frontiers | Frontiers in Conservation Science

TYPE Original Research
PUBLISHED 21 October 2024
DOI 10.3389/fcosc.2024.1464332



OPEN ACCESS

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RECEIVED 13 July 2024
ACCEPTED 10 September 2024
PUBLISHED 21 October 2024

CITATION
D'Cruze N, Elwin A, Perez-Peña PE, Vieto R, Asfaw AE and Harrington LA (2024) Wildlife trade at Belén and Modelo market, Peru: defining a baseline for conservation monitoring. *Front. Conserv. Sci.* 5:1464332. doi: 10.3389/fcosc.2024.1464332



# Wildlife trade at Belén and Modelo market, Peru: defining a baseline for conservation monitoring

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**Introduction:** Domestic wildlife markets have important nutritional, medicinal, cultural, and financial significance for local communities, but the scale and diversity of wildlife trade that passes through them is also associated with negative impacts on biodiversity, poor animal welfare, and potential human health risk. To design, and monitor the effectiveness of, interventions to ameliorate such impacts, an understanding of the species sold at the markets and their purpose is required, together with a robust (and potentially flexible) baseline. Here we focus on Belén (the largest open wildlife market in the Peruvian Amazon) and Modelo market, in Iquitos, Peru.

**Methods:** We surveyed wildlife products for sale at both markets approximately weekly over a year, using two different survey methods (open and discreet). To provide a baseline to support future conservation monitoring, we estimated a number of different market metrics (including indices of product availability, volume (observed per survey), and price), for the most frequently observed species 'groups', and compared indices of trade volume with daily river water levels. To provide a complete understanding of the range of species involved, we also described all threatened species recorded at the markets, the products sold, and their uses, including those that were only observed occasionally.

**Results:** Both markets sold predominantly wild meat, and some pets; at Belén Market >30% observations were of decorative, spiritual, or medicinal products. At least 71 unique species (including mammals, reptiles, birds, and invertebrates) were observed in total. The most frequently observed species 'groups' were: lowland paca, peccaries, caiman, river turtles, boas, yellow footed tortoise, parrots, and brocket deer. 27.7% of species were threatened or Near Threatened globally or nationally but there was no evidence that discreet surveys increased their detection. Daily river water levels were positively correlated with indices of trade volume for lowland paca, caiman, and yellow-footed tortoise, and negatively correlated with indices of trade volume for parrots and river turtle eggs.

10.3389/fcosc.2024.1464332

**Discussion:** Beyond providing a comparative dataset, and insights regarding the apparent availability and value of a diversity of products (including food items, live pets, and other decorative, spiritual, and medicinal items), we suggest that simulations using these data could be used to optimize future monitoring efforts. Finally, our observations of correlations of per survey trade volumes of some species with daily river water levels in Iquitos may inform optimal time of year for species- specific surveys.

KEYWORDS

**pets, belief-based use, illegal wildlife trade, traditional medicine, wild-meat**

# 1 Introduction

In conservation, interest in wildlife use tends to focus predominantly on international, illegal wildlife trade (IWT), primarily of a few high-profile threatened taxa (Sas-Rolfes et al., 2019). However, the scale and diversity of wildlife trade that passes through local, domestic wildlife markets can be substantial and the impacts on biodiversity significant. Across the tropics, an estimated six million tons of animals (mostly ungulates and rodents) are extracted from the wild every year for wild meat (Nasi et al., 2011), and overhunting (for food and medicines) is considered among the most immediate threats to the persistence of hundreds of tropical vertebrate species (Ripple et al., 2016; Ingram et al., 2021; Brashares et al., 2004). Alongside food and medicines, local wildlife markets may sell wild animal body parts as talismans (objects believed to have protective powers or bring luck), or decorative items (e.g. Nijman and Nekaris, 2014) and live wild animals as pets (e.g. Regueira and Bernard, 2012). This trade can be a serious threat to wild populations (e.g. Harris et al., 2017; Nijman et al., 2022 and references therein), has welfare impacts for individual animals (e.g. Baker et al., 2013), and potential health impacts for humans (Warwick and Steedman, 2021). Talismans and decorative or fashionable items derived from protected or globally threatened species are often openly sold (e.g. Nijman and Nekaris, 2014), and their trade fuelled not only by local consumers but also by international tourists (through purchases and photo tourism, e.g. Braczkowski et al., 2019; Kapera and Kapera, 2021).

Identifying appropriate solutions to mitigate the conservation impacts of domestic wildlife markets in the tropics is challenging (Milner-Gulland and Bennett, 2003; Cawthorn and Hoffman, 2015) because bushmeat often provides an important and affordable source of protein for local communities (Ingram et al., 2021), the use of local, traditional products (for medicines and belief-based purposes) may be culturally important (e.g. Williams and Whiting, 2016), and the markets themselves (and associated hunting) provide jobs and income (often in rural areas where there are few alternatives, Leberatto, 2017; Prasad et al., 2022). Monitoring the effectiveness of any action taken is also challenging because it requires data (population densities and productivities of hunted wildlife species) that are often difficult, costly, and time consuming to obtain, and rarely exist (Milner-Gulland and Bennett, 2003), especially for markets dealing in diverse species and diverse products. In the absence of high-quality wildlife population data for key species, market data (i.e. changes in price and trade volume) can, however, provide useful insights (Harris et al., 2017) provided any change in hunting methods or effort can be accounted for (e.g. Nijman, 2022), and the markets are monitored and compared against a robust baseline.

Although wildlife and bushmeat markets occur across the world, studies characterizing this type of trade have generally focused on African and Asian markets (Peros et al., 2021). There are relatively few studies of Latin American bushmeat markets (exceptions are Bodmer and Lozano, 2001; Vliet et al., 2014; Mayor et al., 2019, Mayor et al., 2022; D'Cruze et al., 2021) and wildlife trade research is comparatively neglected in this region (Esmail et al., 2020), domestic trade in particular (Mendoza et al., 2022). Despite the lack of previous research and policy focus, wildlife trade in Latin America has been recognized as one of the top emerging issues in this field, in part because of the vast range of commodity types traded (Esmail et al., 2020). Peru, in particular, is considered an important wildlife trade hotspot in the Latin America region (Reuter et al., 2018). Commercialization of wildlife products that are not sourced from legal origins (i.e. captive breeding sites or managed areas), and without permits, is prohibited in Peru (Article 126 Law 29763) but there is generally little enforcement of this law (Mayor et al., 2022; World Animal Protection, 2021), and consumption of wildlife-origin items (particularly bushmeat) is commonplace (D'Cruze et al., 2021; Moorhouse et al., 2024).

Belén Market, located in Iquitos, is considered to be the largest and most important open market selling wildlife in the Peruvian Amazon (Mayor et al., 2019). This market is known to trade in a wide variety of wildlife products, primarily wild meat (Bodmer and Lozano, 2001), which is typically considered a traditional food item for urban consumers in Iquitos, rather than a daily staple such as domesticated chicken and fish (Mayor et al., 2019). The market also sells wildlife-origin traditional medicinal and spiritual or belief-based items, along

with wild animal pets (Mayor et al., 2019). In addition to Belén, smaller open-air markets contribute to the wider wildlife trade network in and around Iquitos. Local markets in Peru are also popular amongst international travellers (Braczkowski et al., 2019) and Belén Market in particular is advertised online as a unique tourist destination with guided tours available from a number of local and international tourism operators (e.g. https://www.perunorth.com/news/2023/6/6/Bel%C3%A9n-market-iquitos).

An earlier survey of wildlife markets in and around Iquitos (D'Cruze et al., 2021) was carried out with the aim of identifying the species most likely to be affected by trade. D'Cruze et al. (2021) questioned market vendors directly and sought to understand which species vendors considered most profitable, which they perceived to have increased in rarity, and what purpose they were sold for. In the current study, we use observational data obtained from a 12-month market monitoring survey to describe the nature of wildlife trade at Belén Market and a neighbouring outdoor food market (Modelo) in terms of the species involved and the products sold, and to quantify key market metrics for potential indicator species and products, with a view to establishing a robust baseline for conservation monitoring against which the effectiveness of future behaviour change initiatives and other IWT reduction strategies can be assessed. Specific objectives of the study were: (1) to provide an overview of species and products offered for sale at both markets over a 12-month period; (2) to quantify product availability, volume traded, and price, for the most frequently observed wild animal species or groups of species; (3) to record observations (and uses) of threatened species observed infrequently; and (4) to compare and summarize key differences between the two different data collection approaches to inform future monitoring efforts (the first being a more open systematic approach carried out by taxonomists and the second being applied in a more discreet manner by journalists).

# 2 Materials and methods

## 2.1 Study area

Belén Market lies on the banks of the Itaya River, close to the edge of the Belén District in the city of Iquitos (see Figure 1; Supplementary Data Sheet 1). Iquitos city in the Department of Loreto, north-east Peru (73.2′ W, 3.7° S), is situated ~120 m above sea level at the confluence of the Nanay, Itaya, and Amazon Rivers in the Amazon River Basin. Most of the population is mixed Spanish and American Indian (Mestizo). The urban area of Iquitos merges with peri urban and rural populations and is surrounded by secondary rainforest, with transportation into and out of the city confined to boats and aeroplanes. The climate in Iquitos is hot, humid, and rainy throughout the year. Mean daily precipitation ranges from 155 mm in August to 350 mm in March, and rainfall is heaviest between November and May. The mean daily temperature ranges from 26.3°C in July to 27.6°C in November.

