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

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Article impact statement: Community-based wildlife management, trade bans for threatened taxa

Abstract

The trade in wild meat is an important economic component of rural people's livelihoods, but it has been perceived to be among 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 human-health challenge. We analyzed data from the largest longitudinal monitoring (1973–2018) of the most important urban wild-meat markets in Iquitos, Peru, to examine the trends in and impacts of these markets on people's livelihoods. Over the last 45 years, wild meat sales increased at a rate of 6.4 t/year (SD 2.17), paralleling urban population growth. Wild meat sales were highest in 2018 (442 t), contributing US$2.6 million (0.76%) to the regional gross domestic product. 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 growth in sales, the contribution of wild meat to overall urban diet was constant: 1–2%/year of total meat consumed. This result was due to greater availability and higher consumption of cheaper meats (e.g., in 2018, poultry was 45.8% cheaper and was the most consumed meat) coupled with the lack of economic incentives to harvest wild meat species in rural areas. Most wild meat was sold salted or smoked, reducing the likelihood of foodborne diseases. Community-based wildlife management plans and the continued trade bans on primates and threatened taxa may avoid biodiversity loss. Considering the recent COVID-19 pandemic, future management plans should include potential viral hosts and regulation and enforcement of hygiene practices in wild-meat markets.

KEYWORDS
Amazonia, bushmeat, mammals, public health, sustainability, urban markets, wildlife trade

Comercio de Carne de Monte en los Últimos 45 Años en la Amazonia Peruana

Resumen: El comercio de carne de monte es un componente económico importante del sustento de habitantes de zonas rurales, pero se ha percibido como una de las principales causas de la declinación de especies de vida silvestre. Recientemente, la pandemia de COVID-19 ha traído a la luz una preocupación adicional de los mercados de vida silvestre como un reto importante para la salud humana. Analizamos datos del monitoreo longitudinal más extenso (1973-2018) de los mercados urbanos de carne de monte más importantes en Iquitos, Perú, para examinar las tendencias y los impactos de estos mercados sobre el sustento de los habitantes. Las ventas de carne de monte incrementaron en and enforced hygiene practices in wild meat markets are needed to protect biodiversity and public health.

los últimos 45 años a una tasa de 6.4 t/año (DS 2.17), en paralelo con el crecimiento de la población. Las ventas de carne de monte fueron más altas en 2018 (442 t), aportando U.S. $2.6 millones (0.76%) al producto interno bruto de la región. Cinco especies de ungulados y roedores comprendieron el 88.5% de la biomasa comercializada. Especies vulnerables y en peligro representaron 7.0% y 0.4% de los individuos vendidos, respectivamente. A pesar del incremento de las ventas, la contribución de la carne de monte al total de la dieta urbana fue constante: 1–2%/año del total de carne consumida. Este resultado se debió a una mayor disponibilidad y consumo de carnes más baratas (e. g., en 2018 la carne de pollo fue 45.8% más barata y fue la más consumida) aparejado con la falta de incentivos económicos para cosechar carne de especies silvestres en áreas rurales. La mayor parte de la carne de monte se vendía salada o ahumada, reduciendo con ello la probabilidad de enfermedades transmitidas por alimentos. Los planes de manejo de vida silvestre basados en comunidades y la prohibición continua del comercio de primates y taxa amenazados pueden evitar la pérdida de biodiversidad. Considerando la reciente pandemia de COVID-19, los planes de manejo futuros deben incluir potenciales huéspedes virales y la regulación y aplicación de prácticas de higiene en los mercados de carne de especies silvestres.

PALABRAS CLAVE:
Amazonía, carne de monte, comercio de vida silvestre, mamíferos, mercados urbanos, salud pública, sustentabilidad

摘要: 野味贸易是农村人民维持生计的重要经济组成部分, 但也一直被认为是野生动物数量下降的主要原因之一。近期的新冠肺炎疫情暴露了野生动物市场另一个令人担忧的问题, 即对人类健康的重大挑战。本研究利用秘鲁伊基托斯市区内最重要的野味市场的最大纵向监测数据集 (1973–2018 年), 分析了野味市场的趋势及其对人们生计的影响。在过去的 45 年里, 野味销售量以每年 6.4 吨 (标准差 2.17) 的速度增长, 与城市人口增长同步。 2018 年野味的销售量最高 (442 吨), 为该地区国内生产总值贡献了 260 万美元 (0.76%) 。其中五种有蹄类和啮齿类动物占交易重量的 88.5%。易危物种和濒危物种分别占售出个体的7.0%和0.4%。尽管野味销售量有所增长, 但它对城市整体饮食的贡献仍保持不变, 占每年肉类消费总量的 1%–2%。这一结果是由于廉价的肉类有更高的供应量和消费量 (例如, 2018 年家禽价格比野味便宜 45.8%, 是消费最多的肉类), 再加上农村地区捕猎野味物种缺乏经济激励。此外, 该地区大多数野味都是腌制或熏制后出售的, 降低了导致食源性疾病的可能性。基于社区的野生动物管理计划以及对灵长类动物和受威胁物种的长期贸易禁令可能有助于遏制生物多样性丧失。考虑到近期的新冠肺炎疫情, 未来的管理计划应将潜在病毒宿主及野味市场卫生规范监管与执行纳入考虑。**【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 丛林肉, 野生动物贸易, 城市市场, 可持续性, 公共卫生, 哺乳动物, 亚马逊

INTRODUCTION

In tropical forests worldwide, wild meat represents a significant source of animal protein and income for rural and urban people (El Bizri et al., 2020; Fa et al., 2015). 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 centers (Chaves et al., 2017; Fa et al., 2015). 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 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 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 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, yet few studies have been conducted to assess the factors underlying wild meat trade in this region (van Vliet et al., 2014; El 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 (number 21147), 2000 (number 27308), and 2011 (number 29763), only authorized the sale of wild meat 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, illegal sale of wild meat remains the norm.

