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RESEARCH ARTICLE

Predicting animal abundance through local ecological knowledge: An internal validation using consensus analysis

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Abstract

1. Given the ongoing environmental degradation from local to global scales, it is fundamental to develop more efficient means of gathering data on species and ecosystems. Local ecological knowledge, in which local communities can consistently provide information on the status of animal species over time, has been shown to be effective. Several studies demonstrate that data gathered using local ecological knowledge (LEK)-based methods are comparable with data obtained from conventional methods (such as line transects and camera traps).
2. Here, we employ a consensus analysis to validate and evaluate the accuracy of interview data on LEK. Additionally, we investigate the influence of social and bioecological variables on enhancing data quality. We interviewed 323 persons in 19 villages in the Western and Central Amazon to determine the level of consensus on the abundance of hunted and non-hunted forest species. These villages varied in size, socio-economic characteristics and in the experience with wildlife of their dwellers. Interviewees estimated the relative abundance of 101 species with a broad spectrum of bioecological characteristics using a four-point Likert scale.
3. High consensus was found for species population abundance in all sampled villages and for 79.6% of interviewees. The village consensus of all species abundance pooled was negatively correlated with village population size. The consensus level

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was high regardless of the interviewees' hunting experience. Species that are more frequently hunted or are more apparent had greater consensus values; only two species presented a low consensus level, which are rare and solitary species.

4. We show in our study in the Amazon that information gathered by local peoples, Indigenous as well as non-Indigenous, can be useful in understanding the status of animal species found within their environment. The high level of cultural consensus we describe likely arises from knowledge sharing and the strong connection between the persons interviewed and the forest. We suggest that consensus analysis can be used to validate LEK-generated data instead of comparing these types of data with information obtained by conventional methods.

KEYWORDS
Amazon, consensus, hunting, Indigenous People, local communities, wild meat

1 | INTRODUCTION

Forest peoples directly interact with animals throughout their lives. Since childhood, they can identify animals' signs and interpret these in terms of the animal's behaviour or potential environmental changes (Albert, 2016). The engagement of human communities with the forest and its diverse array of life forms encompasses a complex network of relationships that extend beyond the human realm. These connections are intertwined with kinship ties, social interactions, cultural norms, ceremonial practices and cosmological beliefs (Ingold, 2000). This comprehensive understanding of the ecosystem is commonly referred to as local ecological knowledge (LEK), a term that encompasses traditional, Indigenous and local knowledge. In this context, we employ the term LEK to refer to the collective wisdom and insights derived from these diverse knowledge systems, moving away from the singular use of terms like traditional or Indigenous ecological knowledge.

An increasing number of wildlife conservation and research projects have used LEK-based methods to collect data (including historical information) that would otherwise be less cost-effective if only scientists were involved (Braga-Pereira et al., 2020, 2022; Farhadinia et al., 2018; Ponce-Martins et al., 2022; Van Damme et al., 2015). To establish the reliability of data obtained using LEK-based methods, it is common practice to compare and cross-reference information gathered during interviews with data collected through conventional techniques, for example, line transects and camera traps (Braga-Pereira et al., 2022; Camino et al., 2020; Madsen et al., 2020). However, rather than relying solely on comparisons with other methods, it is also possible to validate interview data (the most commonly used method to generate data on LEK) through an analysis of the consistency of information provided by informants.

This process of internal validation can be achieved by assessing the level of consensus or agreement among the interview responses, which serves as an indicator of shared knowledge within a particular group or community (Burgess et al., 2017). Given that culture is built upon the foundation of collective knowledge, the presence of consensus within a group of experts regarding the information on wildlife can be seen as a reflection of what the group collectively considers to be accurate or accepted truth (Borgatti & Halgin, 2011a, 2011b; Romney et al., 1986; Weller, 2007). By evaluating the degree of agreement among responses, the internal validation process provides a means to gauge the reliability and validity of the interview data itself, resulting in consensus among individuals who possess expertise in a given domain. On the other hand, people who do not know the answer, due to differences in their experiences, are less likely to provide a consensual answer. This allows for the identification and recognition of patterns and shared understandings within the interview data, reinforcing the credibility and accuracy of the information obtained through LEK-based methods.