Iquitos comprises four principal districts with a combined population of 413,556. The districts are Iquitos (population 146,853), San Jaun Bautista (127,005), Punchana (75,210), and Belén (64,488) (INEI, 2023). Belén Market is located on several streets in Belén District. In 2023, Belén Market contained approximately 61 permanent stalls selling wildlife along with a number of temporary stalls and sellers which varied weekly. Modelo Market is situated ~3 km north-east of Belén Market on the edge of

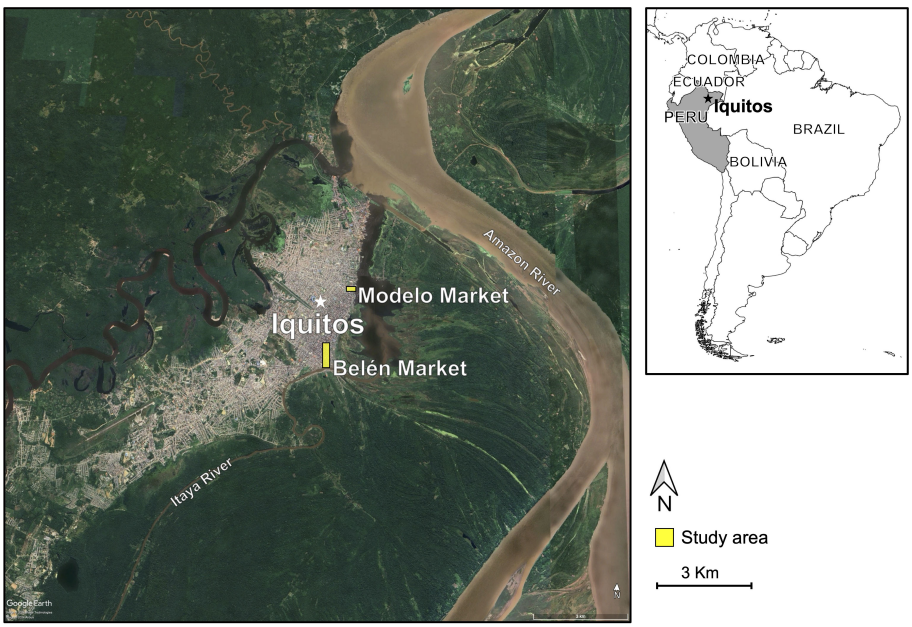


FIGURE 1
Map of study area in Iquitos, Peru, showing the location of Belén Market and Modelo Market. Satellite image of Iquitos: Google Earth, Maxar Technologies, 2024. Available at https://earth.google.com/web.

the district of Iquitos (Figure 1). The central part of the market is located between the streets Nanay, Callao, Arequipa and Celendín, and contains approximately 29 permanent stalls along with several temporary stalls.

## 2.2 Market surveys

Inventories of all stalls selling wildlife and/or wildlife products at Belén and Modelo markets were conducted on an approximately weekly basis (alternating between weekday and weekend visits) over a 12-month period between September 2022 and September 2023. Two survey methods were used – open (cameras on open display and no restrictions on verbal engagement with vendors) and discreet (cameras not on public display and verbal engagements with vendors kept to an absolute minimum) – each of which was carried out by independent local field teams employed by in-country project partners including Instituto de Investigaciones de la Amazonia Peruana (IIAP). For both methods, inventories of individual stalls were limited to products offered for sale that were openly and publicly displayed; there was no attempt to search beyond that which was on display (with the exception of animals that could be seen underneath the stall). Surveys were carried out by two investigators who followed a delineated transect through the market, recorded observations in notebooks, and took images of species/products on mobile phones. Discreet surveys differed from open surveys only in that observations were recorded via hidden body-worn cameras to reduce the possibility of open recording affecting market activity. Species names were recorded as local, common, and scientific names (identification was verified by a taxonomist with expertise in Peruvian wildlife). Global and national threat status was noted for each species identified, in accordance with the IUCN Red List of Threatened Species (Version 2023-1, IUCN, 2023, Table 1) and the Peruvian Red List (published by SERFOR in 2018), respectively. Prices were recorded in Peruvian sols (PEN) and converted to USD using 1 PEN=0.26635933 USD (xe.com, 06.11.23). Full details of the field methods and data recorded are in Supplementary Data Sheet 1.

## 2.3 Ethical considerations

No personal or identifying vendor data were collected. Stall locations were recorded only for assessing variations over time, individual stalls were coded in the database, and no data were linked

TABLE 1 Summary and definitions of market metrics and terms used.

| Metric/term | Definition | Indicator of |
|---|---|---|
| number of surveys | the number of surveys during which a species-product was observed (regardless of whether an observation comprised a single observation of a single individual, or multiple individuals offered for sale at multiple market stalls) | temporal availability |
| number of stalls per survey | range in the number of stalls at which the species/product was observed for sale per survey[1] (including surveys where the species-product was not observed, i.e. = 0 stalls) | prevalence (at any one point in time)<br>range in values indicates variation in prevalence over the year |
| number of individuals per stall | mean and maximum of the number of individuals per stall per survey estimated on the basis of the number of whole animals and identifiable body parts observed (e.g. the number of legs/heads) or the estimated weight of meat (see Supplementary Data Sheet 1) for all observations per stall > 0<br>(the number of eggs was estimated on the basis of total counts of all eggs seen in bags and served on plates) | number of individuals involved[2] |
| number of individuals per survey | number of individuals observed per survey based on the sum of the number of individuals per stall for all stalls 'occupied' per survey | number of individuals involved[2]/trade volume index (at any one point in time)<br>range in values indicates variation in trade volume over the year |
| species-product price | mean and standard deviation/range[3] of price per item, or per kg of meat | market value |
| | | **Categories** |
| product purpose | categories for why customers purchase wildlife products at markets, based on the local knowledge of field surveyors | Food, Pets, Accessories, Spiritual, Medicine[4] |
| species threat status | global/national conservation status of all unique species based on the IUCN Red List of Threatened Species (https://www.iucnredlist.org/) and the Peruvian Red List (published by SERFOR in 2018), respectively | Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, Not Listed |

[1] This can be used to identify popular species in the market and provides more information on market structure than market abundance (Fiennes et al., 2021); [2] This metric avoids making assumptions about turnover but is not comparable among species-products where turnover is likely to be very different (e.g. edible vs. non-edible products); [3] range rather than standard deviation was used for low trade volume species-products or where price data were only available for a few observations; [4]Not all categories are mutually exclusive because, for example, the product purpose can vary between individual products and stalls: larvae are offered as food and for medicinal use, necklaces/bracelets made with teeth, claws, vertebrae, skulls and bones are offered as accessories and for spiritual use, skins are offered as accessories and for spiritual use, skulls and heads are offered as accessories and for spiritual use, dreamcatchers made with feathers are offered as accessories and for spiritual use, meat powder is offered for spiritual and medicinal use, horns are offered for spiritual and medicinal purposes, loose teeth are offered as accessories and for medicinal use (see Supplementary Data Sheet 1).

to individual vendors to protect vendors from harm or discrimination (John et al., 2016). The database collated is entirely anonymous and is stored in a password-protected cloud storage platform, with access restricted to immediate project staff.

## 2.4 Data and statistical analysis

First, to provide an overview of the nature of the two markets, and the differences between them, data were summarized as 'observations' (the observed presence of a particular product of a particular species on one market stall, each unique species-product recorded only once per stall per survey). Observations reflect the availability, prevalence, and salience of species-products over the period of the study and allow broad descriptions and comparisons but do not necessarily relate – or relate consistently - to either the overall, or relative, numbers of individual animals involved.

Second, using rankings based on the number of observations of individual species, we identified species and species 'groups' that were most frequently observed. To provide baseline data that would allow detection of change in market dynamics we then quantified, for each of the most frequently observed species or species 'group', a number of variables (market metrics, Table 1) that collectively provide an index of the temporal availability of species-products and any seasonal changes over the year, their prevalence, an index of the number of individuals involved, and their market value.

Third, to provide as complete a picture as possible of the diversity of species traded at the market, and their uses, and, in particular, the prevalence of threatened species at the market, we provide a qualitative summary of threatened species (and products derived from threatened species) observed at the markets that were observed relatively rarely (i.e. all threatened species that were not included in the most frequently observed species, above).