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

METHODS

Study area

This study was conducted in Iquitos, the largest city in the Peruvian Amazon, which had a population of 486,338 inhabitants in 2018 (Gobierno Regional de Loreto [GOREL], personal communication). In this region, there are few roads, and products, including wildlife products, are mainly transported from rural to urban centers through fluvial passage. Iquitos has two large open markets: Belén, which is one of the most important wild meat markets in Amazonia in terms of amounts traded, and Modelo, 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. Because the legislation on wild meat trade is not enforced and the traditional culture of consuming wild meat is supported 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, loggers, or by rural hunters, who 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

We used data from seven surveys conducted from 1973 to 2018 (Appendix S1). Data for 1973, 1986, and 1987, 1996, and 2001 and 2002 came from Castro et al. (1976), Bendayan (1991), Bodmer and Pezo (2001), and Bendayan and Bardales (2004), respectively. More recently, we conducted market surveys in September 2006–August 2007, November 2013–October 2014, and September 2017–August 2018.

We used long-term data gathered using similar survey methods from the same markets in Iquitos to assess changes in wild meat sales through time. In all surveys, interviews with market vendors were conducted and meat counts were taken daily or every 2 days. Castro et al. (1976) surveyed the markets of Belén, Central, and Camal for 5 months. Surveys in 1986 and 1987 (Bendayan, 1991), 1996 (Bodmer & Pezo, 2001), 2001 and 2002 (Bendayan & Bardales, 2004), 2006 and 2007, and 2017 and 2018 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 and 2014 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 methods performed all surveys. The method consisted of market vendors participating willingly in the survey. Vendors fully understood the study and were confident in their anonymity. To engage vendors and encourage participation, preliminary visits to the markets were made during the first 2 months before each survey period. Because mammals make up 70–80% of all wild meat traded in the Amazon (El Bizri et al., 2020), we 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 validated with observational information. We followed the ethical-human-subject guidelines in Buppert and McKeehan (2013). Interviewees were made comfortable with our research process by informing them of the study aims prior to the interview and by assuring them that all data would be anonymous. Respondents were free to participate or not. All regular vendors and a large number of occasional vendors of wild meat agreed to participate (5–10% of occasional sellers declined to participate). Survey questions are provided below.

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/month recommended to obtain proper accuracy and precision in wild meat sales and price estimations (Mayor et al., 2019). Interviews were conducted daily from 0600 to 1200. The date, species, type of meat preservation (fresh, salted, or smoked), selling price per kilogram, 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. We avoided double counting of meat brought out again the next day.

We counted the number of species sold at each market and listed them by threat category according to the International

Union for Conservation of Nature (IUCN) (2020). Unidentified species were grouped by genus and their threat category was filled in by identifying the most likely species traded within the genus.

The amount of salted and smoked meat recorded per species was transformed into fresh meat based on 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 masses were obtained from 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 * number individuals per species)/total number of individuals of all species sold.

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 kilogram of wild meat. Prices of all domestic meat products came from interviews conducted by the local government employees from 2006 to 2018 (GOREL, personal communication). During the survey conducted in 2017 and 2018, we interviewed local sellers to calculate the average daily price per kilogram of meat for all domestic species and the most frequently traded fish, *Prochilodus nigricans*. All prices were converted to U.S. dollars based on exchange rates from 10 October 2007 (PS3.00 = US$1.00), 4 July 2014 (PS3.28 = US$1.00), and 4 October 2018 (PS3.32 = US$1.00). We corrected prices based on the Peruvian yearly rate of 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 GDP, annual production and prices of meat of domestic animals and fish landing rates (GOREL, personal communication) in Iquitos from 2000 to 2018 in our 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 from 2000 to 2018. A similar index of wild meat consumption per capita considered the overall amount of wild meat sold annually and daily by the number of inhabitants. Data were expressed in terms of grams per inhabitant per year and grams per inhabitant per day. These indices were used to describe temporal trends in meat consumption and to estimate the relative importance of wild meat for the urban population.

Statistical analyses

We used generalized additive (GAMs) and linear models (GLMs) to assess temporal trends in wild meat amount, number of individuals, species richness, and average body mass of taxa traded from 1973 to 2018; the relationship between body mass and the amount of fresh wild meat and number of individuals traded per taxon (transformed to a log scale) and whether this relationship was similar among years; and the relationship between GDP per capita in Iquitos and 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 from 2000 to 2018 (period for which data on human population and consumption of domestic meat were available). In the results, we report the coefficient estimates of the GAMs and GLMs, which are the values used to multiply the predictor variables in the models. These values determine how many units the response variable increases or decreases as the predictor variable is increased by 1 unit. 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, University of Augsburg).

RESULTS

Trends of wild meat sales

The amount of wild meat biomass sold from 1973 to 2018 increased significantly at a rate of 6.4 t/year (estimate = 6.4 [SE 2.17], $t = 2.94$, $p = 0.032$) (Figure 1a & Table 1). The number of individuals traded also increased over time, but not significantly, likely because of the high number of primate individuals sold in 1973 (480 individuals that year) (estimate = 0.48, $t = 1.86$, $p = 0.12$) (Figure 1b & Table 1). Belén Market accounted for 65.2–68.2% of the total biomass sold, and the Modelo Market made up the difference.