Consensus analysis (CA) has been applied in several fields to measure people's perceptions of a given subject and to assess whether individuals share the same cultural concepts. Initially, CA was widely used in health research (Garro, 1986; Moore et al., 1997; Romney et al., 1986; Weller & Baer, 2001). In the last decades, CA has been applied to environmental conservation and resource management issues (De Mattos Vieira et al., 2019; Grant & Miller, 2004; Miller et al., 2004), such as to analyse the use and classification of plants (Canales et al., 2005; Case et al., 2005; Galeano, 2000; Hanazaki et al., 2010) and animals (Alves et al., 2011; Kent, 2011; Rickenbach, 2015; Van Holt et al., 2010; Volpato et al., 2015) by local people. For CA to be considered suitable, certain conditions need to be met: (1) participants must share a common culture; (2) there should be a single 'true answer' to each question; (3) responses should be solicited independently (i.e. not in a focus group); (4) only one domain of knowledge is tested at a time, for example, a test of knowledge about animal abundance and medicinal plants together would not be appropriate (Borgatti & Halgin, 2011a, 2011b; Romney et al., 1986; Weller, 2007); and (5) the information sought should be majorly derived from a single cultural process (i.e. hunting).

To validate local hunter interviews estimating the relative abundance of terrestrial vertebrates, several studies have compared

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hunters' responses with abundance estimates obtained using conventional methods, such as linear transects, camera traps and GPS collars; strong positive correlations were found in most studies (Braga-Pereira et al., 2021; Brittain et al., 2022; Camino et al., 2020; Madsen et al., 2020; Zayonc & Coomes, 2022). Our objective is to renew the form of measuring the accuracy of abundance estimates from LEK. Here, we validate and evaluate the accuracy of interview data on LEK through CA. Additionally, we investigate the social and bioecological predictors of consensus, determining when the abundance data generated through LEK is accurate or not and so enhancing data quality. For that purpose, we interviewed inhabitants of socially and demographically distinct settlements (villages) in Western and Central Amazonia about their perceptions of the abundance of local vertebrate species. We determined consensus levels among interviewees in each village regarding the abundance of species found in their environment and tested the following hypotheses:

- Nature contact hypothesis: Individuals who have greater contact with nature, such as through hunting experience, extended periods of living in villages or reliance on wild meat, are expected to exhibit higher levels of personal consensus.
- Information transmission hypothesis: The level of consensus is expected to be influenced by the number of inhabitants in each village, as information and experiences are likely to circulate more quickly in villages with smaller populations.
- Apparency hypothesis: Species that are more easily detected in the Amazon due to their group living behaviour, medium to large body size, diurnal activity and arboreal or terrestrial locomotion are predicted to have higher consensus levels.
- Hunted species hypothesis: Certain species that are hunted and possess distinct characteristics or are significant to local communities are expected to attract greater attention and exhibit higher levels of consensus among individuals.

2 | METHODS

2.1 | Study areas and human populations

The Amazon River Basin, spanning the central and eastern regions in the north of South America, is home to a significant human population of approximately 12 million rural residents. These inhabitants consist of Indigenous communities, traditional groups and peasants who have established their livelihoods within the rainforest area. Most rely on hunting and fishing to obtain animal protein, an important component of their food security (FAO & FILAC, 2021). This study was conducted in a total of 18 villages in the Brazilian ($n = 9$) and the Peruvian ($n = 9$) Amazon. These included eight sites in upland forest, four in flooded forest and six in transitional forests (Figure 1). In the Peruvian Amazon we