All statistical analyses were carried out in R (R Core Team, 2023). Chi-squared tests were used to test for statistical associations between taxa, product type, and market, using simulated p values (based on 2000 replicates) for tests with low expected values, and effect sizes calculated using Cohen's ω (in the "rcompanion" package) where a value of < 0.3 is considered 'small', and > 0.5 considered 'large' (Mangiafico, 2016). Rolling window correlations (estimated using Pearson's correlation coefficient) were used to test for correlations between the number of individuals observed (as an index of trade volume) of each of the most frequently observed species groups at Belén Market and river water level (data obtained from the National Meteorology and Hydrology Service (SENAMHI), Peru; https://www.senamhi.gob.pe). Correlation coefficients were estimated in the R package "NonParRolCor" (Polanco-Martínez and López-Martínez, 2023), which takes account of multiple testing, for a window length of 55 to test for an overall association between the two time series, statistical significance was accepted at $p < 0.05$ and approximated using Monte Carlo simulations with 1000 replicates. Linear models were used to test the effect of species, type of meat (fresh or smoked), and market, on price, with *post-hoc* pairwise comparisons carried out using the "grafify" package (Shenoy, 2021) and p-values adjusted for multiple tests using Tukey's method. Additional *post-hoc* tests are as stated in the text. Graphs were drawn using "ggplot2" (Wickham, 2016) and "gridExtra" (Auguie, 2017).

# 3 Results

## 3.1 Dataset

Over the duration of the study, we carried out 48 open and 49 discreet surveys of Belén market (hereafter Belén) and 50 open surveys of Modelo market (hereafter Modelo) (Supplementary Data Sheet 1). The resulting dataset comprises 4,355 observations (3,498 at Belén, and 855 at Modelo) resulting from open surveys and 1,973 from discreet surveys (at Belén). The following analysis is based on data derived from open surveys; a comparison of species detected using the two methods is in section 3.5.

## 3.2 Species and products sold

At least 66 unique species (27 Mammalia, 20 Reptilia, 17 Aves, and two Insecta; Supplementary Data Sheet 2) were observed by open surveys across the two markets (63 at Belén, 21 at Modelo). We did not detect any amphibians. All species observed are native to the Amazon. In total, 27.3% (n = 18) of species observed are threatened or Near Threatened at either a global or national level (28% [n = 18] at Belén, 33% [n = 7] at Modelo).

Across both markets, observations were primarily of mammals or mammal-origin products (hereafter mammals) (43.8% and 71.3% at Belén and Modelo, respectively) and reptiles or reptile-origin products (hereafter reptiles) (46.9% and 24.5%, Figure 2). Birds or bird-origin products (hereafter birds) comprised only 6.6% and 3.2% observations, and invertebrates 2.7% and 0.9%, respectively (Figure 2). Observations were most often (67% at both markets) of species classified on the IUCN Red List as Least Concern; 24.2% and 28.5% (at Belén and Modelo respectively) were of threatened or Near Threatened species (Figure 2). The products observed were predominantly food items (96.7% and 59.1% at Belén and Modelo, respectively); pets comprised 4.9% and 3.0% (respectively), and 'other' products 35.8% and 0.2% (respectively, Figure 2). Where 'other' included spiritual items (20% observations), ornaments or decorative items (10%) and musical instruments (0.5%; combined for analysis as "accessories'), and medicine (5%).

Across both markets mammals (89.6%) and insects (92.9%) were sold primarily for food, reptiles primarily for food (49.2%) and spiritual purposes (34.5%), and birds primarily for ornamental purposes (40%), and as pets (55.7%) ($X^2 = 3074.3$, df=4, $p<0.001$, Cohen's ω~0.85; Figure 2). Effect sizes were small (Cohen's ω≤0.32) for all other differences detected (details in Supplementary Data Sheet 2).

Animals sold live comprised 6.4% of all observations and involved 38.1% (n = 24) of the species identified. Most (71.8%) observations of live animals were for pets; 27.6% were for food. Pets were most commonly parrots/parakeets (69.8%) or turtles (24.1%) but also occasionally other species (including primates). Live animals sold for food were exclusively turtles/tortoises, with the

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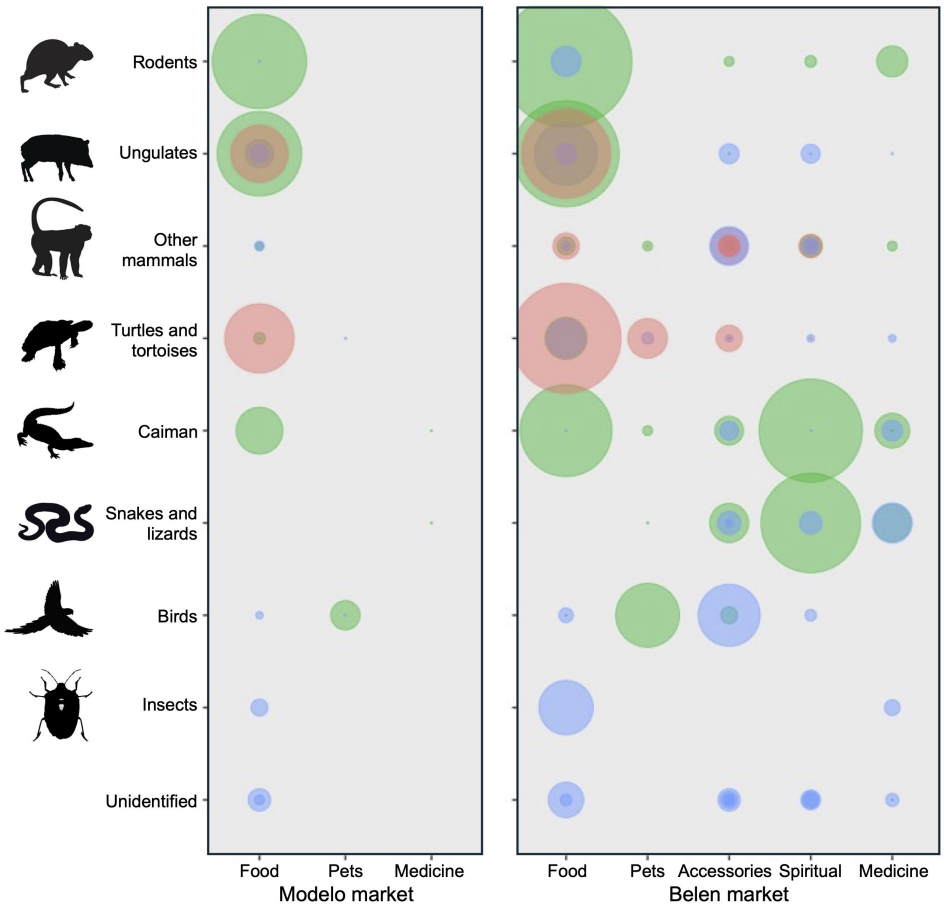


FIGURE 2
Wild animal species and products observed at Belén (n = 3,503) and Modelo (n = 855) markets. 'Bubbles' are proportional in size to the number of observations of each species-product and range between 1 (smallest) and 508 (largest), where an 'observation' was the observed presence of a particular product of a particular species on one market stall and each unique species-product was recorded only once per stall per survey. Colours depict the species' threat status: threatened or Near Threatened (pink) = species categorized on the IUCN Red List as Near Threatened, Vulnerable, or Endangered; not threatened (green) = species categorized as Least Concern; unknown (blue) = species categorized as Data Deficient, species that are not listed, and observations where species could not be identified. 'Other mammals' include carnivores, primates, opossums, xenarthrans (armadillos, sloths, anteaters), and river dolphins; 'Accessories' include decorations or ornaments, crafts and fashion items, practical items (wallets, keychains) and musical instruments made from wild animals.

exception of one observation of live weevil larvae. A preliminary assessment of the welfare conditions of the live animals sold as pets is in Supplementary Data Sheet 3.

## 3.3 Most frequently observed species: product availability, volume traded, and price

The nine most frequently observed species were (in order of occurrence) lowland paca *Cuniculus paca*, collared peccary *Pecari tajacu*, common caiman *Caiman crocodilus*, yellow-spotted river turtle *Podocnemis unifilis*, green anaconda *Eunectes murinus*, white-lipped peccary *Tayassu pecari*, yellow footed tortoise *Chelonoidis denticulatus*, red brocket deer *Mazama americana*, and the giant South American turtle *P. expansa*. The following quantitative summaries are based on eight species 'groups' (lowland paca, peccaries [Tayassuidae], caiman [Alligatoridae], river turtles [*Podocnemis* spp.], boas and anacondas [Boidae], yellow-footed tortoise, brocket deer [*Mazama* spp.], and parrots [Psittacidae]) that include these nine species, and with the inclusion of the parrots, collectively comprise 82% of all market observations (both markets combined). Comparable metrics are given separately for each species-product in Supplementary Data Sheet 4.

### 3.3.1 Lowland paca *Cuniculus paca*

Lowland paca comprised 17.1% of all market observations (n = 745), and were observed on all surveys (at up to 21 stalls per survey) at Belén and 96% surveys (maximum 13 stalls) at Modelo. Lowland paca were sold exclusively as meat for food (72.7% smoked, 26.7% fresh, <1% 'salty'). 'Fresh' meat was sometimes frozen. At Belén, the estimated number of individuals observed per survey (fresh and smoked meat combined) ranged from 1-20 in August-November to > 80 in mid-April and was strongly positively correlated with river water level (r=0.83, Figure 3). The price of lowland paca meat was statistically significantly more expensive when fresh and when sold at Belén market, and was the

most expensive of the wild meats observed with an overall mean of 8.25 USD per kg (Table 2).

