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Wild meat trade over the last 45 years in the Peruvian Amazon

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Article impact statement: Trade bans for threatened taxa and enforced hygiene practices in wild met markets are needed to protect biodiversity and public health.

Abstract: The trade in wild meat is an important economic component for rural people's livelihoods, but it has often been perceived to be amongst the main causes of the decline of wildlife species. Recently, the COVID-19 pandemic has brought to light an additional concern of wildlife markets as a major health challenge for humanity. This study brings data analyses from the largest longitudinal monitoring of wild meat markets in Amazonia, comprising surveys between 1973 and 2018 carried out in the most important urban markets of Iquitos, Peru, and examine the trends and impacts of these markets in people's livelihood. Over the last five decades, wild meat sales increased, paralleling urban population growth. They reached their highest numbers in 2018 (442 tons), contributing US$2.6 million (0.76%) to the regional GDP. Five species of ungulates and rodents accounted for 88.5% of the amount of biomass traded; Vulnerable and Endangered species represented 7.0% and 0.4% of individuals sold, respectively. Despite the growth in sales, the contribution of wild meat to overall urban dietary intake maintained a constant low annual rate (1-2% of total meat consumed). Wild meat may be considered an expensive product, since it is 45.8% more expensive than poultry, the most consumed meat. The higher availability and consumption of cheaper sources of meat coupled with the lack of economic incentives to harvest wild meat species in rural areas, retained urban wild meat consumption at low rates. Most wild meat was sold salted or smoked, reducing the likelihood of

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foodborne diseases. Community-based wildlife management plans and the continued trade bans for primates and threatened taxa may avoid biodiversity loss. Considering the recent global collapse due to COVID-19 pandemic, plans should include potential hosts for pandemic viruses along with regulated and enforced hygiene practices in markets for better public health.

Introduction

In tropical forests worldwide, wild meat represents a significant source of animal protein and income for rural and urban people (Fa et al. 2015; El Bizri et al. 2020). Recent overhunting of wild meat species has been attributed, in part, to the integration of rural and Indigenous populations into the market economy during the late 20th century. The improvement of river navigation and roads, plus the advent of new hunting technologies, led to an increase in supply and demand for wildlife products in urban centres (Fa et al. 2015; Chaves et al. 2017). Wild meat therefore represents an increasingly important product for the economy and survival of rural people (de Merode et al. 2004), and changes in sales of wild meat markets affect their livelihoods.

Recently, the supposed connection between the SARS-CoV-2 virus and wet markets in China resulted in several calls for bans on wild meat trade worldwide because these markets may pose risks to human health through the spillover of pathogens from wildlife (Roe & Lee 2021). However, such calls are controversial because shutting markets down can ultimately backfire and cause severe poverty and lack of food for many (Fa et al. 2015). Thus, should the trade of wild meat be banned completely, or should it be kept operating to some extent to continue to lessen rural poverty and ensure food and economic

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security? To make a fair and informed decision, detailed information on the wild meat trade can provide insights regarding their sustainability and guide the development of health protocols to avoid health risks to hunters, vendors and consumers.

To date, much attention has been focused on the sustainability and drivers of wild meat markets in West and Central Africa (de Merode et al. 2004; Fa et al. 2015). However, wildlife markets are also important in the Amazon, and yet few studies have been conducted to assess the factors underlying wild meat trade in this region (van Vliet et al. 2014; Bizri et al. 2020). One exception is the long-term monitoring of wild meat trade in the urban markets of Iquitos, the largest city in the Peruvian Amazon, which has involved intermittent data collection since 1973 (Castro et al. 1976; Bendayan 1991; Bodmer & Pezo 2001; Mayor et al. 2019).

The Peruvian Ministry of Agriculture, through laws enacted in 1976 (nº 21147), 2000 (nº 27308) and 2011 (nº 29763), only authorized the sale of wild meat proceeding from areas with planned sustainable wildlife management. However, these wildlife management practices are administratively difficult to implement and authorities have been unable to adequately enforce these laws; thus, the illegal sale of wild meat remains the norm.

Herein, we assess temporal trends in the amounts and prices of wild meat over the last 45 years in the main urban markets of Iquitos, from 1973 to 2018. We assess the influence of economic and socio-cultural drivers, including human population, GDP and the domestic meat supply, on the rates of wild meat sales, and their implications for sanitary risks. These results can inform decision-making regarding the future of wild meat markets in the Amazon, and improve our understanding of the health and conservation implications of these markets.

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Methods

Study area

This study was conducted in Iquitos, the largest city in the Peruvian Amazon, which has a population of 486,338 inhabitants in 2018 (Gobierno Regional de Loreto –GOREL, pers. comm.). In this region, there is a scarcity of roads, and products, including wildlife products, are mainly supplied between rural and urban centers through fluvial transportations. Iquitos has two main large open markets: (i) Belén Market, which is one of the most important wild meat market in Amazonia in terms of amounts traded; and (ii) Modelo Market, which is a secondary urban market (Bendayan 1991; Bodmer & Pezo 2001). Both markets offer many types of goods extracted from the rainforest, from traditional medicines and pets to fish, fresh fruits and vegetables.

Most wild meat is sold openly in these two markets, making it relatively easy to track. Since the legislation on wild meat trade is not enforced, and the traditional culture of consuming wild meat is support by the general public there is no need for a hidden trade, and these two markets offer a good proxy for the general consumption of wild meat in Iquitos. Wild meat is typically supplied by intermediaries, timbermen or by rural hunters that travel to the cities to sell products directly to market vendors, who then sell the wild meat from individual stalls in urban markets (Mayor et al. 2019).

Data collection

The present study includes seven surveys conducted between 1973 and 2018 (Table 1). Data from the 1973 (Castro et al. 1976), 1986/87, (Bendayan 1991), 1996 (Bodmer & Pezo 2001) and 2001/02 (Bendayan & Bardales 2004) used published results, whereas the more recent 12-month surveys conducted during Sept 2006-Aug 2007, Nov 2013-Oct 2014, and Sept 2017-Aug 2018 used original

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data sets.

