183.
- BIVAND, R.S., PEBESMA, E.J. & GÓMEZ-RUBIO, V. (2013) *Applied Spatial Data Analysis with R*. 2nd edition. Springer, New York, USA.

- BODMER, R.E., EISENBERG, J.F. & REDFORD, K.H. (1997) Hunting and the likelihood of extinction of Amazonian mammals. *Conservation Biology*, 11, 460–466.
- BRASHARES, J.S., ARCESE, P., SAM, M.K., COPPOLILLO, P.B., SINCLAIR, A.R. & BALMFORD, A. (2004) Bushmeat hunting, wildlife declines, and fish supply in West Africa. *Science*, 306, 1180–1183.
- CARVALHO, W.D. & MUSTIN, K. (2017) The highly threatened and little known Amazonian savannahs. *Nature Ecology & Evolution*, 1, 0100.
- COCHRAN, W.G. (1977) *Sampling Techniques*. 3rd edition. John Wiley & Sons, New York, USA.
- CONTEH, A., GAVIN, M.C. & SOLOMON, J. (2015) Quantifying illegal hunting: a novel application of the quantitative randomised response technique. *Biological Conservation*, 189, 16–23.
- DAMANIA, R., MILNER-GULLAND, E.J. & CROOKES, D.J. (2005) A bioeconomic analysis of bushmeat hunting. *Proceedings of the Royal Society of London B: Biological Sciences*, 272, 259–266.
- DIAS JUNIOR, M.B.F., CUNHA, H.F.A. & DE CASTRO DIAS, T.C.A. (2014) Caracterização das apreensões de fauna silvestre no estado do Amapá, Amazônia oriental, Brasil. *Biota Amazônia (Biota Amazonie, Biota Amazonia, Amazonian Biota)*, 4, 65–73.
- FA, J.E., CURRIE, D. & MEEUWIG, J. (2003) Bushmeat and food security in the Congo Basin: linkages between wildlife and people's future. *Environmental Conservation*, 30, 71–78.
- FA, J.E., FARFÁN, M.A., MARQUEZ, A.L., DUARTE, J., NACKONEY, J., HALL, A.M.Y. et al. (2014) Mapping hotspots of threatened species traded in bushmeat markets in the Cross-Sanaga Rivers Region. *Conservation Biology*, 28, 224–233.
- FAHRIG, L. (2013) Rethinking patch size and isolation effects: the habitat amount hypothesis. *Journal of Biogeography*, 40, 1649–1663.
- FAO (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS) (2019) *Pesticides Use (1990–2017)*. FAO, Rome, Italy. faostat.fao.org/faostat/en/?#data/RP [accessed 6 November 2019].
- FOX, J. & WEISBERG, S. (2011) *An R Companion to Applied Regression*. Sage Publications, Thousand Oaks, USA.
- FRAGOSO, J.M., LEVI, T., OLIVEIRA, L.F., LUZAR, J.B., OVERMAN, H., READ, J.M. & SILVIUS, K.M. (2016) Line transect surveys underdetect terrestrial mammals: implications for the sustainability of subsistence hunting. *PLOS ONE*, 11, e0152659.
- HILÁRIO, R.R., DE TOLEDO, J.J., MUSTIN, K., CASTRO, I.J., COSTA-NETO, S.V., KAUANO, Ê.E. et al. (2017) The fate of an Amazonian savanna: government land-use planning endangers sustainable development in Amapá, the most protected Brazilian state. *Tropical Conservation Science*, 10, 1940082917735416.
- IBGE (2010) *Censo Demográfico 2010–Grade Estatística*. Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Brazil.
- IBGE (2015) *Base Cartográfica Contínua 1:250.000*. Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Brazil. geoftp.ibge.gov.br/cartas_e_mapas/bases_cartograficas_continuas/bc250/versao2015/Shapefile [accessed 6 November 2019].
- IBGE (2017) *Panorama das Unidades Federativas com Base no Censo Demográfico de 2010. v4.3.8.5*. Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Brazil. cidades.ibge.gov.br/brasil/ap [accessed 2 October 2019].
- IEPA (2008) *Macrodiagnóstico do Estado do Amapá: Primeira Aproximação do ZEE/Equipe Técnica do ZEE - AP*. 3rd edition, IEPA (Instituto de Pesquisas Científicas e Tecnológicas do Estado do Amapá), Macapá, Brazil.