### 3.3.2 Peccaries (Tayassuidae)

Peccary species (Tayassuidae) comprised 18.8% of all market observations (n=821; 6.6% white-lipped peccary, 12% collared peccary, 0.1% unidentified species), and were observed on all surveys at both markets (at up to 16 stalls at Belén and 11 stalls at Modelo per survey). Both species were sold predominantly as meat for food (96.2% smoked, 2.1% fresh, <1% 'salty') (Figure 4); occasionally their teeth were sold (alone or as necklaces, Supplementary Data Sheet 4). At Belén, the estimated number of individuals observed per survey (fresh and smoked meat, both species combined) ranged between 5 and > 20 (maximum 33) over the year but there was no apparent seasonal pattern and no correlation with river water level (r=0.04, Figure 3). Per survey, the number of the two species appeared to be moderately negatively correlated (Pearson's product-moment correlation=-0.54, p<0.001). The price of peccary meat was statistically significantly more expensive when sold at Belén Market, but there was no

TABLE 2 Wild meat and egg prices at Belén and Modelo markets, Iquitos, Peru, for the seven most frequently observed 'groups' of wild animal species sold as food.

| Species | Type | Market | No. obs (surveys) | Mean price/ kg PEN (USD) | SD | Model and variable effects |
|---|---|---|---|---|---|---|
| Lowland paca | Fresh | Belén | 141 (42) | 31.39 (8.36) | 3.84 | Model: $F_{2, 721} = 38.07$, $p < 0.001$, $R^2 = 0.09$<br>Type of meat: $F_{1, 721} = 16.43$, $p < 0.001$<br>Market: $F_{1, 721} = 59.71$, $p < 0.001$ |
| | Smoked | Belén | 354 (46) | 30.67 (8.17) | 2.94 | |
| | Fresh | Modelo | 55 (33) | 29.76 (7.93) | 4.51 | |
| | Smoked | Modelo | 174 (46) | 28.55 (7.60) | 3.79 | |
| Collared peccary | Fresh | Belén | 8 (8) | 26.13 (6.96) | 2.85 | Model: $F_{3, 783} = 12.32$, $p < 0.001$, $R^2 = 0.04$<br>Type of meat: $F_{1, 783} = 0.65$, $p = 0.422$<br>Market: $F_{1, 783} = 12.82$, $p < 0.001$<br>Species: $F_{1, 783} = 23.48$, $p < 0.001$[1] |
| | Smoked | Belén | 293 (42) | 26.49 (7.06) | 1.74 | |
| | Fresh | Modelo | 3 (3) | 26.00 (6.93) | 5.29 | |
| | Smoked | Modelo | 198 (42) | 26.05 (6.94) | 3.17 | |
| White-lipped peccary | Fresh | Belén | 3 (30 | 28.00 (7.46) | 0 | |
| | Smoked | Belén | 200 (36) | 26.70 (7.11) | 1.45 | |
| | Fresh | Modelo | 3 (3) | 28.00 (7.46) | 0 | |
| | Smoked | Modelo | 79 (29) | 26.63 (7.09) | 1.45 | |
| Common caiman[2] | Fresh | Belén | 52 (27) | 19.19 (5.11) | 7.63 | Model: $F_{2, 76} = 0.96$, $p = 0.387$, $R^2 = 0.02$<br>Market: $F_{1, 76} = 1.73$, $p = 0.193$<br>Species: $F_{1, 76} = 0.19$, $p = 0.660$ |
| | Fresh | Modelo | 19 (18) | 17.75 (4.73) | 4.73 | |
| Black caiman[2] | Fresh | Belén | 5 (3) | 18.33 (4.88) | 5.77 | |
| | Fresh | Modelo | 3 (3) | 12.67 (3.37) | 6.43 | |
| Red brocket deer | Fresh | Belén | 10 (8) | 27.25 (7.26) | 1.04 | Model: $F_{3, 134} = 2.03$, $p = 0.113$, $R^2 = {}_{0.04}$<br>Type of meat: $F^1_{, 134} = 0.01$, $p = 0.911$<br>Market: $F^1_{, 134} = 2.66$, $p = 0.106$<br>Species: $F^1_{, 134} = 3.41$, $p = 0.067$ |
| | Smoked | Belén | 89 (38) | 26.60 (7.09) | 3.19 | |
| | Fresh | Modelo | 4 (4) | 24.50 (6.53) | 3.32 | |
| | Smoked | Modelo | 16 (14) | 26.32 (7.01) | 2.22 | |
| Brown brocket deer | Fresh | Belén | 5 (2) | 25.75 (6.86) | 1.06 | |
| | Smoked | Belén | 12 (8) | 25.63 (6.83) | 2.20 | |
| | Fresh | Modelo | 1 | 25.00 (6.66) | – | |
| | Smoked | Modelo | 1 | 22.00 (5.86) | – | |
| Yellow-spotted river turtle | Eggs | Belén | 138 | 1.49 (0.40) | 0.46 | Model: $F_{2, 238} = 1.316$, $p = 0.270$, $R^2 = 0.01$<br>Market: $F_{1, 238} = 2.54$, $p < 0.112$<br>Species: $F_{1, 238} = 0.09$, $p < 0.763$ |
| | Eggs | Modelo | 21 | 1.30 (0.35) | 0.33 | |
| Giant South American river turtle | Eggs | Belén | 79 | 1.44 (0.38) | 0.45 | |
| | Eggs | Modelo | 3 | 1.5 (0.40) | 0.29 | |

*(Continued)*

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TABLE 2 Continued

| Species | Type | Market | No. obs (surveys) | Mean price/ kg PEN (USD) | SD | Model and variable effects |
|---|---|---|---|---|---|---|
| | Fresh | Belén | 1 | 45.00 (11.99)[4] | – | |
| Yellow-spotted river turtle | Fresh | Belén | 16 (13) | 35.46 (9.45) | 5.88 | $F_{3, 140} = 11.19$, $p < 0.001$, $R^2 = 0.19$ Species*Market interaction effect: $F_{1, 140} = 24.81$, $p < 0.001$[3] |
| | Fresh | Modelo | 10 (6) | 22.33 (5.95) | 2.27 | |
| Yellow-footed tortoise | Fresh | Belén | 51 (30) | 33.51 (8.93) | 5.30 | |
| | Fresh | Modelo | 38 (29) | 38.00 (10.12) | 6.20 | |

[1] Species difference only statistically significant when compared between the two species, not when compared amongst all species: Combined rodents and ungulates model: post-hoc model contrasts (peccaries): $t_{1641}$=-3.44, p = 0.135; [2] smoked meat prices not included due to insufficient sample size; [3] post hoc model contrasts: yellow-footed tortoise market effect $t_{140}$ = -2.86, p = 0.025; yellow-spotted river turtle market effect $t_{140}$ = 4.16, p < 0.001; species effect at Modelo market $t_{140}$ = 5.67, p < 0.001; species effect at Belén market $t_{140}$ = -0.85, p = 0.828; [4] within but close to the upper 95% tolerance limit (mean ± 2 SD) of the price of yellow-spotted river turtle meat.
Data are mean prices per weekly survey over a year (n = 48 surveys at Belén Market and 50 at Modelo market). Prices are in PEN per kg (and USD, see Methods for conversion); SD = standard deviation; n is number of observations (obs) of a product (where each product was counted only once per stall per survey) for which price was known and the number of surveys (s) on which the product was observed at least once. For river turtles and tortoise meat prices are per 'half' an individual. Statistical model formula = price per kg ~ species + type + market (as appropriate for each species 'group'). Combined species models showed that prices per kg differed statistically significantly across species (brocket deer < peccaries < lowland paca, model including rodents and ungulates and fresh and smoked meat, species effect: $F_{4, 1641} = 118.60$, $p < 0.001$; caiman < ungulates and rodents, model including only fresh meat, species effect: $F_{6, 304} = 67.40$, $p < 0.001$).

statistically significant difference between the price of fresh and smoked meat (Table 2). The meat of white-lipped peccary was statistically significantly more expensive than that of collared peccary (but not when compared amongst all species, see Table 2).

### 3.3.3 Caiman (Alligatoridae)

Caiman species (Alligatoridae) comprised 15.2% of all market observations (n = 662; 13.0% common caiman, 2.0% black caiman *Melanosuchus niger*, 0.2% smooth-fronted caiman *Paleosuchus trigonatus*, and were observed on all but one of Belén surveys (at up to 19 stalls per survey), and 70% surveys at Modelo (maximum 3 stalls). Caiman were sold as meat for food (46.2% observations, predominantly [79.8%] fresh meat, 6.25% smoked or salted) (Figure 4), as 'other' products (53.3%), and occasionally (< 1%) as pets (Supplementary Data Sheet 4). 'Other' products included stuffed legs for "luck", or to "attract money" or customers, fat for medicinal purposes, dried skins for medicinal purposes or decoration, and teeth for ornamental purposes and for "luck" or to "ward off bad vibes". At Belén, the estimated number of individuals observed per survey (fresh meat and stuffed heads and bodies, common caiman and black caiman combined) ranged between < 10 in November and > 30 (maximum 50) in April and May and was positively correlated with river water level (r=0.65, Figure 3). The price of caiman products varied between 1.33 USD for a small bottle of oil and > 500 USD for a large stuffed black caiman head (Supplementary Data Sheet 4). The price of fresh caiman meat did not differ significantly between species or markets (Table 2; although stuffed black caiman heads were statistically significantly more expensive than were stuffed common caiman heads (t-test: $t_{48.66} = 2.73$, p=0.009).