Long-term data gathered from the same markets in Iquitos, using similar survey methodology, were used to assess changes in wild meat sales through time. All studies conducted interviews with market vendors supported by observations of meat counters daily or every two days. In 1973, Castro et al. (1976) surveyed the markets of Belén, Central and Camal for five months; surveys in 1986-1987 (Bendayan1991), 1996 (Bodmer & Pezo 2001), 2001/02 (Bendayan & Bardales 2004), 2006/07, 2017/18 were conducted by our research group in the markets of Belén and Modelo for 12 months. An additional survey was conducted by our team in 2013/14 in the market of Belén, and considering the representativeness of each market in wild meat sales from the other surveys, a correction of 0.33 was used to estimate the total biomass and individuals sold in Modelo market in that year.

The same team using the same methodology performed all surveys. Castro taught RB and NB, who were involved in all subsequent surveys. The method consisted of market vendors participating willingly in the information collected, with a full understanding of the study and confidence in their anonymity. In order to engage vendors and encourage participation, preliminary visits to the markets were made during the first 2 months before each survey period. Since mammals make up between 70-80% of all wild meat traded in the Amazon (El Bizri et al. 2020), our study focused on this group only. To gather information on the amounts and prices of traded wild meat, we used structured interviews and observation of meat presented on the counter and stored in the stall. Team members and local students conducted interviews and responses were constantly validated with observational information. All regular vendors of wild meat were interviewed and a large sample of occasional vendors; 5-10% of occasional sellers declined to participate.

In the 2006-2018 surveys the average monthly frequency of interviews was 9.9 (SD 4.9; range 2.7-15.0), which is above the minimum sampling effort of two interviews per month

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recommended to obtain proper accuracy and precision in wild meat sales and price estimations (Mayor et al. 2019). Interviews were conducted daily between 6:00 a.m. and 12:00 p.m. The date, species, type of meat preservation (fresh, salted or smoked), selling price per kg, the amount of wild meat brought by sellers at the start of the day, including the amount of wild meat displayed on the stall and stored indoors, and the amount left at the end of the day were recorded. The amount of wild meat sold was calculated as the difference between the amounts on sale at the beginning minus the amount left at the end of the day, and avoiding double counting of meat brought out again the next day.

Richness, biomass and number of individuals sold

We counted the number of species sold at each market and listed them by threat category according to the Red List of the IUCN (2020). Unidentified species were grouped into genera, and their threat category was filled in by identifying the most likely species traded within the genera.

The amount of meat salted and smoked recorded per species was transformed into fresh meat using the conversion indices proposed by Bardales-García et al. (2004). For those species for which there were no conversion indices, we applied the index for a taxonomically related species of similar body mass. The number of traded individuals per species was estimated by dividing the amount of fresh meat by the body weight estimates after evisceration following the calculation proposed by Bardales-García et al. (2004). Both estimations were extrapolated to 365 days to calculate the fresh wild meat biomass and number of individuals traded annually. Species' body mass values were obtained in Peres and Dolman (2000) and Bardales-García et al. (2004). The estimated average body mass of species sold annually was calculated following the equation Σ (species' body mass * nº individuals per species)/total nº of individuals of all species sold.

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Meat prices

Sellers were asked about the daily amount of wild meat sold, the money spent on purchases to obtain wild meat from intermediaries or hunters, and the daily sale price per kg of wild meat. Prices of all domestic meat products came from interviews conducted by the local government between 2006 and 2018 (GOREL, pers. comm.). In addition, during the survey conducted in 2017/18, we interviewed local sellers to calculate the average daily price per kg of meat for all domestic species, and the most frequently traded fish, *Prochilodus nigricans*. All prices were converted into US dollars using the exchange rates from 10 October 2007 (PS3.00 = US$1.00), 04 July 2014 (PS3.28 = US$1.00), and 04 October 2018 (PS3.32 = US$1.00). We corrected prices using the Peruvian yearly inflation(https://datos.bancomundial.org/indicador/FP.CPI.TOTL.ZG?end=2017&locations=PE&start=1993).

Economic and demographic drivers of wild meat consumption

We used the total human population, per-capita Gross Domestic Product (GDP), annual production and prices of meat of domestic animals and fish landing rates (GOREL, pers. comm.) in Iquitos, between 2000 and 2018, as annual estimates of meat and fish consumption. The index of domestic meat and fish consumption per-capita (ICPC) was calculated by dividing the overall amount of meat produced (for domestic species) or fish landed annually and daily, by the number of inhabitants in Iquitos between 2000 and 2018. A similar index of wild meat consumption per-capita (ICPC) considered the overall amount of wild meat sold annually and daily by the number of inhabitants. Data were expressed in terms of g/inhabitant/year and g/inhabitant/day. These indices were used to

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describe temporal trends in meat consumption and to estimate the relative importance of wild meat for the urban population.

Statistical analysis

We used generalized additive models (GAMs) and linear models to assess: (1) temporal trends in wild meat amount, number of individuals, richness and average body mass of taxa traded from 1973 up to 2018; (2) the relationship between body mass and the amount of fresh wild meat and number of individuals traded per taxon (transformed to a log scale), also testing whether this relationship was similar among years, and (3) the relationship between GDP per capita in Iquitos and the ICPC of all domestic meat pooled. All models were conducted using the Gaussian family of distribution. We used analysis of variance (ANOVA) to assess differences between the price of meat and survey year, preservation type and species (considering only repeated species in all surveys); post-hoc differences were tested using the Tukey–Kramer Multiple Comparisons Test. A Chi-squared test was used to compare percentages of different types of meat preservation in different years. We also calculated the percentage, ICPC and difference of prices of wild meat relative to the total amount of meat consumed in Iquitos over years between 2000 and 2018 (period for which data on human population and consumption of domestic meat were available). Statistical analyses were performed using R-Studio version 0.98.1062 (RStudio, Inc.) with *lme4* and *mgcv* packages, and Deducer JRG version 1.7.9.2003-2011 (RoSuDa, Univ. Augsburg).