An average of 15 (SD 3.5) taxa of wild mammals was sold in Iquitos from 1973 to 2018, a decrease over time in the richness of taxa sold (rate of decrease 0.17 species/year) (estimate = −0.17 [SE 0.06], $t = -2.85$, $p = 0.036$) (Figure 1c). In all surveys from 1973 to 2018, Artiodactyla was the most traded order in terms of biomass (70.5% [SD 11.7]) and individuals (52.7% [14.7]), followed by Rodentia (25.7% [9.6] of biomass traded and 44.6% [14.5] of individuals traded) (Table 2). Large numbers of primates were sold in 1973 (six 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,

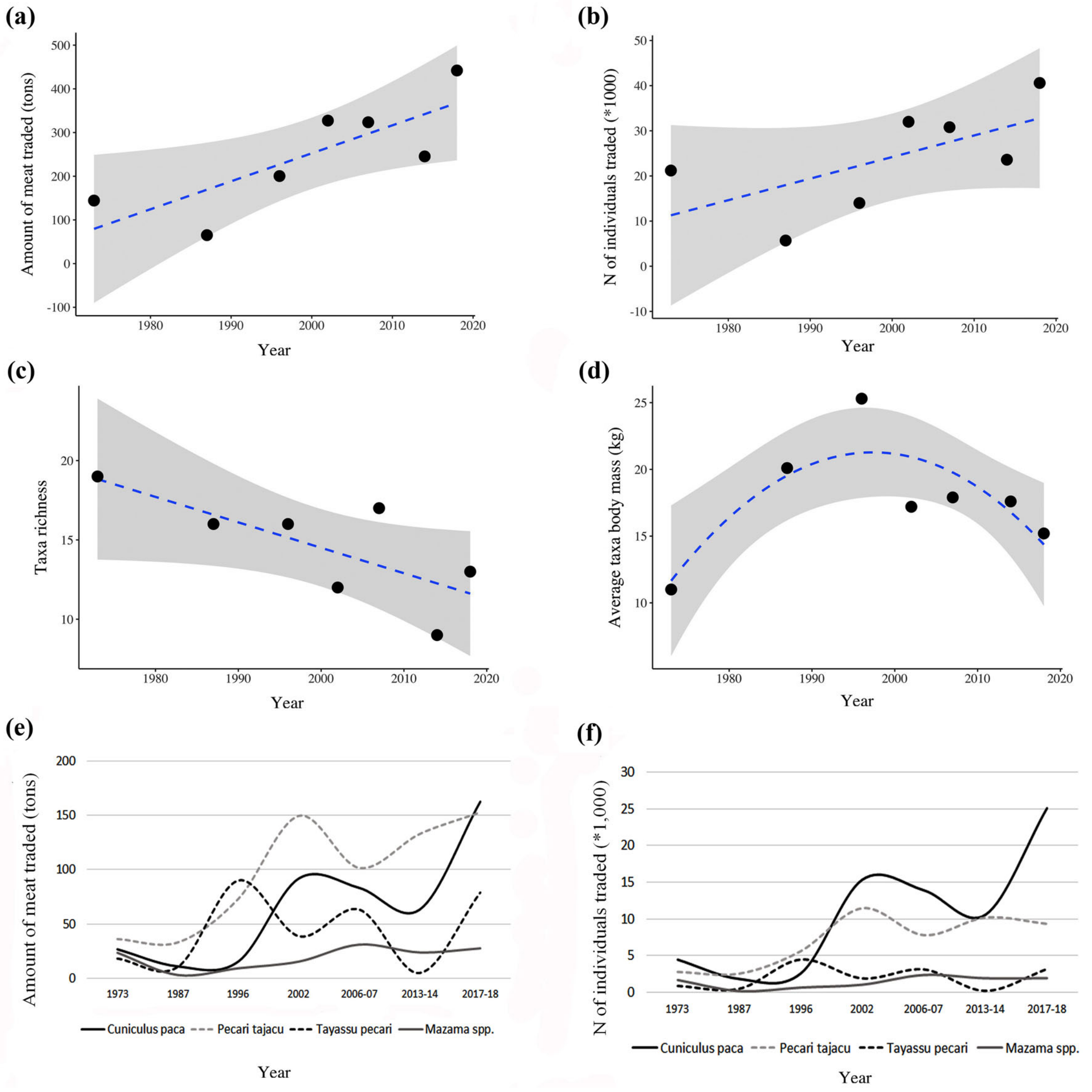

FIGURE 1 Trends in trade of wild meat in Iquitos from 1973 to 2018: (a) overall biomass, (b) overall number of individuals, (c) number of different species, (d) average body mass, and (e) biomass and (f) number of individuals of species sold the most (shaded areas, 95% confidence intervals)