- JACKMAN, S. (2017) *pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory*. R package version 1.5.2. github.com/atahk/pscl [accessed 9 September 2019].
- MAXWELL, S.L., FULLER, R.A., BROOKS, T.M. & WATSON, J.E. (2016) Biodiversity: the ravages of guns, nets and bulldozers. *Nature*, 536, 143–145.
- MILNER-GULLAND, E.J. & BENNETT, E.L. (2003) Wild meat: the bigger picture. *Trends in Ecology & Evolution*, 18, 351–357.
- MORO, M., FISCHER, A., CZAJKOWSKI, M., BRENNAN, D., LOWASSA, A., NAIMAN, L.C. & HANLEY, N. (2013) An investigation using the choice experiment method into options for reducing illegal bushmeat hunting in western Serengeti. *Conservation Letters*, 6, 37–45.
- MUSTIN, K., CARVALHO, W.D., HILÁRIO, R.R., COSTA-NETO, S.V., SILVA, C., VASCONCELOS, I.M. et al. (2017) Biodiversity, threats and conservation challenges in the Cerrado of Amapá, an Amazonian savanna. *Nature Conservation*, 22, 107–127.
- NASI, R., BROWN, D., WILKIE, D., BENNETT, E., TUTIN, C., VAN TOL, G. & CHRISTOPHERSEN, T. (2008) *Conservation and Use of Wildlife-Based Resources: the Bushmeat Crisis*. CBD Technical Series Number 33. Secretariat of the Convention on Biological Diversity, Montréal, Québec, Canada, and Center for International Forestry Research, Bogor, Indonesia.
- PANGAU-ADAM, M., NOSKE, R. & MUEHLENBERG, M. (2012) Wildmeat or bushmeat? Subsistence hunting and commercial harvesting in Papua (West New Guinea), Indonesia. *Human Ecology*, 40, 611–621.
- PASSOS, C.J.S., DA SILVA, D.S., LEMIRE, M., FILLION, M., GUIMARÃES, J.R.D., LUCOTTE, M. & MERGLER, D. (2008) Daily mercury intake in fish-eating populations in the Brazilian Amazon. *Journal of Exposure Science and Environmental Epidemiology*, 18, 76–87.
- PEBESMA, E.J. (2004) Multivariable geostatistics in S: the *gstat* package. *Computers & Geosciences*, 30, 683–691.
- PEBESMA, E.J. & BIVAND, R.S. (2005) Classes and methods for spatial data in R. *R News*, 5, 9–13.
- PERES, C.A. (1997) *Evaluating the Sustainability of Subsistence Hunting in Tropical Forests*. CSERGE Working Paper GEC 97-22. Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich, UK.
- R CORE TEAM (2017) *R: a Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- RIPPLE, W.J., ABERNETHY, K., BETTS, M.G., CHAPRON, G., DIRZO, R., GALETTI, M. et al. (2016) Bushmeat hunting and extinction risk to the world's mammals. *Royal Society Open Science*, 3, 160498.
- ROOSEVELT, A.C., DA COSTA, M.L., MACHADO, C.L., MICHAB, M., MERCIER, N., VALLADAS, H. et al. (1996) Paleoindian cave dwellers in the Amazon: the peopling of the Americas. *Science*, 272, 373–384.
- SAFFIRO, G. & SCAGLION, R. (1982) Hunting efficiency in acculturated and unacculturated Yanomama villages. *Journal of Anthropological Research*, 38, 315–327.
- SAMPAIO, R., LIMA, A.P., MAGNUSSON, W.E. & PERES, C.A. (2010) Long-term persistence of midsized to large-bodied mammals in Amazonian landscapes under varying contexts of forest cover. *Biodiversity and Conservation*, 19, 2421–2439.
- TORRES, P.C., MORSELLO, C., PARRY, L., BARLOW, J., FERREIRA, J., GARDNER, T. & PARDINI, R. (2017) Landscape correlates of bushmeat consumption and hunting in a post-frontier Amazonian region. *Environmental Conservation*, 45, 315–323.
- ULLAH, S., ZUBERI, A., ALAGAWANY, M., FARAG, M.R., DADAR, M., KARTHIK, K. et al. (2018) Cypermethrin induced toxicities in fish and adverse health outcomes: its prevention and control measure adaptation. *Journal of Environmental Management*, 206, 863–871.
- ZUUR, A.F., IENO, E.N., WALKER, N.J., SAVELIEV, A.A. & SMITH, G.M. (2009) *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, USA.