Results

Trends of wild meat sales in the urban markets over the last 45 years

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The amount of wild meat biomass sold from 1973 to 2018 significantly increased (t-value = 2.94, p = 0.032, Fig. 1a, Table 1). The number of individuals traded also showed an increasing trend over the years, but it was not significant likely due to the high number of primate individuals sold in 1973 (t-value = 1.86, p = 0.12, Fig. 1b, Table 1). Belén Market accounted for 65.2%-68.2% of the total biomass sold and the Modelo Market made up the difference.

We recorded an average of 15.0 (SD 3.5) taxa of wild mammals sold in Iquitos from 1973-2018, showing a decrease in the richness of taxa sold through the years (AIC = 34.80, F = 8.10, df = 1, p = 0.035; Fig. 1c). In all surveys between 1973 and 2018, Artiodactyla was the most traded Order in terms of biomass (70.5% [SD 11.7]) and individuals (52.7% [SD 14.7]), followed by Rodentia with 25.7% (SD 9.6%) of biomass traded and 44.6% (SD 14.5) of individuals traded (Table 2). Large numbers of primates were sold in 1973 (6 species, 12.7% biomass sold). Primates were prohibited from market sale and excluded from the list of permitted subsistence species in the 1976 wildlife law, and more recently, excluded as sustainably hunted species in community wildlife plans. From 1987 onwards, the trade of primate meat diminished sharply, decreasing to 0.8% of the overall biomass traded in 2013/14 and 2017/18.

Taxa with larger body masses were usually sold in larger quantities, both in terms of biomass ($F_{3.63}$ = 19.73, $p < 0.001$) and individuals ($F_{3.67}$ = 13.15, $p < 0.001$) (Fig. 2). An inverted-U-pattern described the temporal trend in the average body mass of species sold (Fig. 1d), due to an increase in the average body mass of species sold from 1973 to 2002 (t-value = -2.9, p = 0.04), and the decline of the sales of white-lipped peccary in 2014 (t-value = -2.85, p = 0.036).

Five taxa made up 88.5% (SD 7.6) of the total biomass sold in all years (Figs. 1e and 1f): paca, collared peccary, white-lipped peccary, and red and grey brocket deer. The collared peccary was the most frequently sold taxon in terms of biomass (39.8% [SD 10.7]) and the second in terms of

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individuals (32.3% [SD 11.9]. The paca was the most commonly sold taxon in terms of individuals (38.6% [SD 15.6]), and the second in terms of biomass (22.8% [SD 9.4]). White-lipped peccary sales crashed in the 2013/14 survey, going from the most commonly sold wild meat in 1996 (90,211 kg, 45.0%) to virtually disappearing from the urban markets in 2014 (5,052 kg, 2.1%), with the decline showing a corresponding increase in paca sales. In 2017/2018, the trade in white-lipped peccary showed signs of increasing (79,125 kg, 17.9%). Red and grey brocket deer (*Mazama* spp.) were also frequently sold (27,762 Kg, 8.0% [SD 4.3]) (Table 1).

Five taxa are or comprehend Vulnerable species according to the IUCN (2020); woolly monkey *Lagothrix* spp., spider monkey *Ateles* spp., white-lipped peccary (*Tayassu pecari*) and lowland tapir (*Tapirus terrestris*); these taxa accounted for 5.6% (SD 4.2) of individuals sold, ranging from 1.8% to 11.1%. Prior to 2006, primates represented 72.8% (SD 17.8) of threatened taxa sold. From 2006 onwards, white-lipped peccary and tapir were uplisted to Vulnerable and accounted for 91% of threatened taxa (75.9% [SD 24.4] and 15.0% [SD 19.8], respectively), and primates decreased to 9.2% (SD 5.0).

There was no significant difference between surveying year and type of meat preservation (χ^2= 24, df = 22, p = 0.3472). Smoked wild meat represented 54.1%, 53.5% and 56.0% of the biomass sold in 2006/07, 2013/14, and 2017/18; salted wild meat 31.4%, 32.5% and 40.0%; and fresh meat 14.5%, 14.0% and 4.0%, respectively.

Economic value of wildlife

Between 2006 and 2018, consumers spent US$1,053,851 (2006/07), US$1,217,673 (2013/14), and US$2,591,591 (2017/18) on wild meat in the markets of Iquitos. Taking into account yearly inflation, wild meat presented a similar economic benefit for the regional economy between 2006/7 and

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2013/14 (US$1,053,850 and US$999,223, respectively), but showed a growth of 92.0% in 2017/18 (US$1,918,972).

The price was significantly influenced by the year, the taxon and the type of meat preservation, with a significant interaction between taxon and type of meat preservation ($F_{15,8487}$ = 8.24, p-value < 2.2e-16). The average selling price of wild meat grew by 101.0% from US$2.88 (SD 0.25) per kg (2006/07) to US$4.26 (SD 0.93) (2013/14), and to US$5.79 (SD 0.74) (2017/18) ($F_{2,8487}$ = 9739.1, $p < 0.001$; Table 3). The paca was the most expensive meat ($F_{8,8496}$ = 715.7, $p < 0.001$), followed by brocket deer and peccaries; tapir and primates were the least expensive taxa. The preservation method also affected the price ($F_{2,8502}$ = 22.97, $p < 2.2e-16$); salted meat was less expensive than smoked and fresh meat. The money spent by sellers to obtain wild meat from intermediaries and hunters showed a decrease of 9.9%, from US$2.21 (SD 0.60) per kg in 2006/07 to US$1.91 (SD 0.23) in 2017/18. The increase in sale prices and the decrease in purchase price resulted in an increase in average profit per kg of wild meat of 214.1% for vendors going from 30.3% (2006/7) to 67.0% (2017/18).