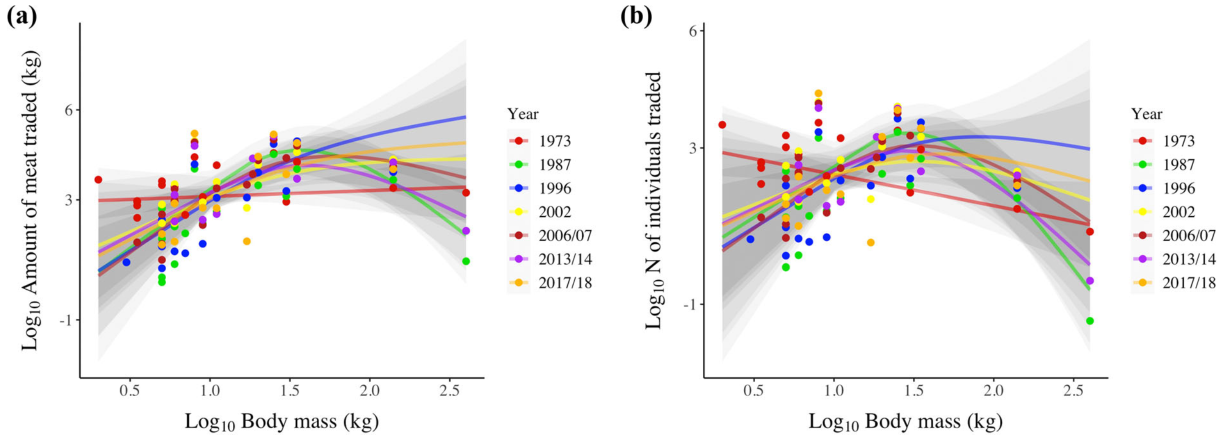

FIGURE 2 Association between body mass and (a) amount of fresh meat traded and (b) number of individual wild mammals sold in Iquitos from 1973 to 2018 (shaded areas, 95% confidence intervals)

TABLE 1 Kilograms of meat of wild mammals and number of individuals (in parentheses) sold per year in Belén and Modelo markets in Iquitos based on data from literature[a] (1973, 1986, and 1987, 1996, and 2001 and 2002) and from our surveys in 2006 and 2007, 2013 and 2014, and 2017 and 2018

Year and market sampled			1973[c]	1986 and 1987	1996	2001 and 2002	2006 and 2007	2013 and 2014[d]	2017 and 2018	Yearly average kg (%) [SD]	
Species (threat category)[b]	Body mass (kg)	Meat mass (kg)	Belén	Belén and Modelo	Belén and Modelo	Belén and Modelo	Belén and Modelo	Belén	Belén and Modelo	Biomass	Individuals
Alouatta seniculus (LC)	6	4	2736 (648)	7.2 (1.8)	19 (4.8)	168 (42)	947 (236)	192 (48)	40 (10)	587.18 [1003.0] (0.3 [0.7])	146.8 [250.8] (0.6 [1.2])
Ateles spp. (VU-EN)	9	6.6	1253 (190)	163 (25)	34 (5.2)	831 (126)	145 (22)	217 (33)	498 (83)	456.0 [447.7] (0.2 [0.3])	69.1 [67.8] (0.3 [0.3])
Cebus albifrons (LC)	3.5	2.1	912 (434)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	182.4 [407.9] (0.1 [0.2])	108.6 [217.1] (0.3 [0.8])
Coendou sp. (DD-LC)	3.5	2.1	252 (120)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	50.4 [112.7] (0.0 [0.1])	30.0 [60.0] (0.1 [0.2])
Cuniculus paca (LC)	8	6	26,640 (4440)	10,876 (1812)	15,397 (2566)	91,950 (15,325)	83,264 (13,877)	63,310 (10,552)	162,753 (25,037)	64,884.5 [53,974 (22.7 [9.4])	10,515.7 [8378.0] (38.6 [15.6])
Dasyprocta fuliginosa (LC)	5	2	4194 (2097)	516 (258)	219 (110)	705 (325)	329 (164)	0 (0)	73 (36)	862.3 [1489.4] (0.6 [1.1])	431.1 [744.7] (2.4 [3.6])
Dasypus spp. (LC)	6	4	874 (218)	130 (32)	187 (47)	3325 (831)	2285 (571)	1468 (367)	763 (186)	1290.3 [1167.4] (0.5 [0.3])	321.9 [292.2] (1.2 [0.8])
Didelphis marsupialis (LC)	3	1.8	0 (0)	0 (0)	8.3 (4.6)	0 (0)	0 (0)	0 (0)	0 (0)	1.4 [3.4] (0.0 [0.0])	0.9 [2.1] (0.0 [0.0])
Hidrochaeris hidrochaeris (LC)	30	12	864 (72)	1323 (110)	1975 (164)	540 (45)	24,917 (2076)	0 (0)	7132 (554)	6035.2 [9587.2] (1.8 [2.7])	431.8 [748.3] (1.7 [2.3])
Lagothrix spp. (VU)	11	8	14,302 (1788)	418 (52)	1176 (147)	3974 (497)	2442 (305)	338 (42)	526 (66)	3311.0 [5025.4] (1.9 [3.5])	413.9 [628.2] (1.9 [2.9])
Mazama americana (DD)	20	13.7	23,677 (1691)	3048 (218)	8149 (582)	14,974 (1069)	20,836 (1488)	0 (0)	27,720 (1932)	14,058.0 [10,643.7] (6.1 [5.0])	1000.7 [750.7] (4.1 [2.4])
Mazama nemorivaga (DD)	17	11	0.0 (0.0)	0.0 (0.0)	1195 (109)	0 (0)	3207 (292)	0 (0)	42 (4)	711.9 [1187.3] (0.2 [0.4])	90.6 [120.6] (0.3 [0.4])
Mazama spp. (DD-LC)	18.5	1.25	0.0 (0.0)	0.0 (0.0)	0 (0)	0 (0)	7177 (574)	23,983 (1919)	0 (0)	6232.1 [10,398.4] (1.7 [3.6])	623.2 [905.1] (1.7 [3.2])

(Continues)

TABLE 1 (Continued)