### 3.3.4 River turtles (*Podocnemis* spp.)

River turtles (*Podocnemis* spp.) comprised 9.5% of all market observations (n=412; 7.3% yellow-spotted river turtle, 2.3% giant South American turtle, <1% six-tubercled Amazon river turtle *P. sextuberculata*), and were observed on 97.9% surveys at Belén (at up to 25 stalls per survey) and 54% surveys at Modelo (maximum 6 stalls). River turtles were sold predominantly (86.2%) for food; mostly (80.6%) eggs (Figure 4), but also meat (10.7%), live animals (5.9%), and soup (2.8%). Other products included hatchlings and juveniles live as pets (8.7% observations), stuffed as keychains, and painted heads and small shells for decoration (or spiritual purposes), and large shells for cooking (Supplementary Data Sheet 4). At Belén, the estimated number of river turtle eggs observed per survey ranged between 200 or less in November-July and > 3,000 in September, and was strongly negatively correlated with river water level (r=-0.69). The estimated number of yellow spotted river turtles observed per survey (all products combined) ranged between 0–5 and > 10 (maximum 21) but showed no apparent seasonal pattern (Figure 3). The price of river turtle food products varied between 3.20 USD for giblets and 17.18 USD for a live animal (Supplementary Data Sheet 4). The price of fresh yellow-spotted turtle meat was statistically significantly more expensive at Belén than at Modelo and statistically significantly less expensive than was yellow-footed tortoise meat (but only at Modelo); the price of eggs did not differ between markets or species; Table 2).

### 3.3.5 Anacondas and boas (Boidae)

Anacondas and boas (hereafter boas, Boidae) comprised 7.5% of all market observations (n = 328; 6.9% green anaconda, 0.4% boa constrictor *Boa constrictor*, 0.2% rainbow boa *Epicrates cenchria*) and were observed on all surveys (at up to 13 stalls per survey) at Belén but only once (at one stall) at Modelo. Boas were sold in various forms (stuffed whole animal, heads/bones, skins, and dried ground meat) for predominantly spiritual purposes (81.1% observations), as leather accessories (purses, wallets, dream catchers) and vertebrate necklaces for ornamental purposes (12.5%), and oil for medicinal purposes (5.8%). Two live boa constrictors were also observed (Supplementary Data Sheet 4). At Belén, the estimated number of individuals observed per survey (heads and bodies combined) varied between < 4 and > 10 (maximum 14; 24 if skins are included) in March-May, and September, but did not appear to show any consistent seasonal pattern and was not correlated with river water

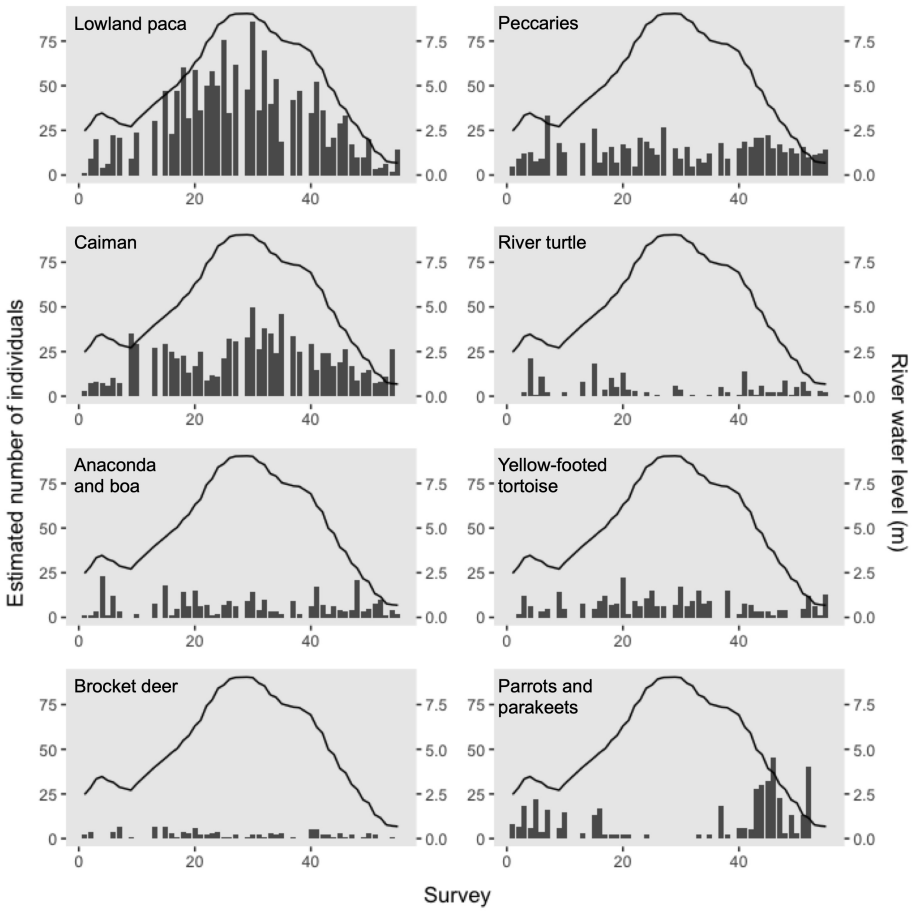


FIGURE 3
Estimated number of individuals (based on most frequently observed species-product type for each species, see text) (bars) observed per survey at Belén Market for the eight most-frequently observed species groups in relation to river water levels in Iquitos (lines). Surveys are numbered consecutively between 1 (29th October 2022) and 55 (30th September 2023), each depicting approximately weekly intervals and alternating between weekday and weekend surveys (some missing surveys, n total = 48).

level (r=0.11, Figure 3). The price of boa products ranged between 1.33 USD for loose vertebrae and 53.27 USD for a whole stuffed snake.

### 3.3.6 Yellow-footed tortoise *Chelonoidis denticulatus*

Yellow-footed tortoise comprised 5.6% of all market observations (n = 242) and were observed on 93.8% surveys (at up to 7 stalls per survey) at Belén and on 80% surveys (maximum 5 stalls) at Modelo. Yellow-footed tortoises were sold predominantly (94.5% observations) for food (Figure 4), occasionally (5.2%) as pets, and their shells for preparing food. Food items were mostly (69.0%) fresh meat [usually served with eggs], 25.8% live animals, 4.7% soup (once as eggs). At Belén, the estimated number of individuals observed per survey (fresh meat and live animals combined) ranged between < 5 and 15–25 (with peaks in January and February) and was weakly positively correlated with river water level (r=0.38, Figure 3); hatchling tortoises sold as pets were observed between mid-June and mid-July. The price of yellow-footed tortoise meat was dependent on tortoise size and ranged between 4 and 13 USD per half tortoise for fresh meat or between 8 and 32 USD for a whole live tortoise. In contrast with most other wild meats, yellow-footed tortoise meat (per half tortoise) was ~10% less expensive at Belén than at Modelo (Table 2).

### 3.3.7 Parrots (Psittacidae)

Parrots comprised 5.0% of market observations (n = 220; 3.2% [n = 140] live parrots [primarily but not exclusively *Brotogeris* spp.] for sale as pets, 1.8% [n = 80] macaw *Ara* spp. feathers, Figure 4; Supplementary Data Sheet 2). Of the live parrots, the yellow wing parakeet *Brotogeris versicolurus* was the most frequently observed species (1.9% observations), followed by the tui parakeet *B. sanctithomae* (0.8%) (Figure 4). Live parrots were observed on 72.9% surveys (at up to 5 stalls per survey) at Belén and 36% surveys (maximum 2 stalls) at Modelo. At Belén, the estimated number of live individuals observed per survey (all species combined) ranged between < 10 and 45 (with the highest numbers observed in July-September) and was weakly negatively correlated with river water level (r=-0.40, Figure 3). Average prices for parrots sold as pets varied ten-fold among species (Supplementary Data Sheet 4) and differed statistically significantly among species ($F_{7,\ 124} = 56.36$, $p < 0.001$)


FIGURE 4
Wildlife products intended for commercial sale at Belén and Modelo Markets in Iquitos, Peru. **(A)** Brocket deer (*Mazama* sp), Lowland paca (*Cuniculus paca*), and Collared peccary (*Pecari tajacu*) sold as meat; **(B)** Macaw feathers (*Ara* sp.) sold as a decorative item; **(C)** Yellow-footed tortoise (*Chelonoidis denticulata*) sold as meat; **(D)** Tui parakeet (*Brotogeris sanctithomae*) sold live as a pet; **(E)** primate skull (c.f. *Alouatta* sp.) sold as a decorative item; **(F)** Amazon river dolphin (*Inia geoffrensis*) sold as traditional medicine; **(G)** common caiman (*Caiman crocodilus*) sold as meat; **(H)** yellow-spotted river turtle *Podocnemis unifilis* eggs sold as food; **(I)** Jaguar (*Panthera onca*) skin sold as a musical instrument. Images Neil D'Cruze/World Animal Protection.

but not between markets ($F_{2,\ 124}$ = 2.12, p = 0.124, model [price ~ species+ market] $F_{9,\ 124}$ = 44.3, p < 0.001, $R^2$ = 0.75). Observations of macaw feather products (n = 80; including feathers of the red and green macaw *Ara chloropterus* and the blue and yellow macaw *A. ararauna*) included earrings, necklaces, crowns, decorations "for dances", maracas, and dreamcatchers (1 - 28 items of each). Feather products were observed on 60.4% surveys, from 10 different stalls, exclusively at Belén Market, year round for between 2.66 and 15.98 USD.