In parallel, prices of domestic meat showed a moderate increase of 8.4% between 2006/7 and 2017/18, including poultry, the most purchased meat, which grew in price by 14.4%, from US$1.93 (2006/07) to US$2.21 (2017/18). In 2017/18, wild meat was the most expensive meat, with an average price 47.1% higher than the most frequently consumed fish, *Prochilodus nigricans*, 45.8% higher than poultry, 24.7% higher than pork and 16.9% higher than beef.

Demographic drivers and per-capita consumption of wild meat

The ICPC of wild meat in Iquitos remained low over the years (1.99 [SD 0.49] g/inhabitant/day), with minimum and maximum rates of 435 and 926 g/inhabitant/year (1.0 and 2.5 g/inhabitant/day) in

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2013/14 and 2006/07, respectively. Wild meat represented only 3.2% of total meat consumed in 2001/02, and its contribution decreased to 0.7% (2013/14) and 0.9% (2017/18). Between 1973 and 2018, the human population in Iquitos grew from 182,738 to 486,338 inhabitants. The GDP per capita showed an average yearly increment of 8.5% (SD 7.6%) from US$2,016 (2001) to US$6,177 (2015). The overall consumption of animal protein grew 6.9%, from 82.1 (2000) to 240.7 (2018) g/inhabitant/day.

There was a high association between GDP per capita and the ICPC of all meat pooled (AIC = 134.62, $F_{2.61} = 32.57$, $p < 0.001$; Fig. 3a). The daily consumption of domestic species increased from 56.3 (2000) to 215.1 (2018) g/inhabitant/day, exhibiting an average yearly increase of 8.1% (SD 8.7). Poultry was the most consumed meat, with a yearly increase of 8.2% in daily consumption from 49.4 (60.2% of total meat) g/inhabitant/day in 2000 to 192.9 (80.1%) g/inhabitant/day in 2018 (Fig. 3b). Although the daily consumption of fish remained constant, its contribution to diet decreased from 31.4% to 10.6%. Daily consumption of sheep, buffalo, pork, and beef showed a high yearly increase of 21.6%, 15.7%, 9.9% and 5.9%, respectively, but their contribution to overall meat consumption was scarce (≤ 5%).

Discussion

The emergence of the COVID-19 pandemic has initiated substantial global political and economic changes and brought about one of the main challenges that humanity has ever faced with links to loss of biodiversity, and health and food insecurity. This study provides fundamental information for decision-making regarding the sustainability and risks posed by the trade of wild meat. Continuous surveys over the last 45 years using similar surveying methodologies in urban markets enabled the assessment of trends and the economic and socio-cultural drivers of wild meat trade in Amazonia.

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The population of Iquitos has been rising by 1.3% per year due to both population growth and urban migration. As a result, over the last five decades, overall wild meat sales in urban markets have increased, though maintaining a constant ICPC. The inclusion of new technologies and transportation has enhanced the capacity of hunters to capture prey, even in previously inaccessible areas (Chaves et al. 2017; Bowler et al. 2020). However, different from what was expected based on the findings from the Brazilian Amazon (Chaves et al. 2020), we did not find any evidence of a decrease in wild meat consumption over generations. However, even if the ICPC remains constant, the overall sustainability threshold could be exceeded because of the constant increase in the urban population. This scenario needs consideration and would require regulating all traded species, even non-threatened ones, in order to ensure long-term sustainability.

Despite the increasing trend of the trade of wild meat, decreased levels of trade were recorded within the period. Results from the survey conducted in 1987 probably reflect the regulatory effect of the implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora in 1973. In addition, the transient decrease in sales in 2013/14 could likely be explained by ecological factors. In the flooded forests of Loreto, the extreme floods of 2011–2015 caused large-scale die-offs of game species; latterly, consecutive normal floods between 2016 and 2018 allowed their population recovery (Bodmer et al. 2020). Nevertheless, we must be cautious with that estimate because Modelo market was not surveyed in 2013/14.

Amazonian people have traditionally used different subsistence resources such as fish and wild meat. More recently, local inhabitants have adjusted their diets to include meat from domestic species, and wild meat is turning from a traditional component in the dietary intake into a complementary and expensive but still relatively affordable meat. Simultaneously, the rise of domestic meat production, especially the broiler industry, has resulted in higher consumption of protein from domestic species. Between 2001 and 2014, poultry production grew by 284% and

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comprised 76% of the total animal daily intake. In contrast, the improvement of local economies did not result in an increase in the proportion of wild meat traded among all available meat, which maintained low levels (<2% of total meat traded). The higher price of wild meat compared to that of fish (+47%) and poultry (+45%) has likely contributed to the consideration of wild meat as an expensive dish, restricting its accessibility.

Based on the optimal foraging theory, hunters should harvest more profitable, large-sized and available prey (Hawkes et al. 1982). Accordingly, we found that taxa with higher body mass were generally traded more often. However, we detected an inverted U-shaped curve in the amount of meat and individuals traded caused especially by the tapir and manatee (*Trichechus inunguis*). Although tapir and manatee are among the largest and more profitable species due to their large size and high amounts of meat, these species are less dense and therefore more difficult to catch in the forest, making them slightly less prevalent in the market than expected for its body mass. Tapir also shows less demand due to its dark oily meat, which is less preferred by consumers. In 1973 this trend was not clear, mainly because of the high numbers of primates sold, which likely reflect a cultural preference for these species 45 years ago. As reported in other studies in the Amazon (van Vliet et al. 2014; El Bizri et al. 2020), ungulates and rodents accounted for 90% of the amount of biomass of mammals traded in the Iquitos markets. The most frequently sold taxa, the collared peccary and the paca, are less vulnerable to over-hunting and more appropriate to be used as a source of wild meat due to their large population size and relatively fast reproductive rates (Mayor et al. 2017). Accordingly, we highlight the necessity for creating and reinforcing management strategies to ensure that these species can sustain current levels of hunting and commercialization. The Peruvian Forestry and Wildlife Service (SERFOR) has an annual subsistence hunting quota for peccaries, because pelts originating from subsistence hunters are sold on the international market in accordance with CITES II

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regulations (Fang et al. 2008). There is no annual subsistence hunting quota for paca, whose pelts are not traded.