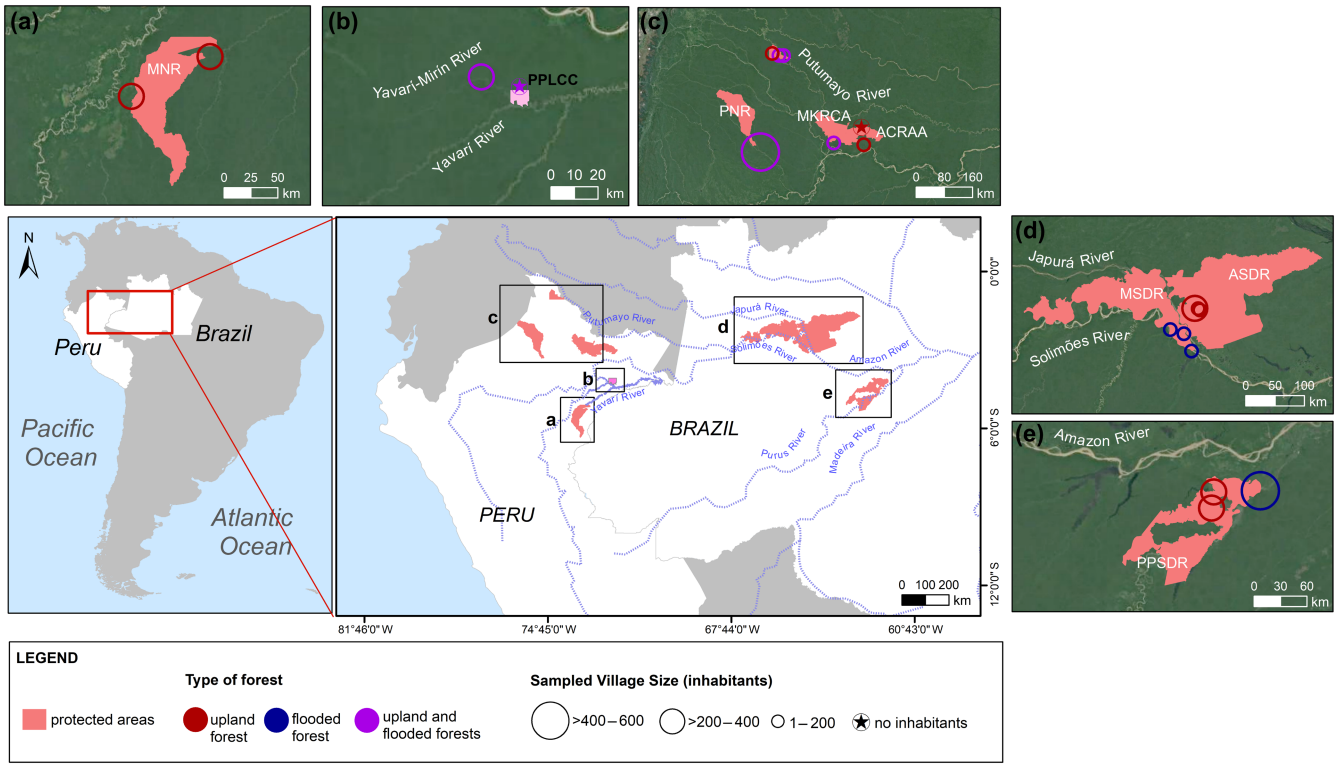

FIGURE 1 Map of the study area, portraying the 18 sites in Central and Western Amazonia. Pink background areas represent protected areas. Letters (a–e) provide close-up views of the sampled regions and study areas; AARCA, Ampiyacu Apayacu Regional Conservation Area; ASDR, Amanã Sustainable Development Reserve; MKRCA, Maijuna-Kichwa Regional Conservation Area; MNR, Matsés National Reserve; MSDR, Mamirauá Sustainable Development Reserve; PNR, Pucacuro National Reserve; PPLCC, Lago Preto and Paredón Conservation Concession; PPSDR, Piagaçu-Purus Sustainable Development Reserve. Map generated using ArcGIS 10.3.1; Datum: WGS84 Source: ESRI.

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surveyed Indigenous villages of various ethnicities, including Boras, Huitotos, Kichwas, Maijuna, Matses, Secoyas and Yagua, whereas all nine Brazilian villages were composed of non-Indigenous riverine settlements inside sustainable-use protected areas inhabited by *caboclos* or *ribeirinhos*. This latter group is peasant populations living along the river margins of the Amazon basin, descendants of intermarriage and cultural and economic assimilation between remnant Indigenous populations, European descendants and Afro-Brazilian settlers from north-eastern Brazil (El Bizri et al., 2020; Fraser, 2010).

People in all study villages are legally allowed to take part in decision-making on natural resource use and management in their areas of influence for food and other subsistence purposes. Fishing and hunting are the most important subsistence activities, and hunters are mostly adult men older than 15 years, but often children may accompany their fathers from around 11 years (De Mattos Vieira et al., 2019). In some villages, timber, fish, wild meat or agricultural products are also sporadically traded for small-scale income. Accessibility to urban areas is difficult but has increased with more frequent trade of natural resources, facilitating the introduction of urban customs that require monetary income, such as the use of electrical appliances (Bernárdez-Rodriguez et al., 2021).