Year and market sampled			1973[c]	1986 and 1987	1996	2001 and 2002	2006 and 2007	2013 and 2014[d]	2017 and 2018	Yearly average kg (%) [SD]	
Species (threat category)[b]	**Body mass (kg)**	**Meat mass (kg)**	**Belén**	**Belén and Modelo**	**Belén and Modelo**	**Belén and Modelo**	**Belén and Modelo**	**Belén**	**Belén and Modelo**	**Biomass**	**Individuals**
Myoprocta pratti (LC)	5	2	0.0 (0.0)	1.8 (0.9)	0 (0)	0 (0)	10 (5)	0 (0)	32 (16)	8.8 [13,6] (0.0 [0.0])	4.4 [6.8] (0.0 [0.0])
Nasua nasua (LC)	5	3	0.0 (0.0)	50 (17)	28 (9.3)	168 (56)	34 (11)	0 (0)	0 (0)	40.0 [59,8] (0.0 [0.0])	15.8 [20.9] (0.1 [0.1])
Pecari tajacu (LC)	25	13	36,366 (2797)	33,290 (2561)	73,291 (5638)	149,454 (11,496)	101,647 (7.819)	132,872 (10,221)	152,658 (9365)	97,082.6 [50,752.7] (39.8 [10.7])	7128.2 [3559.2] (32.3 [11.9])
Pithecia sp. (DD-LC)	3.5	2.1	648 (309)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	129.6 [289.8] (0.1 [0.2])	77.1 [154.3] (0.2 [0.5])
Potos flavus (LC)	5	3	4716 (1044)	2.6 (0.9)	5.2 (1.7)	0 (0)	0 (0)	0 (0)	0 (0)	523.4 [1278.2] (0.3 [0.8])	174.5 [426.1] (0.7 [1.8])
Proechimys spp. (DD-LC)	2	1.2	4716 (3930)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	943.2 [2109.1] (0.5 [1.2])	982.5 [1965.0] 82.6 [7.0])
Sapajus apella (LC)	3.5	2.1	864 (411)	0 (0)	0 (0)	0 (0)	38 (17)	0 (0)	0 (0)	180.4 [382.4] (0.1 [0.2])	107.0 [203.1] (0.3 [0.7])
Tamandua tetradactyla (LC)	7	4.2	315 (75)	76 (18)	17 (3.9)	0 (0)	0 (0)	0 (0)	0 (0)	68.0 [124.5] (0.0 [0.0])	16.2 [29.7] (0.1 [0.2])
Tapirus terrestres (VU)	140	90	2493 (28)	4692 (52)	8499 (94)	22,290 (248)	12,799 (142)	17,979 (200)	10,565 (109)	11,331.0 [7038.6] (4.8 [2.3])	124.8 [78.4] (0.6 [0.3])
Tayassu pecari (VU)	35	20	18,352 (918)	10,641 (532)	90,211 (4510)	38,913 (1946)	63,404 (3.170)	5052 (253)	79,125 (3227)	43,671.3 [34,298.9] (17.9 [13.2])	2079.3 [1608.1] (10.2 [10.2])
Trichechus inunguis (VU)	400	240	1732 (7)	9 (0.04)	0 (0)	0 (0)	93 (0)	0 (0)	0 (0)	366.9 [764.4] (0.2 [0.4])	1.5 [3.2] (0.0 [0.0])
Total			144,325 (21,246)	65,237 (5692)	200,411 (13,997)	327,293 (32,061)	323,576 (30,772)	245,412 (23,634)	441,977 (40,647)	249,748.5 [126,506.8] (100)	24,007.1 [11.768.0] (100)

[a]Sources: 1973 Castro et al. (1976), 1986 and 1987, Bendayan (1991), 1996 Bodmer and Pezo (2001), and 2001 and 2002 Bendayan and Bardales (2004).
[b]Threat categories according to International Union for Conservation of Nature 2020: DD, data deficient; LC, least concern; VU, vulnerable; EN, endangered.
[c]Local markets included the large market of Belén and two minor markets (Arequipa and Central). Modelo market did not exist at the time.
[d]Modelo market was not surveyed in 2013 and 2014, but we estimated total amount of meat based on the average representativeness of the wild meat amount traded in these markets (33.3% and 66.7% in Modelo and Belén markets, respectively).

TABLE 2 Kilograms of fresh meat of wild mammals[a] and number of individuals by taxonomic order sold in local markets in Iquitos from 1973 to 2018. Numbers in parentheses are the percentages of each order within each year