The low presence of species threatened with extinction in the markets suggests that the trade exerts mild pressure on species of high conservation concern, which mainly comprise taxa with low reproductive rates such as primates and tapir (Mayor et al. 2017). We observed a significant decrease in the sale of primate meat over time possibly because of a greater stigma associated with consumption of primates due to their taxonomic proximity to humans and their human-like appearance. The presence of primates in the markets in Iquitos is low compared to the numbers hunted in rural areas (Mayor et al. 2015). However, hunting and trade combined may compromise primate populations (Pérez-Peña et al. 2018). Furthermore, primates may be important hosts for emergent viruses of pandemic potential, increasing the chances of spillover from host migration/switch to humans (Johnson et al. 2020). The best measure for safeguarding primate conservation and public health is to continue the prohibition of primate meat sales in the markets and continue to exclude primates from sustainable use wildlife plans.

The amount of money spent by consumers gives an estimate of the economic value of wild meat in urban centers (Bodmer & Pezo 2001). The revenue from wild meat sales reached US$2.6 million in 2018, when it contributed 0.76% to the total GDP of the Loreto region (US$34,340 million). Compared to other activities, wildlife use makes up a relatively low proportion of the total GDP (oil industry 81.1%, fisheries 6.9%, agriculture 5.7%, timber industry 4.6%; DDPI–Mincetur 2018). Unlike those activities, the harvest and trade in wildlife does not generate long-standing socio-environmental conflict (Yusta et al. 2017). Wild meat in Iquitos shows high potential to increase the economic returns for local people, but while urban vendors have optimized their economic performance, with a 55% increment over the years, this process brought no economic incentives for rural people, with their profit decreasing by 10% instead. Because urban sale of wild meat is mostly

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illegal, it is excluded from official statistics, which hampers tracking the actual economic value of wildlife, and it is why wildlife specialists have been collecting market sales intermittently over the past 45 years.

The low livestock productivity in the Afrotropics makes wild meat hunting one of the more profitable rural economic activities in this region (Milner-Gulland et al. 2002). In contrast, as reported across the Amazon basin (Oestreicher et al. 2020; Chaves et al. 2020), in Iquitos the increasing availability of cheaper sources of animal protein, such as poultry and fish appears to have reduced the dependence on wild meat. This suggests that economic development may be compatible with game species conservation. As long as strategies to minimize the impacts of harvests on populations are developed, wild meat may be sustainably used as subsistence food in rural areas (Bodmer & Pezo 2001) and as an income source for local people by acting as a complementary good to domestic meat in urban areas (Wilkie & Godoy 2001). For instance, wildlife management plans in Pucacuro National Reserve and the Ampiyacu-Apayacu Regional Conservation Area have been approved in the Peruvian Amazon that legally permit the sale of wild meat in urban markets for the first time since the ban on the urban wild meat trade in 1976.

However, authorities need to consider foodborne diseases that have always been of major public health, and the recent emergence of COVID-19 has put wild meat in the spotlight of this discussion. In Amazonian markets, wild meat and animals are often stored for sale in open-air settings, in close proximity to domestic meat, breaching health sanitation standards. The main route for contamination by foodborne pathogens in wildlife markets is through direct contact with vectors or body fluids of animals, handling of carcasses and ingestion of raw or undercooked meat (van Vliet et al. 2017). Moreover, in the tropics, the presence of high nutrients, in combination with high humidity, play an essential role in the proliferation and survival of microorganisms in the meat and on wood surfaces (Carpentier 1997).

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These conditions are common in markets throughout tropical forests worldwide. Existing global food safety regulations have helped improve hygienic practices and hazard analysis at critical control points for safer processed foods (Mahajan et al. 2014). However, these are not frequently implemented in traditional wildlife markets, thereby causing food safety concerns (Blanck et al. 2014). To the best of our knowledge, the only microbiological study conducted for wild meat in the markets of Iquitos showed high contamination levels (Lozano et al. 2014); however, similar results were found for domestic meat (Soplin & Tulumba 2013), demonstrating general deficiencies in safety hygienic practices.

The meat preservation methods combining salting, drying and smoking methods have a long tradition. In Iquitos, 85% of wild meat is sold smoked or salted, which reduces sanitary risks; while fresh carcasses have a high susceptibility to be contaminated with a variety of microorganisms (Alekruse et al. 1997). A range of pathogens are susceptible to changes in temperature, pH, relative humidity and time. Many viruses may be deactivated when exposed to 60ºC temperatures for 60 minutes, i.e. coronaviruses (Hessling et al. 2020). Smoked meat is usually cooked to 65–75◦C, a temperature sufficient to destroy most vegetative microorganisms, but not thermoduric enterococci and bacterial sporeformers (Cerveny et al. 2009). The salting process in dry-curing reduces the amount of water available for microbial growth (Scolari et al. 2003). Thus, a proper salting and smoking process should significantly reduce sanitary risks. However, further studies into this subject are still needed.

It has been suggested that banning the trade of wild meat could reduce the risk of future pandemics. However, this is a complex issue, because these markets support informal food systems for millions of urban and rural people. The number of zoonotic viruses in mammalian species is related with these species' ability to adapt to human-dominated landscapes, with domesticated species, primates, and bats having more zoonotic viruses than other species (Johnson et al. 2020).