2.2 | Data collection

Using structured interviews in all villages between 2013 and 2017, we surveyed the abundance perceptions of villagers of a total of 101 vertebrate species, including 84 (83.1%) mammals, 14 birds (13.9%), and three reptiles (2.9%). Mammals were composed by species from the following Orders: Primates ($n=42$, 50% of the total number of mammal species), Carnivora ($n=14$, 16.6%), Rodentia ($n=10$, 11.9%), Pilosa ($n=7$, 8.3%), Artiodactyla ($n=5$, 5.9%), Cingulata ($n=3$, 3.6%), Didelphimorphia ($n=2$, 2.4%) and Perissodactyla ($n=1$, 1.2%). All birds considered in this study were hunted birds (Braga-Pereira et al., 2022). The species that were asked in each village were selected based on the known occurrence of these animals from previous surveys in the area. A median of 35 species (range = 14–45) were asked per site. Since the assembly of species of primates, birds, and reptiles varied among sites, we pooled these taxa at the genus level (hereafter ecospecies) to enable meaningful comparisons among sites (Table S1).

We interviewed only persons who were known to be knowledgeable of wild animals and their environments. To select the first person to interview, we identified potential interviewees using our previous knowledge of residents in each village. We then employed a snowball sampling technique (Bailey, 1994) and asked the first person approached to suggest others and ask them to participate in the study. We interviewed each person independently (Kent, 2011), using an illustrated checklist with colour plates of the species asked in each study area (Figure S1). Research groups involved in this study who conducted the interviews were already working in each site for 10–20 years and had built relationships of trust in the communities prior to data collection. This prevented that only one group of hunters in larger villages would be interviewed, which could inflate consensus estimates. Interviews did not require local translators, as both interviewers and interviewees, including those from Indigenous territories, were fluent in Portuguese or Spanish.

For each species, we asked the interviewee to estimate its relative abundance on a Likert scale: 0 (when the species was 'absent'), 1 (low abundance), 2 (medium abundance) and 3 (high abundance) (Braga-Pereira et al., 2022; Van Holt et al., 2010, 2016). The abundance of a species was assessed in comparison to others occurring in the area (the abundance of each new species presented during the interview was compared to the previous ones, and at the end, the abundance presented for each species was revised). We also added a species that did not occur locally to test the veracity of the answers. The abundance of a species indicated its status within a radius of approximately 5 km from the centre of the village where each hunter lived.

We recognize that perceived abundance of species might be influenced not just by their observable presence but also by cultural and spiritual beliefs, especially if a species holds significant spiritual value in the local community. Our study derives data from the hunters' perspective; therefore, we consider that, despite the possible influence from cultural and spiritual aspects, information is derived mostly from people's observations during their hunting activities.

2.3 | Predictor variables

Predictor variables were classified into social, biological and ecological variables. Social variables included (1) the number of years an interviewee had dedicated to hunting as a measure of their hunting experience; (2) the percentage time each respondent spent out from their village; and (3) village population size.

Biological and ecological predictor variables included (1) forest type (non-flooded or flooded forests); (2) '*Apparency index*', a mixed variable based on traits that influence species apparency; and (3) hunting rate (Peres, 2000).

Ecological apparency is a concept in ecology that pertains to the characteristics of animals and plants that make them more conspicuous, detectable or noticeable within their environment. For the *apparency index*, we used traits that consist of continuous and categorical variables that make a specimen more or less apparent:

For the continuous variables, we used the exact value of the trait in the index formula. This variable included: (i) species' body mass; and (ii) sociality (solitary/social—with two or more individuals);

For the categorical variables, we attributed a score in accordance with the apparency of each variable level. This variable included: (iii) habit category as nocturnal (scored as 1) or diurnal (scored as 2); and (iv) locomotion mode category as aquatic (scored as 1), arboreal (scored as 2) or terrestrial (scored as 3).

Finally, the *Apparency index* was calculated as follows:

$$\text{Apparency index} = \text{body mass} \times \text{sociality} \times \text{habit} \times \text{locomotion mode}.$$

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In this *Apparency index*, all traits referring to higher crypticity were scored with low scores (see Table S2).

Hunting rate is expressed as the number of individuals hunted per person per year in the Brazilian Amazon, according to Peres (2000); any species not listed by Peres (2000) was considered to have a hunting rate of 0.