	Year	Artiodactyla 6 species	Rodentia 4 species	Primates 4 species	Cingulata 3 species	Carnivora 2 species	Total 19 species
Kg body mass (SD)		42.6 (48.2)	12.0 (12.1)	6.1 (3.2)	5.3 (2.1)	4.75 (0.35)	18.89 (30.8)
Kg eviscerated mass (SD)		26.8 (31.1)	5.5 (4.7)	4.6 (2.6)	3.3 (1.3)	2.8 (0.2)	11.54 (19.7)
Total biomass sold (kg/year)	1973	80,889 (56.0)	36,666 (25.4)	20,715 (14.4)	874 (0.6)	3132 (2.2)	144,325 (100.0)
	1986 and 1987	51,672 (79.2)	12,717 (19.5)	588 (0.9)	130 (0.2)	53 (0.1)	65,246 (100.0)
	1996	181,345 (90.5)	17,591 (8.8)	1229 (0.6)	187 (0.1)	33 (0.0)	200,411 (100.0)
	2001 and 2002	226,171 (69.1)	92,655 (28.3)	4974 (1.5)	3325 (1.0)	168 (0.1)	327,293 (100.0)
	2006 and 2007	209,071 (64.6)	108,520 (33.5)	3573 (1.1)	2285 (0.7)	34 (0.0)	323,576 (100.0)
	2013 and 2014[b]	179,887 (73.3)	63,310 (25.8)	748 (0.3)	1468 (0.6)	0 (0.0)	245,412 (100.0)
	2017 and 2018	270,109 (61.1)	169,990 (38.5)	1115 (0.3)	763 (0.2)	0 (0.0)	441,977 (100.0)
Total individuals sold (ind./year)	1973	5434 (25.6)	10,659 (50.2)	3816 (18.0)	219 (1.0)	1044 (4.9)	21,247 (100.0)
	1986 and 1987	3363 (59.1)	2182 (38.3)	79 (1.4)	32 (0.6)	18 (0.3)	5691 (100)
	1996	10,934 (78.1)	2840 (20.3)	157.0 (1.1)	47 (0.3)	11.1 (0.1)	13,997 (100.0)
	2001 and 2002	14,822,7 (46.2)	15,723 (49.0)	665 (2.1)	831.3 (2.6)	56.0 (0.2)	32,061 (100.0)
	2006 and 2007	13,486 (43.8)	16,123 (52.4)	581 (1.9)	11 (0.0)	11 (0.0)	30,772 (100.0)
	2013 and 2014[b]	12,592 (53.3)	10,552 (44.6)	123 (0.5)	367 (1.6)	0.0 (0.0)	23,634 (100.0)
	2017 and 2018	14,638 (36.0)	25,644 (63.1)	159 (0.4)	186 (0.5)	0 (0.0)	40,647 (100.0)

[a]The orders Sirenia, Didelphimorphia, and Pilosa are not included here due to their low representativeness (<0.1%).
[b]The Modelo market was not surveyed in 2013 and 2014, 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 markets, respectively).

and, more recently, excluded as sustainably hunted species in community wildlife plans. From 1987 onward, the trade of primate meat diminished sharply, decreasing to 0.8% of the overall biomass traded in 2013 and 2014, and 2017 and 2018.

Taxa with large body masses were usually sold in larger quantities than small species, both in terms of biomass (spline term = 3.21, $F_{3.63} = 19.73$, $p < 0.001$) and individuals (spline term = 3.26, $F_{3.67} = 13.15$, $p < 0.001$), but with a decrease in quantities sold for taxa with body mass higher than 100 kg (Figure 2). An inverted U-pattern described the temporal trend in the average body mass of species sold (Figure 1d) (polynomial estimate 1 = 1.91, polynomial estimate 2 = −8.68 [SE 3.00], $t = -2.9$, $p = 0.04$) and was due to an increase in the average body mass of species sold from 1973 to 2002 and the decline of the sales of white-lipped peccary (*Tayassu pecari*) in 2014.

Five taxa made up 88.5% (SD 7.6) of the total biomass sold in all years (Figures 1e,f): paca (*Cuniculus paca*), collared peccary (*Pecari tajacu*), white-lipped peccary, and red (*Mazama americana*) and grey (*Mazama nemorivaga*) brocket deer. The collared peccary was the most frequently sold taxon in terms of biomass (39.8% [10.7]) and the second most sold in terms of individuals (32.3% [11.9]). The paca was the most commonly sold taxon in terms of individuals (38.6% [15.6]) and the second most sold in terms of biomass (22.8% [9.4]). White-lipped peccary sales crashed in the 2013 and 2014 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 (5052 kg, 2.1%). As white-lipped peccary sales declined, paca sales increased. In 2017 and 2018, the trade in white-lipped peccary showed signs of increasing (79,125 kg, 17.9%). Red and grey brocket deer were also frequently sold (27,762 kg, 8.0% [4.3]) (Table 1).

Five Vulnerable species, woolly monkey (*Lagothrix* spp.), spider monkey *Ateles* spp., white-lipped peccary, and lowland tapir (*Tapirus terrestris*), accounted for 5.6% (SD 4.2) of individuals sold (range 1.8–11.1%). Prior to 2006, primates represented 72.8% (17.8) of threatened taxa sold. From 2006 onward, white-lipped peccary and tapir were uplisted to Vulnerable and accounted for 91% of threatened taxa (75.9% [24.4] and 15.0% [19.8], respectively), and primates decreased to 9.2% (5.0).

There was no significant difference between survey year and type of meat preservation ($\chi^2 = 24$, df = 22, $p = 0.3472$). Smoked wild meat represented 54.1%, 53.5%, and 56.0% of the biomass sold in 2006 and 2007, 2013 and 2014, and 2017 and 2018, respectively. In these same years, salted wild meat accounted for 31.4%, 32.5%, and 40.0% and fresh meat accounted for 14.5%, 14.0%, and 4.0% of biomass sold, respectively.

Economic value of wildlife

From 2006 to 2018, consumers spent US$1,053,851 (2006 and 2007), US$1,217,673 (2013 and 2014), and US$2,591,591 (2017 and 2018) on wild meat in the markets of Iquitos. Taking into account yearly inflation, wild meat presented a similar economic benefit for the regional economy from 2006 and 2007 to 2013 and 2014 (US$1,053,850 and US$999,223, respectively), but showed a growth of 92.0% in 2017 and 2018 (US$1,918,972).