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Local markets involve wild and domestic species in close proximity, providing opportunities for pathogens to move between them. Alternatively, the combination of restrictive and regulating measures, the creation of particular management strategies to resilient wild species that sustain commercialization, and effective educational programs on appropriate hygiene practices may be a working solution for both wild meat sustainability and the resolution of sanitary risks. As main restrictive measures, we advocate that trade of live animals, and the sale of fresh wild meat be banned and continue the prohibition on the sale of primate meat. These measures should ultimately meet peoples' needs and safety, reducing the potential risks involved with the animal-human interaction during the trade and consumption of wild meat whilst guaranteeing the sustainable use and conservation of wildlife.

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Yusta-García R, Orta-Martínez M, Mayor P, González-Crespo C, Rosell-Melé A. 2017. Water contamination from oil extraction activities in Northern Peruvian Amazonian rivers. Environmental Pollution **225**:370-380.**Table 1.** Total amount of meat sold per year (in converted kg of fresh meat and in individuals) from wild mammals from wild mammals in Belén and Modelo Markets in Iquitos based on data from literature (1973, 1986/87, 1996, and 2001/02), and from our surveys in years 2006/07, 2013/14 and 2017/18.

Year			1973 [a]	1986/87	1996	2001/02	2006/07	2013/14 [b]	2017/1
Nº of interviews (nº of vendors)			-	-	-	-	3,543 (41)	1,700 (25)	2,317 (4
Sampling days (% sampling			158 (43.3)	156 (42.8)	167 (45.8)	208 (57.1)	182 (50.1)	68 (18.6)	171 (46

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coverage)									
Nº months			5	12	11	12	12	12	12
Large Markets sampled			Belén	Belén and Modelo	Belén and Modelo	Belén and Modelo	Belén and Modelo	Belén	Belén a Model
Species (Threat category IUCN 2000) [c]	Body Mass (kg)	Meat Mass (kg)	kg-year (ind-year)	kg-year (ind-year)	kg-year (ind-year)	kg-year (ind-year)	kg-year (ind-year)	kg-year (ind-year)	kg-yea (ind-ye
Alouatta seniculus (LC)	6	4	2,736 (648)	7.2 (1.8)	19 (4.8)	168 (42)	947 (236)	192 (48)	40 (10
Ateles spp. (VU-EN)	9	6.6	1,253 (190)	163 (25)	34 (5.2)	831 (126)	145 (22)	217 (33)	498 (8
Cebus albifrons (LC)	3.5	2.1	912 (434)	0	0	0	0	0	0
Coendou sp. (DD-LC)	3.5	2.1	252 (120)	0	0	0	0	0	0
Cuniculus paca (LC)	8	6	26,640 (4,440)	10,876 (1,812)	15,397 (2,566)	91,950 (15,325)	83,264 (13,877)	63,310 (10,552)	162,75 (25,03
Dasyprocta fuliginosa (LC)	5	2	4,194 (2,097)	516 (258)	219 (110)	705 (325)	329 (164)	0	73 (36
Dasypus spp. (LC)	6	4	874 (218)	130 (32)	187 (47)	3,325 (831)	2,285 (571)	1,468 (367)	763 (18

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Didelphis marsupialis (LC)	3	1.8	0 (0)	0	8.3 (4.6)	0	0	0	0
Hidrochaeris hidrochaeris (LC)	30	12	864 (72)	1,323 (110)	1,975 (164)	540 (45)	24,917 (2,076)	0	7,132 (5
Lagothrix spp. (VU)	11	8	14,302 (1,788)	418 (52)	1,176 (147)	3,974 (497)	2442 (305)	338 (42)	526 (6
Mazama americana (DD)	20	13.7	23,677 (1,691)	3,048 (218)	8,149 (582)	14,974 (1069)	20,836 (1,488)	0	27,72 (1,932
Mazama nemorivaga (DD)	17	11	0.0 (0.0)	0.0 (0.0)	1,195 (109)	49,0 (	3,207 (292)	0	42 (4
Mazama spp. (DD-LC)	18.5	1.25	0.0 (0.0)	0.0 (0.0)	0	0	7,177 (574)	23,983 (1,919)	0
Myoprocta pratti (LC)	5	2	0.0 (0.0)	1.8 (0.9)	0	0	10 (5)	0	32 (16
Nasua nasua (LC)	5	3	0.0 (0.0)	50 (17)	28 (9.3)	168 (56)	34 (11)	0	0
Pecari tajacu (LC)	25	13	36,366	33,290	73,291	149,454	101,647	132,872	152,65

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			(2,797)	(2,561)	(5,638)	(11,496)	(7.819)	(10,221)	(9,365
Pithecia sp. (DD-LC)	3.5	2.1	648 (309)	0	0	0	0	0	0
Potos flavus (LC)	5	3	4,716 (1,044)	2.6 (0.9)	5.2 (1.7)	0	0	0	0
Proechimys spp. (DD-LC)	2	1.2	4,716 (3,930)	0	0	0	0	0	0
Sapajus apella (LC)	3.5	2.1	864 (411)	0	0	0	38 (17)	0	0
Tamandua tetradactyla (LC)	7	4.2	315 (75)	76 (18)	17 (3.9)	0	0	0	0
Tapirus terrestres (VU)	140	90	2,493 (28)	4,692 (52)	8,499 (94)	22,290 (248)	12,799 (142)	17,979 (200)	10,56 (109)
Tayassu pecari (VU)	35	20	18,352 (918)	10,641 (532)	90,211 (4,510)	38,913 (1,946)	63,404 (3.170)	5,052 (253)	79,12 (3,227
Trichechus inunguis (VU)	400	240	1,732 (7)	9 (0.04)	0	0	93 (0)	0	0
Total			144,325 (21,246)	65,237 (5,692)	200,411 (13,997)	327,293 (32,061)	323,576 (30,772)	245,412 (23,634)	441,97 (40,64

Source: Data from the earliest surveys were collected from literature: 1973 (Castro et al. 1976),

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1986/87, (Bendayan 1991), 1996 (Bodmer & Pezo 2001) and 2001/02 (Bendayan & Bardales 2004).