### 3.3.8 Brocket deer *Mazama* spp.

Brocket deer (*Mazama* spp.) comprised 3.4% of all market observations (n=146; 2.9% red brocket deer, <1% Amazonian brown brocket deer *M. nemorivaga*, n = 2 unidentified spp.) and were observed for sale on 87.5% surveys (at up to 7 stalls per survey) at Belén and 32% surveys (maximum 2 stalls) at Modelo. Brocket deer were sold almost exclusively as meat for food (98.6% observations; of these 84.7% were smoked, 14.6% fresh, and 0.7% salted) (Figure 4), occasionally (<2%) as horns or antlers for spiritual or medicinal purposes. At Belén, the estimated number of individuals observed per survey (fresh and smoked meat combined) ranged between 1-2 and >10 (maximum 11) but exceeded 5 only in November-February (the brown brocket deer was observed only in November-March); this apparent seasonal variation was not correlated with river water level (r=0.11, Figure 3). The price of brocket deer meat did not differ significantly between markets or types of meat and there was no statistically significant difference between the price of meat of the two species (Table 2).

## 3.4 Threatened species observed infrequently: observations and uses

Threatened and Near Threatened species that were observed infrequently (by open and discreet surveys) included globally Endangered spider monkey *Ateles* spp. (n=1 observation) and

Amazon river dolphin *Inia geoffrensis* (n=16), Vulnerable giant armadillo *Priodontes maximus* (n=14), Amazon tapir *Tapirus terrestris* (n=33), and common woolly monkey *Lagothrix lagotricha* (n=19), and Near Threatened jaguar *Panthera onca* (n=52), Neotropical otter *Lontra longicaudis* (n=10), Illiger's saddle-back tamarin *Leontocebus illigeri* (n=1), and ornate eagle-hawk *Spizaetus ornatus* (n=1), as well as puma *Puma concolor* (n=6) that are Near Threatened nationally, and Colombian red howler monkey *Alouatta seniculus* (n=6) that is Vulnerable nationally. The products that these species were used in, their prevalence, total number of items observed, price, and purpose, are in Table 3 (see also Figure 4).

Individual items cost between 3.19 USD for a jaguar skin bracelet and > 200 USD for a whole jaguar skin (Table 2). Primate meat (fresh and smoked combined) cost 3.19-7.45 USD per kg, and smoked tapir meat cost 4.00-7.45 USD per kg (Table 3). Fresh primate meat (woolly and red howler monkeys combined) cost statistically significantly less than the cheapest frequently observed fresh meat (common caiman, above) at Belén (one-tailed t-test: $t_{47.77}$=-3.91, $p < 0.001$) and both smoked primate meat (woolly monkey) and smoked tapir meat cost statistically significantly less than the cheapest frequently observed smoked meat (red brocket deer) (one-tailed t-test: primate - $t_{12.07}$=-4.96, $p < 0.001$; tapir - $t_{51.73}$=-7.66, $p < 0.001$).

Species-product observations equated to an estimated 2 – 3 individual jaguars, 4 pumas, a single Neotropical river otter, 1 – 6 individual giant armadillos, 1 ornate eagle-owl, 1 to 33 Amazon tapirs, 1 Illiger's saddle-back tamarin, 2 spider monkeys, 10 red howler monkeys, and between 12 and 34 individual common woolly monkeys (depending on turnover and longevity of smoked meat), as well as an unknown number of river dolphins (in an estimated 63 bottles of oil) recorded over the duration of the study (Table 3).

## 3.5 Comparison of discreet and open surveys

Forty unique species (17 Mammalia, 12 Reptilia, 10 Aves, and one aquatic invertebrate, Table 1) were identified by discreet survey methods. The taxonomic composition of species detected did not differ from that recorded during open surveys ($X^2$ = 0.060, df=2, p=0.970). Discreet surveys detected five genera that were not detected by open surveys; three of these were identified to species, one of which (the ornate hawk-eagle *Spizaetus ornatus*) is categorised on the IUCN Red List as Near Threatened (others are categorised as Least

TABLE 3 Threatened species observed infrequently at Belén and Modelo markets, Iquitos, Peru, Oct 2022 – Sept 2023. Data are the total number of observations (where a species-product at a particular stall was recorded only once per survey but the same items at the same stall could be counted on multiple surveys), the total number of stalls observed to sell the product over all surveys a, and the estimated number of unique items observed b. Price is given either as a range of prices or mean and range (mean, range) in Peruvian soles (PEN) per item or (for meat) per kg. Purpose categories were as defined in Table 1 (see Methods), where 'Accessories' includes decorations or ornaments, crafts and fashion items, practical items (wallet/purse/keychain) and musical instruments made from wild animals.

| Species | Body part | Product | No. obs. | No. stalls | No. items | Price | Purpose |
|---|---|---|---|---|---|---|---|
| Jaguar | Skin | Leather/fur products<br>-wooden drums<br>-purse/wallet<br>-bracelet | 32 | 4 | <br>2<br>$2^1$, $6^2$, $14^3$<br>1 | <br>80, 150<br>30 – 60<br>12 | Accessories |
| | | Fur, whole skin | 2 | 2 | 1 - 2 | 150 - 800 | Accessories<br>Spiritual |
| | Skull/head | Skull* | 2 | 1 | 1 | 300 | Spiritual |
| | Paw/foot | Paw skin with claws | 1 | 1 | 4 | 25 | Accessories |
| | | Stuffed leg | 5 | 3 | $5^1$, $7^2$, $11^3$ | 100 - 400 | Accessories<br>Spiritual |
| | Teeth/claws | Bracelet/necklace | 10 | 4 | $6^{††}$<br>$16^{1,2}$, $26^{3\,†\,†\,†}$ | 50<br>20 - 30 | Accessories |
| Common woolly monkey | Meat | Fresh meat | 5 | 4 | $7^1$, $15.5^2$, $19^3$ kg | 15.60, 15 - 18 | Food |
| | | Smoked meat | 14 | 10 | $13.5^1$, $46^2$, $60^3$ kg | 19.83, 12 – 28 | |
| Neotropical otter | Skull/head | Stuffed head | 10 | 3 | 1 | 300 - 500 | Spiritual** |
| Giant armadillo | Claws | Bracelet/necklace | 13 | 6 | 2 - 12 | 120, 50 - 170 | Accessories*** |
| Spider monkey | Meat | Smoked meat | 1 | 1 | 7 kg | 12 | Food |

*(Continued)*

TABLE 3 Continued

| Species | Body part | Product | No. obs. | No. stalls | No. items | Price | Purpose |
|---|---|---|---|---|---|---|---|
| Illiger's saddle-back tamarin | Live animal | Live animal | 1 | 1 | 1 | 20 | Pet |
| Amazon tapir | Meat | Smoked meat | 23 (10) | 10 (7) | 15[1], 26[2], or 180[3] kg | 21.94, 15 – 28 | Food |
| Amazon river dolphin | Fat/eye/tooth | Bottle, oil[†] | 16 | 7 | 63 (1 – 21, mean = 5, per stall) | 15 - 25 | Spiritual |
| Puma | Skull/head | Skulls | 6 | 3 | 2[1], 4[2], 4[3] | 100 - 400 | Accessories** |
| Red howler monkey | Meat | Fresh meat | 3 (1) | 2 (1) | 4.5[1], 9[2], 13[3] kg | 14, 12 – 15 | Food |
| | | Smoked meat | 1 | 1 | 4 kg | 15 | |
| | Skull/head | Skull | 1 | 1 | 3 | 30 | Spiritual |
| Ornate eagle-hawk | Claws | Claws | 1 | 1 | 2 | – | – |

[a]note that this differs from the metrics quantified for the most frequently observed species where the number of stalls was provided as a range per survey; [1]max. seen at any one time (for armadillos, assuming that one of the two claws observed on two stalls during the same survey was later made into a necklace), [2] assuming there is no swopping or multiple ownership of stalls (i.e. each separate stall sells a unique product) but that conservatively the same product at the same stall might be the same item that did not sell previously, [3] assuming observations at the same stall on a different survey are of different items (i.e. stalls sold previous item and have replenished it with a new item of the same product), with the exception of any that were noted by market observers to be the same item.
* poor condition non-matching teeth; ** "to attract business"; *** "for luck and [avoiding] bad vibes"; [†]containing an eye or tooth; [††] with claws; [† † †] with teeth.