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 and 2007, 2013 and 2014, and 2017 and 2018

	Official average prices (USD/kg)[a]			Price difference between years (%)			Local average prices (SD) (US$/kg)	Difference compared with wild meat (%)
Meat type	2006 and 2007	2013 and 2014	2017 and 2018	2014 versus 2007	2018 versus 2014	2018 versus 2007	2017 and 2018	
Poultry	1.93	2.38	2.21	23.2	−7.2	14.4	3.14 (0.32)	45.8
Regional hen	3.65	3.66	4.01	0.3	9.7	10.0	–	–
Pork	1.50	1.55	2.14	3.5	37.6	42.4	4.36 (0.22)	24.7
Beef	2.07	1.37	1.66	−33.6	20.7	−19.8	4.81 (0.23)	16.9
Total domestic meat	2.29	2.24	2.50	−2.2	11.6	8.4	4.10 (0.76)	29.2
Fish	–	–	–	–	–	–	3.06 (0.17)	47.1
Wild meat	2.88	4.26	5.79	47.9	35.9	101.0	5.79 (0.24)	0.0

[a]Official average prices of domestic animals (poultry, pork, and beef) were obtained from the Dirección Regional de Agricultura de Loreto (personal communication).

The price was significantly influenced by the year, taxon, and type of meat preservation; the interaction between taxon and type of meat preservation was significant ($F_{15,8487} = 8.24$, $p <$ 2.2e-16). The average selling price of wild meat grew by 101.0% from US$2.88/kg (SD 0.25) (2006 and 2007) to US$4.26/kg (0.93) (2013 and 2014) and to US$5.79/kg (0.74) (2017 and 2018) ($F_{2,8487} = 9739.1, p < 0.001$) (Table 3). Paca was the most expensive meat ($F_{8,8496} = 715.7, p < 0.001$), followed by brocket deer and peccaries; tapir and primates were the least expensive. Preservation method also affected the price ($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 decreased 9.9%, from US$2.21/kg (0.60) in 2006 and 2007 to US$1.91/kg (0.23) in 2017 and 2018. The increase in sale prices and the decrease in purchase price resulted in an increase in average profit per kilogram of wild meat of 214.1% for vendors: 30.3% (2006 and 2007) to 67.0% (2017 and 2018).

In parallel, prices of domestic meat showed a moderate increase of 8.4% from 2006 and 2007 to 2017 and 2018. Poultry, the most purchased meat, increased in price by 14.4%, from US$1.93 (2006 and 2007) to US$2.21 (2017 and 2018). In 2017 and 2018, wild meat was the most expensive meat; average price was 47.1% higher than the most frequently consumed fish, *P. 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 and relatively constant over the years (1.99 g/inhabitant/day [SD 0.49], t = 0.60, p = 0.58); minimum and maximum rates were 435 and

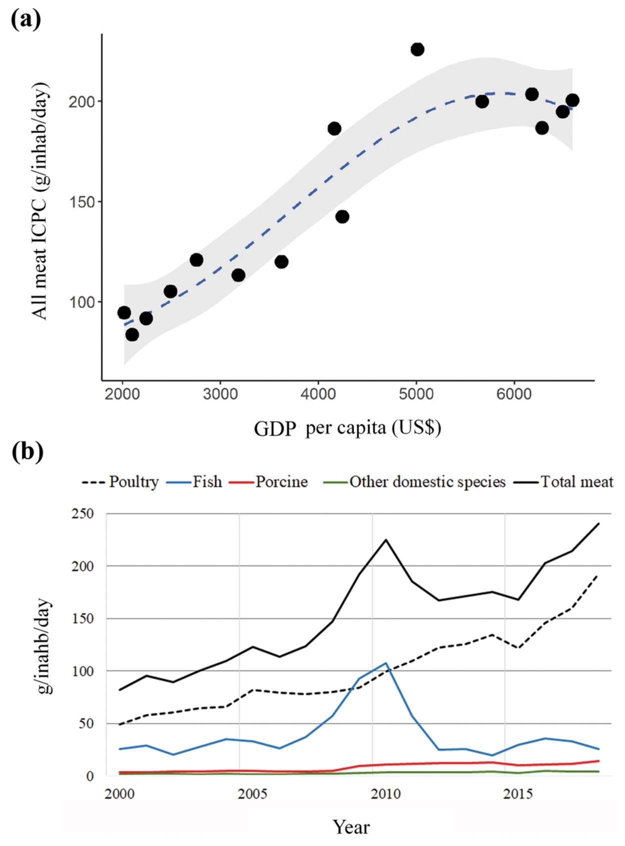

FIGURE 3 Trends in consumption of (a) overall animal protein (ICPC) relative to per capita gross domestic production (GDP) and (b) of domestic meat and fish (Dirección Regional de Agricultura de Loreto, personal communication) and fish (Dirección Regional de la Producción de Loreto, personal communication) in Iquitos during from 2001 to 2015 (total includes domestic meat, fish, and meat of wild mammals) (shaded area, 95% confidence interval)

926 g/inhabitant/year (1.0 and 2.5 g/inhabitant/day) in 2013 and 2014, and 2006 and 2007, respectively. Wild meat represented only 3.2% of total meat consumed in 2001 and 2002, and its contribution decreased to 0.7% (2013 and 2014) and 0.9% (2017 and 2018). From 1973 and 2018, the human population in Iquitos grew from 182,738 to 486,338. The GDP per capita showed an average yearly increase of 8.5% (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.