2.4 | Response variables

Using the software UCINET Version 6.511 (Borgatti et al., 2002), we generated the consensus values below:

2.4.1 | Personal (interviewee) consensus

This calculation involved matrix algebra. The response matrix of the perceived abundance of each species (columns) by all the interviewees in each village (lines) was used to calculate the response that appeared most frequently, considered the *valid response* in each village (Borgatti & Halgin, 2011a, 2011b; Romney et al., 1986; Weller, 2007). With these, a single score was generated for each person to determine how far or close their responses were from the valid response. The general outline of the mathematical procedure for the personal consensus is as follows:

1. Data representation: We set up a data matrix, X, of dimensions $n \times q$. Here, n represents the total number of respondents, and q denotes the total number of species. Every entry in this matrix indicates an individual's response about a species' abundance in a particular village.
2. Eigen decomposition: This step involves breaking down the matrix to extract its eigenvalues and eigenvectors, comparable to performing a Principal Component Analysis (PCA) on the agreement matrix. In PCA, eigenvalues quantify the variance each component holds, and eigenvectors indicate the directions of these components in the data.
3. Personal consensus: The primary eigenvector provides competence scores for each participant, which indicate how closely an individual's answers align with the group consensus. The higher the competence score, the more their response matches the overarching cultural model. Each respondent's agreement with the 'valid' answer gives a personal consensus value, ranging between 0 and 1. A response aligning with the 'valid' answer gets a score near 1, whereas a differing answer is closer to 0 (Romney et al., 1986). Any value exceeding 0.6 signifies a high consensus (Romney et al., 1986).

2.4.2 | Village consensus

We calculated the village consensus as the average consensus value from the sum of the personal consensus values divided by the total number of interviewees belonging to the same village.

2.4.3 | Consensus value per ecospecies

The average and standard deviation of the perceived abundance of each ecospecies by all the interviewees from the same village were calculated. The coefficient of variation (CV), as an inverse indicator of discordance with respect to the average value, was calculated using the formula: $CV = (SD \times 100)/$ average. Finally, the consensus value per ecospecies was calculated as $Consensus = 1/CV$. We defined high ecospecies consensus levels as being represented by CV scores less than one.

2.5 | Data analysis

Using the consensus results obtained, we developed sets of models to assess the following hypotheses:

2.5.1 | Personal consensus (Hypothesis 1)

We conducted a generalized linear mixed model (GLMM), using 'hunting experience' and 'time living in the village' for each interviewee as social predictor variables. We nested the data in the model by village. The model formula was as follows: Personal consensus (continuous variable) ~ hunting experience (continuous variable) + time outside the village (continuous variable) + (1|village).

2.5.2 | Village consensus (Hypothesis 2)

We conducted a GLM using 'village population size' and 'forest type' (flooded and upland forests) of each village as predictor variables. The model formula was as follows: Village consensus (continuous variable) ~ village population size (continuous variable) + forest type (categorical variable, flooded forests, upland forests, mixed [flooded and upland forests]).

2.5.3 | Consensus per species (Hypothesis 3 and 4)

We conducted GLMMs, using the 'apparency index' and 'hunting rate' of each species as predictor variables of fixed effects and 'village' and 'ecospecies' as random variables (Zuur et al., 2007) due to the variable number of interviews in villages and per group of species. The model formula was as follows: Consensus per species (continuous variable) ~ apparency score + (1|village/ecospecies); and Consensus per species (continuous variable) ~ hunting level + (1|village/ecospecies).

We found no collinearity ($p > 0.05$) among the predictor variables assessed in the models. For GLM and GLMM, we used the beta-inflated or zero-adjusted gamma families of distribution, based on the type of data. We used residual checks to verify whether our models were, in principle, suitable or not. We used the Akaike information criterion (AIC) to select models of interest if ΔAIC values >6 (ΔAIC obtained from the difference between a null and complete

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model AIC values) (Harrison et al., 2018; Richards, 2008). All analyses were performed in R ver. 3.5.3 (R Development Core Team, 2019) using the ordinal (Christensen, 2023) and MuMin e lme4 (Oksanen et al., 2013) packages.

We did not analyse the difference in consensus values between Indigenous and non-Indigenous villages because this variable (village ethnicity) was influenced by the variable 'village population size'. This is because most Indigenous (224.4 ± 170.6, range = 50–559 inhabitants) and non-Indigenous (208.4 ± 148.1, range = 35–519 inhabitants) villages coincide with villages of greater and smaller population sizes, respectively (see Table S3). As the number of women interviewed compared to the men was small, we could not verify if gender influenced the consensus level either.