[a] Local markets included the large market of Belén, and two minor markets (Arequipa and Central). Modelo Market did not exist during that time.

[b] The Modelo Market was not surveyed in 2013/14, but we estimated total amount of meat considering the average representativeness of the wild meat amount traded in these markets (33.3% and 66.7% in Modelo and Belén Market, respectively).

[c] Threat categories according to the Red List of the International Union for Conservation of Nature (IUCN) 2020 are shown into brackets after the scientific name of each species: DD=Data deficient, LC=Least concern, VU=Vulnerable, EN=Endangered.**Table 2.** Total amount of meat (in converted kg of fresh meat and in individuals) from wild mammals according to taxonomic order sold in local markets in Iquitos between 1973 and 2018. The order Sirenia, Didelphimorphia and Pilosa are not included here due to their low representativeness (<0.1%).

	Year	Artiodactyls	Rodent	Primate	Cingulata	Carnivore
n		6	4	4	3	2
Body mass in kg (SD)		42.6 (48.2)	12.0 (12.1)	6.1 (3.2)	5.3 (2.1)	4.75 (0.35)
Eviscerated mass in kg (SD)		26.8 (31.1)	5.5 (4.7)	4.6 (2.6)	3.3 (1.3)	2.8 (0.2)
Total biomass sold (kg/year)	1973	80,889 (56.0)	36,666 (25.4)	20,715 (14.4)	874 (0.6)	3,132 (2.2)
	1986/87	51,672 (79.2)	12,717 (19.5)	588 (0.9)	130 (0.2)	53 (0.1)
	1996	181,345 (90.5)	17,591 (8.8)	1,229 (0.6)	187 (0.1)	33 (0.0)

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	2001/02	226,171 (69.1)	92,655 (28.3)	4,974 (1.5)	3,325 (1.0)	168 (0.1)
	2006/07	209,071 (64.6)	108,520 (33.5)	3,573 (1.1)	2,285 (0.7)	34 (0.0)
	2013/14 *	179,887 (73.3)	63,310 (25.8)	748 (0.3)	1,468 (0.6)	0 (0.0)
	2017/18	270,109 (61.1)	169,990 (38.5)	1,115 (0.3)	763 (0.2)	0 (0.0)
Total individuals sold (ind./year)	1973	5,434 (25.6)	10,659 (50.2)	3,816 (18.0)	219 (1.0)	1,044 (4.9)
	1986/87	3,363 (59.1)	2,182 (38.3)	79 (1.4)	32 (0.6)	18 (0.3)
	1996	10,934 (78.1)	2,840 (20.3)	157.0 (1.1)	47 (0.3)	11.1 (0.1)
	2001/02	14,822,7 (46.2)	15,723 (49.0)	665 (2.1)	831.3 (2.6)	56.0 (0.2)
	2006/07	13,486 (43.8)	16,123 (52.4)	581 (1.9)	11 (0.0)	11 (0.0)
	2013/14 *	12,592 (53.3)	10,552 (44.6)	123 (0.5)	367 (1.6)	0.0 (0.0)
	2017/18	14,638 (36.0)	25,644 (63.1)	159 (0.4)	186 (0.5)	0 (0.0)

* The Modelo Market was not surveyed in 2013/14, but we estimated total amount of meat considering the average representativeness of the wild meat amount traded in these markets (33.3% and 66.7% in Modelo and Belén Market, respectively).

Table 3. Average prices (in US$) per type of meat, including domestic and wild meat and fish, in Iquitos during the surveys conducted in 2006/07, 2013/14 and 2017/18, differences (in %) of prices between years.

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Species	Official average prices (USD/kg) *			Difference (%)		
	2007	2014	2018	2014 *vs.* 2007	2018 *vs.* 2014	2018 *vs.* 200
Poultry	1.93	2.38	2.21	23.2	-7.2	14.4
Regional hen	3.65	3.66	4.01	0.3	9.7	10.0
Porcine	1.50	1.55	2.14	3.5	37.6	42.4
Bovine	2.07	1.37	1.66	-33.6	20.7	-19.8
Total domestic meat	2.29	2.24	2.50	-2.2	11.6	8.4
Fish	-	-	-	-	-	-
Wild meat	2.88	4.26	5.79	47.9	35.9	101.0

* Official average prices of domestic animals (poultry, porcine, bovine) were obtained from the Dirección Regional de Agricultura de Loreto, (pers. comm.).