Concern, Supplementary Data Sheet 2). Discreet surveys missed 25 species (and 24 genera) that were detected by open surveys, including spider monkeys that are Endangered and Illiger's saddle-back tamarin that is Near Threatened.

# 4 Discussion

## 4.1 Overview

In this analysis we aimed to portray a picture of the nature of two markets in Iquitos that are heavily engaged in illegal wildlife trade. We did not attempt to summarize or quantify all species-products observed, instead we focused on threatened species because these are of most immediate conservation concern, and the most frequently observed species because these had sufficient sample size to allow precise estimates of market metrics. The latter was intended to establish a baseline for follow-on monitoring (see, e.g., Table 2), against which a number of different changes could be detected in response to legal enforcement or other conservation-oriented interventions.

Modelo is, as described, primarily a food market. Belén, however, was more diverse, with more than a third of observations of wild animal-origin products sold for 'other' (e.g. spiritual, ornamental, or medicinal) purposes. Across both markets, and both open and discreet surveys, approximately a quarter (26.8%) of the 71 unique species identified were threatened or Near Threatened, either nationally or internationally (Supplementary Data Sheet 2). This was true of both markets despite species richness at Modelo being a third that of Belén. Four of the threatened species identified were amongst those most frequently observed: the globally Vulnerable white-lipped peccary, yellow-spotted river turtle, and yellow-footed tortoise, and the nationally Endangered giant South American river turtle, all of which were traded primarily for food. Trade, however, appeared to take place openly as surveyors did not see any sign of legal enforcement during market surveys, and there was little or no evidence that discreet surveys provided market data that could not be obtained from open surveys. Below, we outline some of the key findings associated with the different product purpose types traded – food, traditional medicine/belief-based and ornamental products, and live pets.

## 4.2 Bushmeat

Six of the eight most frequently observed species groups (including rodents, ungulates, and reptiles), and four of the rarely observed threatened species (primates and tapirs), were sold either exclusively or primarily for food. This is not unexpected given that food is reported as the most common use of wildlife in Peru (Bodmer et al., 2004) and the most frequently stated purpose of the sale of wildlife by vendors at Belén and nearby markets in Iquitos (D'Cruze et al., 2021). Amongst the 'meat' products, smoked meat was more common (and was observed in higher volumes) at both markets than was fresh meat for all species except reptiles (caiman were sold primarily as fresh meat, and turtles and tortoises were predominantly sold alive). Smoked meat was presumably prevalent because it has an extended shelf life and keeps better during transport (Bolton, 2012; Buck et al., 2017) but perhaps also due to national or local preference (van Vliet et al., 2014).

Amongst the most frequently observed species groups sold for bushmeat, two - lowland paca and yellow-footed tortoise - were previously identified by Belén vendors as the species to be most profitable but that are also becoming increasingly rare (D'Cruze et al., 2021; see also Morcatty and Valsecchi, 2015). Lowland paca can occur at high densities (Emmons, 2016) and hunting of this species is considered to have been carried out at a sustainable level in some parts of the Peruvian Amazon (e.g. in the Itaya river basin, Aquino, 2009). However, they are one of the most consumed subsistence foods in Peru (Gallina et al., 2012), and elsewhere in

the Amazonia region catch-per-unit-effort appears to be declining (Valsecchi et al., 2014). These observations suggest that the current level of use of lowland paca at Belén and Modelo market cannot automatically be assumed to be sustainable. Yellow-footed tortoises are, similarly, one of the most commonly hunted species across the Amazon (Tavares et al., 2020 and references therein) and a preferred species for both rural and urban communities (Tavares et al., 2020; Morcatty and Valsecchi, 2015). Peccaries are also considered to be threatened by overhunting (combined with habitat destruction), especially white-lipped peccaries that appear to be particularly vulnerable to hunting pressure (Keuroghlian et al., 2013). Peccaries are also widespread and traditionally a preferred source of bush meat in the Amazonian region (Gongora et al., 2011; Keuroghlian et al., 2013). Subsistence hunting of peccaries is legally permitted in Peru (Gongora et al., 2011). However, local extinctions of white-lipped peccary have been recorded in pristine habitats and in large, contiguous protected areas (Peres, 1996; Keuroghlian et al., 2013) and, in the Argentine Chaco, Altrichter (2005) found that white-lipped peccary density was three times lower in areas closer to villages than in protected areas. Our preliminary observations of the relative numbers of these two species at the markets suggest that in terms of availability of peccary meat the two species may be interchangeable. This suggests little incentive to ensure sustainable offtake of the more vulnerable species, and although price differences were small compared with price differences among species, the higher price commanded by white-lipped peccaries could lead to the more vulnerable species being targeted by hunters (cf. the anthropogenic allee effect, Courchamp et al., 2006). Whether the small premium in price is associated with the relative rarity of the species or a genuine preference for white-lipped over collared peccaries is unknown.

For lowland paca, yellow-footed tortoise, and caiman (but not peccaries or brocket deer), the numbers observed at the markets appeared to show some seasonality, with peaks (most pronounced for lowland paca) coinciding with peak river water levels. Similar seasonal patterns were noted by van Vliet et al. (2014), who also referred to a relative scarcity of bushmeat during the dry season. For lowland paca, which showed the greatest increase in numbers observed during high water levels, the seasonal 'excess' appeared to be sold primarily as smoked meat. It is not clear to what extent this might be driven by factors such as consumer preference, or lack of access to refrigeration. In contrast with these patterns, the numbers of river turtle eggs offered for sale appeared to be lowest when river water levels were high, which presumably reflects seasonal nesting behaviour of these species (Norris et al., 2020).

Primate meat (spider monkey, common woolly monkey, and Colombian red howler monkey) was observed only occasionally. All of these species were traditionally preferred species for subsistence hunting in the Amazon basin but all are now thought to have disappeared from some local areas, particularly those close to human settlements (Alves et al., 2021; Aquino et al., 2016; Stevenson et al., 2021; Link et al., 2021a, Link et al., 2021b; SERFOR, 2018). The low numbers observed in this study suggest that primates are rarely encountered by hunters and/or that they are taken opportunistically (Buck et al., 2017), and are in keeping with reports that hunted populations of spider and woolly monkeys in the Amazon basin have declined in recent decades (Peres and Palacios, 2007). Indeed, the illegal trade in wild primates for bushmeat and pets is considered one of the largest threats to this fauna in Peru (Shanee et al., 2017). In a recent consumer survey, none of 265 regular shoppers at Belén Market who stated that they frequently purchased wild meat at the market, mentioned purchase of primate meat (Moorhouse et al., 2023). There was also no evidence that the apparent rarity of these species equated to higher commercial value; however, bush meat vendors reported that woolly monkey meat is "in demand" and that it "reached the market less often than collared peccary or lowland paca meat" (Elwin et al., unpub. data).

## 4.3 Traditional medicine, belief-based, and other decorative or fashion items

In addition to food, medicinal, "belief-based", and "decorative" uses for wildlife products are also considered profitable by vendors (D'Cruze et al., 2021). D'Cruze et al. (2021) referred to the use of parrot feathers as being particularly profitable amongst decorative products. The use of brightly coloured feathers has a long history in the Amazon region (Giuntini, 2006) and in this study macaw feathers were also commonly observed for sale as jewellery and other decorative items. Our observations of jaguar "accessories" is also in keeping with studies elsewhere within the jaguars' range that found these products to be openly sold at local markets (e.g. Elwin et al., 2024), and domestic ownership of jaguar body parts for decorative, medicinal, and cultural purposes to be common (Arias et al., 2021). In contrast with Arias et al. (2021) we did not observe medicinal jaguar products. These types of products (and similar, e.g. necklaces adorned with an armadillo claw) may be bought by foreign tourists as souvenirs as well as by regular market customers (D'Cruze et al., 2021; Bodmer and Lozano, 2001; Braczkowski et al., 2019). For jaguar bones, it has been suggested that they may be used by the increasing Asian community in Latin America as a replacement for tiger bones in traditional medicines (Quigley et al., 2017; Morcatty et al., 2020). Observations of some other objects, such as otter, puma and caiman heads, suggested that actual sales were infrequent; these items were reported by some vendors "to attract customers to the business" and appeared to serve primarily as "shop-windows" (Table 2).

Some potential species-products notably appeared to be absent, presumably because alternative (e.g. international) markets exist. For example, although considerable numbers of peccaries were hunted (evidenced by observations of meat for sale), no peccary (or tapir) pelts or peccary leather products were observed (although leather products of other species such as green anaconda were). Peccary skins can be traded legally by local communities and also exported legally under CITES permits for high-end products in the European leather industry (Keuroghlian et al., 2013). Tapir leather products are also sold internationally (Varela et al., 2019).