2.6 | Ethics statement

We followed the rules and guidelines for applying free, prior and informed consent as detailed in Buppert and McKeehan (2013). This research was approved by the Instituto Chico Mendes de Conservação da Biodiversidade from Brazil (License SISBIO 29092-1; SISBIO 2; 29,092-3; SISBIO 29092-4; SISBIO 29092-5; SISBIO 29092-6; CEUC 1474/2011, CEUC 003/2013 e CEUC 052/2011) and the Dirección General de Flora y Fauna Silvestre from Peru (License 0350-2012-DGFFS-DGEFFS; 0068-2015-SERFOR-DGGSPFFS). Community meetings and coordination with communal authorities were carried out prior to conducting interviews to agree on procedures.

3 | RESULTS

We interviewed a total of 323 inhabitants in the surveyed villages. The average (±SD) number of interviewees per village was 17.8 ± 9.6 (range: 6–42). We interviewed a total of 2 (0.6%) women and 321 (99.4%) men. Ages ranged from 16 to 75 years old (37.8 ± 14.0). The hunting experience of interviewees varied from 0 to 64 years (21.7 ± 14.8 years). The percentage of time that interviewee was out from their villages (either in another village or in the urban area) compared to time living in the village ranged from 0 to 95% (16.4 ± 25.8).

3.1 | Personal and village consensus

When investigating the accuracy of the data, we found consensus values to be above the 0.6 threshold for all villages (Figure 2a) and 79.6% of interviewees (Figure 2b). The overall village consensus was 0.76 ± 0.07 (range = 0.62–0.87), and the personal consensus values were 0.75 ± 0.10 (range = 0.38–0.95).

3.2 | Consensus value per species

We found a high consensus value (CV <1) for 85.3% ($n = 81$) of all 101 sampled ecospecies in villages pooled (Figure 2c). We found a high consensus value among all interviewees for the abundance of agoutis *Dasyprocta* and squirrel monkeys *Saimiri* in the sampled villages. We found low consensus in at least 50% of the villages for two species, jaguarundi *Puma yagouaroundi* and crab-eating raccoon *Procyon cancrivorus* (see the representation of key ecospecies in Figure 3; see all results in Figure S4).

3.3 | Predictors of consensus values

When investigating the predictors of consensus, we did not find any effect of 'hunting experience', 'time living outside the village', 'age' and 'forest type' on the personal consensus model (Table 1; Figures S2 and S3; Figure 3). On the other hand, village consensus was significantly higher in smaller villages (Table 1; Figure 4). The consensus value per ecospecies was higher for ecospecies with higher 'apparency index' and higher 'hunting rate' (Table 2; Figure 5a,b).

4 | DISCUSSION

We found a high consensus of species abundance for most species, by most people and in all villages. Given these results, we can conclude that the LEK of local people can be used to accurately estimate vertebrate population abundance, even by people with little hunting experience and for most cryptic and non-hunted species.

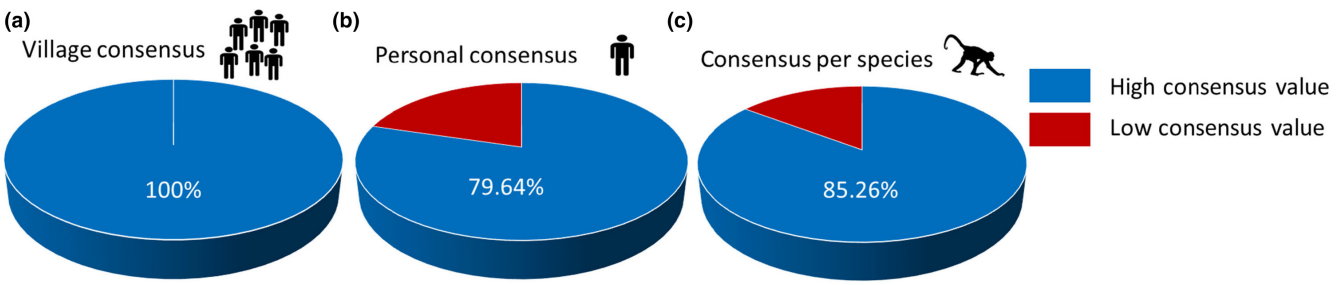

FIGURE 2 Percentage of villages (a), interviewees (b) and ecospecies (c) presenting high and low values of consensus. For village and personal consensus, a high consensus level is above 0.6. For consensus per species, a high consensus level is when the coefficient of variation is below 1.