Gross domestic product per capita and the ICPC of all meat pooled were highly associated (estimate = 0.026 [SE 0.003], $t = 7.96$, $p < 0.001$) (Figure 3a). The daily consumption of domestic species increased from 56.3 (2000) to 215.1 (2018) g/inhabitant/day, an average yearly increase of 8.1% (SD 8.7). Poultry was the most consumed meat, and daily consumption increased yearly by 8.2% from 49.4 (60.2% of total meat) g/inhabitant/day in 2000 to 192.9 (80.1%) g/inhabitant/day in 2018 (Figure 3b). Although the daily consumption of fish remained constant, its dietary contribution decreased from 31.4% to 10.6%. Daily consumption of sheep, buffalo, pork, and beef showed a yearly increase of 21.6%, 15.7%, 9.9%, and 5.9%, respectively, but their contribution to overall meat consumption was low (≤ 5%).

DISCUSSION

The emergence of the COVID-19 pandemic initiated substantial global political and economic changes and brought about one of the main challenges humanity has ever faced with links to loss of biodiversity and human health and food security. Our results provide fundamental information for decision makers regarding the sustainability and risks posed by trade of wild meat. With 45 years of data, we were able to assess trends and the economic and sociocultural drivers of wild meat trade in Amazonia.

The population of Iquitos has been rising 1.3%/year. This increase is due to both population growth and urban migration. Thus, over the last five decades, overall wild meat sales in urban markets have increased, although ICPC remained constant. 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, in contrast to what we expected based on the findings from the Brazilian Amazon (Chaves et al., 2020), we did not find evidence of a decrease in wild meat consumption over generations. Even if ICPC were to remain constant, the overall sustainability threshold could be exceeded because of the constant increase in the urban population. This scenario needs consideration, and addressing the problem would require regulating all traded species, even nonthreatened ones, in order to ensure long-term sustainability.

Despite the increasing trend of the trade in wild meat, decreased levels of trade were recorded in the survey 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 and 2014 is likely explained by ecological factors. In the flooded forests of Loreto, the extreme floods of 2011–2015 caused large-scale die-offs of game species. Consecutive normal floods from 2016 to 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 and 2014.

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 transitioning from a traditional dietary component to a complementary and expensive but still relatively affordable meat. Simultaneously, the rise of domestic meat production, especially the poultry industry, has resulted in higher consumption of protein from domestic species. From 2001 to 2014, poultry production grew by 284% and comprised 76% of the total daily meat 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; meat sales maintained low levels (<2% of total meat traded). The higher price of wild meat compared with that of fish (+47%) and poultry (+45%) likely contributed to restricting its accessibility.

Based on the optimal foraging theory, hunters should harvest the most profitable and largest prey available (Hawkes et al., 1982). Accordingly, we found that species with relatively high body mass were generally traded more often. However, we detected an inverted U-shaped curve in the amount of meat and individuals traded caused 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 based on body mass. Tapir is in 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 species, the collared peccary and the paca, are less vulnerable to overhunting and more likely 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, creation and reinforcement of management strategies to ensure these species are hunted sustainably are needed. The Peruvian Forestry and Wildlife Service 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 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 (Lemos et al., 2021). The presence of primates in the markets in Iquitos is low compared with 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 disease spillover from animals 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 to continue to exclude primates from sustainable-use wildlife management plans.

The amount of money spent by consumers provides 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 with other commercial activities, wildlife sales make up a relatively low proportion of the total GDP (oil industry 81.1%, fisheries 6.9%, agriculture 5.7%, and timber industry 4.6% [DDPI–Mincetur, 2018]). Unlike other activities, the harvest and trade in wildlife does not generate longstanding socioenvironmental conflict (Yusta et al., 2017). Trade in wild meat in Iquitos has the potential to increase the economic returns for local people. However, although urban vendors optimized their economic performance, with a 55% increase from 2006 to 2018, there was no similar economic incentive for rural people to participate in the trade (their profits decreased by 10%). Because urban sale of wild meat is mostly illegal, it is excluded from official statistics. This hampers tracking of the actual economic value of wildlife, which is why wildlife specialists have been collecting market sales intermittently over the past 45 years.

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 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 in the Peruvian Amazon have been approved 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 a public health concern, and the recent emergence of COVID-19 has put wild meat at the center of this discussion. In Amazonian markets, wild meat and animals are often stored for sale in open-air settings and in close proximity to domestic meat, which breaches 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 levels of nutrients, in combination with high humidity, plays an essential role in the proliferation and survival of microorganisms in the meat and on wood surfaces (Carpentier, 1997).

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 hygiene practices.

The meat preservation methods of salting, drying, and smoking have a long tradition. In Iquitos, 85% of wild meat is sold smoked or salted, which reduces sanitary risks. Fresh carcasses are more likely to be contaminated with a variety of microorganisms (Alekruse et al.,). A range of pathogens are susceptible to changes in temperature, pH, relative humidity, and time. Many viruses may be deactivated when exposed to 60° C temperatures for 60 min (e.g., 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, proper salting and smoking should significantly reduce sanitary risks. However, further studies into this subject are 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 to a species' ability to adapt to human-dominated landscapes; domesticated species, primates, and bats have more zoonotic viruses than other species (Johnson et al., 2020). Local markets involve wild and domestic species in close proximity, providing opportunities for pathogens to move between them. Alternatively, the combination of restrictive regulations, creation of management strategies that sustain trade in wild meat, and effective educational programs on appropriate hygiene practices may sustain wild meat trade and resolve sanitation problems. As main restrictive measures, we advocate banning trade in live animals and fresh wild meat and that the sale of primate meat remain prohibited. These measures should ultimately meet peoples' needs and safety, reduce the potential risks involved with the animal–human interaction during the trade and consumption of wild meat, and contribute to sustainable use and conservation of wildlife.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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