Figure 1

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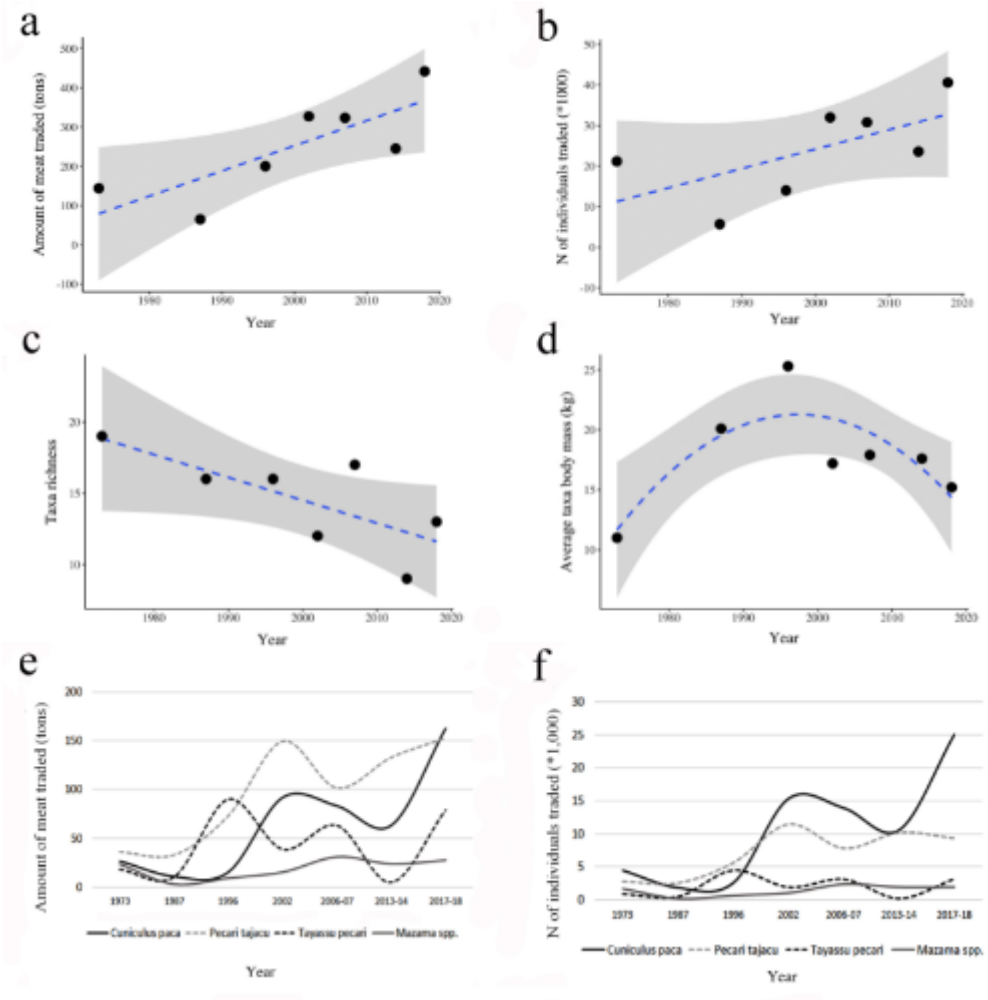

Figure 2

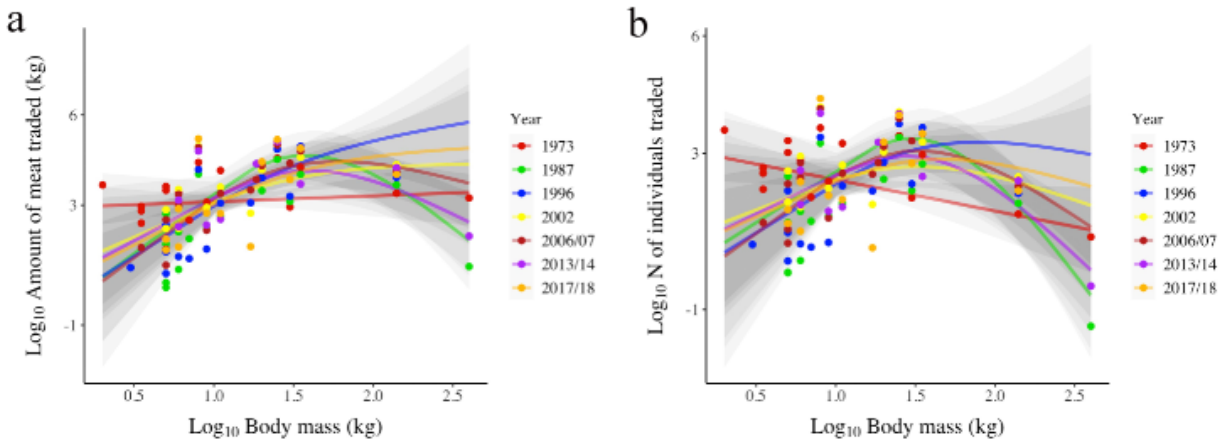

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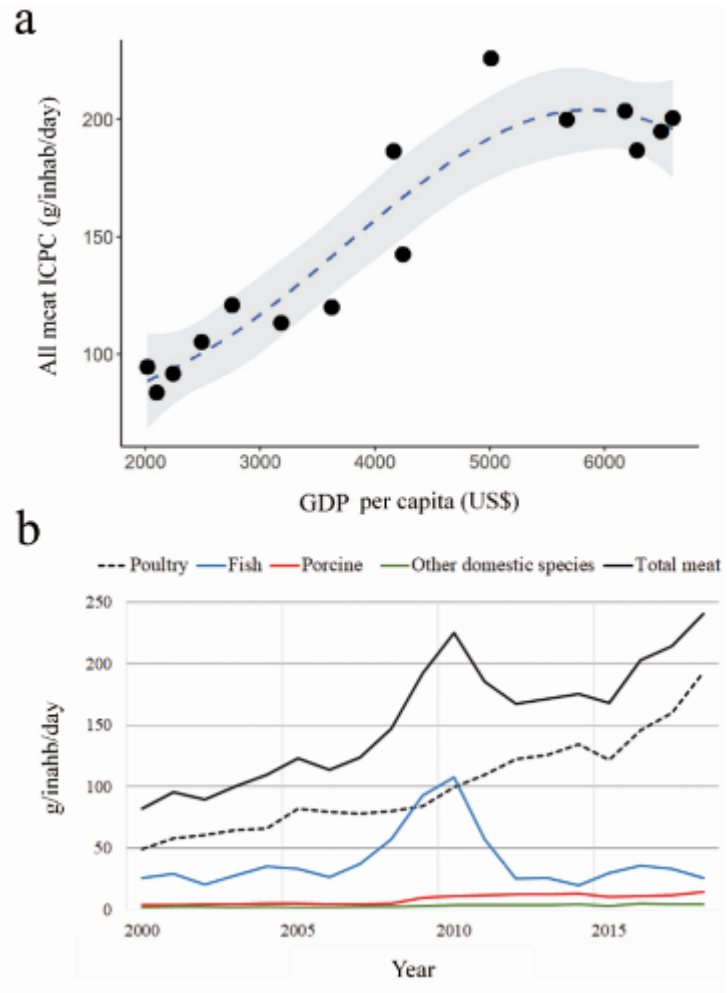
Figure 3



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