The impacts of trade in these types of products on wild populations are difficult to assess. In part, because it is difficult to equate products observed to the number of individuals killed. For jaguars, at least some body parts are most likely obtained from animals killed due to conflict with humans rather than being

targeted for their use per se (Arias et al., 2021; UNODC, 2020). For other products, the species may be mislabelled (deliberately or not): recent molecular studies have for example revealed that products labelled as river dolphin are actually often from domestic pigs or sheep (Gravena et al., 2008 in da Silva et al., 2018).

## 4.4 Pets

Pets comprised a relatively minor component of wildlife trade at Belén and Modelo markets but involved a number of different wild species that varied in both prevalence and price. Parrots and turtles, for example, were observed relatively frequently with up to 23 individual parrots and 15 individual turtles per stall, whereas squirrel monkeys and Illiger's saddle-back tamarin were observed only once and each as a single individual. Similarly, whilst some species (notably the green anaconda) commanded prices of up to 79 USD or more (equivalent to more than three day's salary for an urban worker in Peru, based on average monthly income in December 2023 of 1,581.50 Peruvian soles [INEI, 2023] and 19-22 working days in a month), others (e.g. hatchling turtles and yellow wing parakeet) cost less than one USD, considerably less than a kilogram of meat or a single serving of a cooked turtle meat meal at the market (Supplementary Data Sheet 4). A "baby" brown-throated sloth could be purchased for 5 USD. Regueira and Bernard (2012) similarly reported birds sold at urban street markets in northeastern Brazil for one US dollar. Both extremes have implications in that at the upper end they suggest significant financial incentives for hunters and selective pressure on particular species (cf. Tella and Hiraldo, 2014; Romero-Vidal et al., 2023) whilst at the lower end they highlight the lack of 'value' attached to wild animals in this region.

The pet trade is considered a serious threat to many Neotropical parrot species (Berkunsky et al., 2017) with the potential impacts of market trade and internal exports compounded by local poaching for self-supply or local scale rural sales (Romero-Vidal et al., 2023). An apparent decline in numbers of Illiger's saddle-back tamarin is also attributed in part to hunting for the pet trade, which is believed to have increased in the last decade (Heymann et al., 2020). We did not attempt to estimate turnover rates but note that the lack of repeat observations of the squirrel monkey and the Illiger's saddle-back tamarin (and, similarly, of two toucans observed on two consecutive occasions) suggest that the animals were sold. Others have observed significantly larger trade volumes in wild animal pets in Peru – particularly primates (Shanee et al., 2017), although, notably, none of the vendors in D'Cruze et al (2021) study named primates for sale live as pets as a profitable endeavour. Many of the animals sold as pets were very young – hatchling turtles, "baby" sloths and parrots – presumably because they are both easier to keep and to capture (and are more appealing) than adult animals. For turtles, individuals that were too small to be sold for food appeared to be sold as pets. In contrast with patterns observed for some of the species traded as meat, the numbers of live parrots observed for sale were lowest during peak river water levels; it is not known whether this was due to seasonal changes in the abundance of parrots in floodplain forests (e.g. Lee and Marsden, 2012) or changes in the behaviour or activity area of the hunters during the wet season.

With regards to animal welfare, whilst hunting and killing animals for food or other products almost certainly involves some level of animal suffering, the suffering experienced by animals traded live may be greatest because there is potential for poor welfare impacts during all stages of the trade chain (Baker et al., 2013). Our welfare assessments were preliminary and pertain only to the period while the animals were on display at the market but nevertheless suggest that conditions, in most cases, were poor. Most of the live animals on sale as pets were held in metal cages or plastic containers with bare floors and although the majority appeared to be healthy and in "acceptable" hygiene conditions, most were overcrowded, lacked shelter or enrichment and did not appear to have food or water available (Supplementary Data Sheet 3).

## 4.5 Study limitations

In terms of generating a robust baseline for future comparative market assessments, it is important to note that our survey methods may have failed to detect a 'hidden' component of market trade (Bušina et al., 2020), and it is possible that our dataset is biased towards less threatened species. The openness with which wildlife is traded in urban areas of Peru, much of which takes place illegally, suggests that trade, in this case, is not generally hidden but it is possible that high value items are hidden to avoid confiscation by the authorities (Daut et al., 2015; Romero-Vidal et al., 2023 and references therein) or conducted through alternative channels such as social media (Siriwat and Nijman, 2020). We were also unable to identify many of the bottles of oils observed, and so may have underestimated the diversity (and perhaps threat status) of the species used for medicinal purposes in particular. This may explain why, for example, we did not record medicinal jaguar products, in contrast with Arias et al. (2021). Similarly, for all but a few of the least frequently observed species we can only reliably quantify trade volume as it was observed during each survey. We do not know, for example, to what extent fresh meat is restocked through the day (cf. Bušina et al., 2020). Although the large number of repeat surveys over an entire year and across season lends weight to the accuracy and precision of the various market metrics defined (and provides a measure of annual variation in metrics that might be observed in the absence of any external change) it is important that these data are recognized as providing a 'snapshot' (or index) of the trade that presumably occurred over a full week.

# 5 Conclusions and recommendations

Any future comparative assessment against our baseline will require a broad awareness of the changes that might occur over time and an understanding of the additional information that will be needed to identify the mechanism underlying any apparent change. There are a number of unquantified factors that might be subject to change – these include unknowns, such as the source of the species, turnover rate for most of the species-products observed, and level of intervention by the authorities. Currently, we lack insight from hunters and do not know precisely, for example, how far away species are sourced from, and/or which, and what proportion of, species are offered for sale at the markets as opposed to being kept for subsistence use. Market composition may not reflect hunting composition and these trade filter dynamics between hunter and market may change over time (Allebone-Webb et al., 2011).

Market surveys are just one tool in understanding and monitoring trade dynamics (Allebone-Webb et al., 2011); however, they are a crucial component of a holistic approach, combined with studies of the attitudes and activities of hunters, consumers, and other relevant actors. This is the first study that we are aware of that attempts to describe wildlife trade at Belén Market in its entirety whilst also quantifying a variety of market metrics to provide a robust and flexible baseline against which the changes associated with conservation interventions can be assessed. Our comparison of survey methods suggested that discreet surveys may not currently be necessary, even to detect threatened species at Belén and Modelo markets in Peru, where wildlife trade (although technically illegal in the absence of required permits) appears to take place openly. Earlier experimental surveys in urban areas in Peru revealed that social norms surrounding the acceptability of consumption (or ownership) of wildlife-origin items might be amenable to alteration through repeated demand reduction campaigns, especially if these highlight the zoonotic disease potential of such purchases and the need to conserve native Peruvian species (Moorhouse et al., 2024). To assess the impact of any such campaign, we recommend that repeat market surveys (perhaps focused on one or two species) are carried out combined with additional surveys of hunters, and villagers, to account for potential change in hunting effort, success, or trade filters.

Although a full repeat of our year-long survey of all species-products observed would be ideal, the strategy adopted will inevitably depend on the resources available. Some aspects of the survey approach (e.g. effort, timing) could potentially be optimized to suit specific objectives. For example, two useful aims might be to determine minimum effort required either to detect the majority of species traded, or to provide robust estimates of the price of frequently observed species. Each would require different strategies, but both could be defined by simulations based on existing data. Alternatively, survey methods such as "shopping lists" and/or survival analysis or time-to-detection approaches (Pheasey et al., 2021) might reduce effort if a specific 'list' of species or products could be identified from this broad scoping. The optimal time of year to carry out these types of rapid, snapshot surveys could be further informed by knowledge of trade patterns in relation to river water levels. Ultimately, the success of these types of approaches would depend on the species selected, the ability to accurately predict future change, and the relevant questions of interest.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

ND: Conceptualization, Project administration, Writing – review & editing. AE: Conceptualization, Data curation, Project administration, Writing – review & editing. PP: Data curation, Project administration, Writing – review & editing. RV: Data curation, Project administration, Writing – review & editing. AA: Data curation, Project administration, Writing – review & editing. LH: Formal analysis, Writing – original draft, Writing – review & editing.

## Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was funded by World Animal Protection from a grant from DEFRA's Illegal Wildlife Trade Challenge Fund (IWTCF), Grant Number: IWTEV007. World Animal Protection is a non-profit; four of the authors are employed by the same organization (NDC holds the position of Head of Research). Our intent in carrying out this study was to provide insight that would help inform efforts to reduce demand for illegal wildlife products in Peru. Our results pertaining to this research were in no way influenced by either the funding source, or our own personal views on animal welfare.

## Acknowledgments

Our study was administered by, and designed with extensive input from, collaborators from World Animal Protection, Pacha, and the Sociedad Peruana de Derecho Ambiental (SPDA), and we gratefully acknowledge their expertise. Thanks to Eugenia Morales, Ester Mora, Maddie Pinkess, and Luis Zari for their helpful discussions and input on this research and the wider project in Peru. In addition, we also thank Melissa Lorena Guerrero Tenazoa, Betsy Alva Ocampo, and Wendy Lessy García Torres for their assistance with data collection, and Lucio Gil Perleche for taxonomic review of the data.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2024.1464332/full#supplementary-material

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