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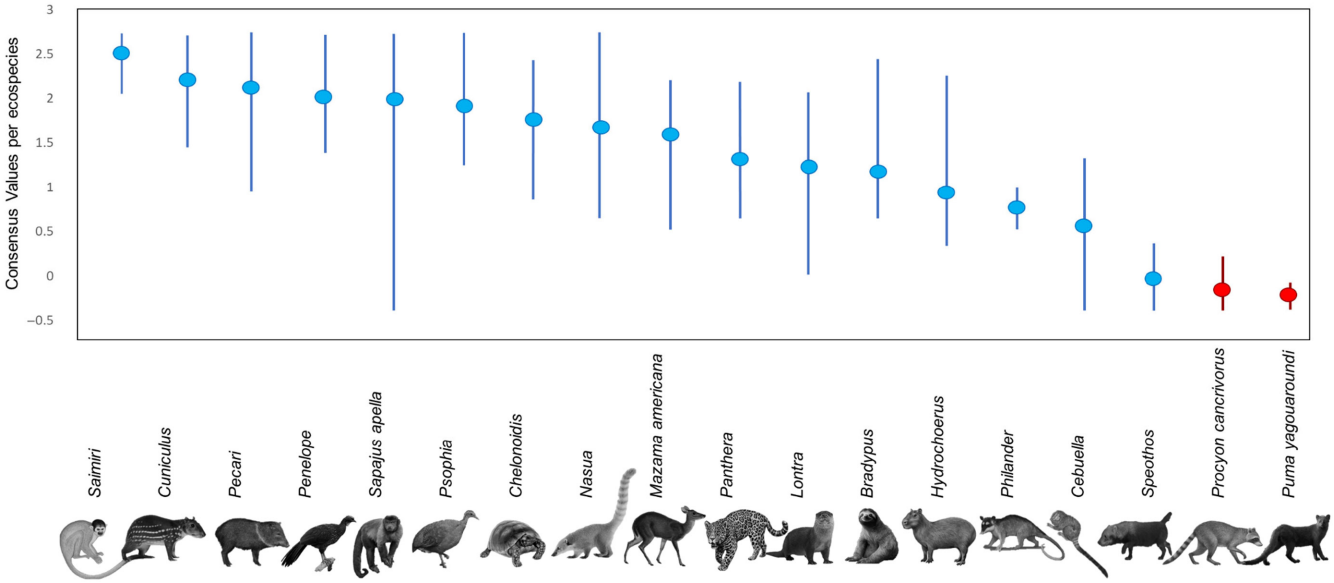

FIGURE 3 Consensus values per ecospecies using some key species for representation. The circles represent the average value of consensus per ecospecies. The bars represent the maximum and minimum consensus values per ecospecies in the surveyed villages. Blue circles represent a high consensus value (coefficient of variation <1). Red circles represent a low consensus value (coefficient of variation >1).

The apparency hypothesis we proposed was validated, as higher consensus values were found for more apparent species. This shows that the noticeability of an animal likely influences its detection probability, increasing the chances of encounter (Hanazaki et al., 2010) and consequently the consensus of their abundance perceived by people. On another hand, less apparent species (e.g. rare, small, solitary, cryptic, silent or nocturnal species) (Atran et al., 2002; Bentley & Rodriguez, 2001; Gosler, 2017; Hunn, 1999; Zamudio & Hilgert, 2015) presented low consensus scores. In this case, the two species that had the lowest consensus levels in our study fit into at least two of these characteristics: while *P. cancrivorus* is a solitary and nocturnal animal; *P. yagouaroundi* is a solitary, silent and furtive species. These species are also not usually hunted (which corroborates with another hypothesis we had proposed).

The hunted species hypothesis was also confirmed, with higher consensus being found for more frequently hunted species. The six species with the highest consensus scores in the studied areas are hunted for the consumption of their meat and other by-products in the region or to be raised as pets. Villagers have a special interest in knowing where they can find these animals, how many there are in the forest and how they behave (Lucena et al., 2012; Wajner et al., 2019). This interest is shared not only by hunters but among everyone in a village, as hunted species are an important source of food and because not only hunters (usually adult men) are involved in the wild meat consumption chain (El Bizri et al., 2021).

Taking into account the invaluable local insights into hunted species, further research with targeted inquiries regarding hunting activities holds great potential. Such studies offer a pathway to comprehensively assess the ecology and population dynamics of these species. This entails quantifying the number of individuals in specific areas, discerning dominant age groups, evaluating reproductive status (e.g. El Bizri et al., 2021) and identifying signs of illness within the population of interest. This can be accomplished by requesting local estimations of the number of perceived individuals, focusing on select target species in specific locations (e.g. 'how many tapirs visit salt lick A?') and employing methods such as using seeds for quantification based on images of the animals (Chaves et al., 2020) (Figure S5).

In a previous study within the same Amazonian villages, it was demonstrated that estimates of vertebrate species abundance obtained through LEK closely matched those acquired through transect surveys (Braga-Pereira et al., 2022). In our current investigation, we have further substantiated the consistency of responses among interviewees, revealing a high level of internal consensus. However, our analysis has identified certain biases, necessitating changes in some procedures to enhance data collection accuracy. Notably, ecospecies like *Saimiri*, *Tinamus*, *Caiman crocodilus*, *Cuniculus paca*, *Dasyprocta* and *Pecari tajacu* exhibited higher consensus levels due to their prominence in the daily lives of the surveyed villages through hunting or because they are easier to detect. However, we recognize that our results might be influenced by the use of only one 'high abundance' category in the Likert scale, which constrained the range of responses by capping it at this category. To improve accuracy, we recommend employing a more extensive category range and transitioning from a nominal to a quantitative scale (as outlined in Figures S5 and S6). We also suggest the use of questions with clear reference points for assessing abundance over time (e.g. 'what is the abundance of species now and 10 years ago?'); across different

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TABLE 1 Details of all GLMMs and linear models elaborated to verify the influence of social factors on the cultural consensus obtained by each interviewee (personal consensus) and by each village (village consensus). Estimated values indicate the coefficients associated with the variable listed on the left. This represents the estimated amount by which the odds (that each response variable would increase if each explanatory variable were one unit higher). *Z*-values indicate the degree to which explanatory variables exert a significant effect. Pr (>|z) denotes significance levels, in which $^{**}p \leq 0.01$. AIC, Akaike information criterion; ΔAIC is the difference of AIC of the null model in relation to the selected model.

Response variable	Predictors	Estimate	SE	z Value	Pr(>|z|)	AIC	AIC null model	ΔAIC	Model
Personal consensus	Time hunting	−2.41E-04	0.0073	−0.033	0.974	493.6	489.6	−4	GLMM
	Time far away from the village	0.0266	0.4165178	0.064	0.949				
Village consensus	Number of inhabitants per village	-4E-04	1E-04	−3.075	0.007**	−1132.32	−1096.21	36.103	GLM
	Flooded: flooded and upland (mixed)	0.04421	0.032	1.382	0.1675				
	Flooded: upland	0.0694	0.03187	2.178	0.0797				

Abbreviations: GLM, generalized linear model; GLMM, generalized linear mixed model.

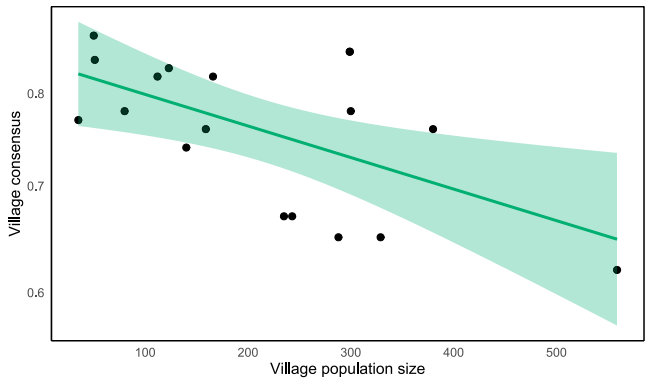

FIGURE 4 Relationship between village consensus and village population size (number of inhabitants). Values of village consensus >0.6 indicate a high consensus levels of perceived animal abundance. The shaded area represents 95% confidence intervals.

areas (e.g. 'what is the abundance of species in area A and B?'); and relative to other species. Additionally, we propose the use of maps to help interviewers accurately delineate the surveyed area. Given the cultural variations in mental quantification, we also propose using the number of hunters who last observed each species as an indicator of species abundance across the selected area. This approach suggests that the greater the number of hunters who reported recent sightings or hunting of a specific species (e.g. within the current year), the more abundant that species is in a particular area (van Vliet et al., in press; see also Oliveira et al. (2022) for a comparison of harvest rates and freelisting citations of hunted animals).

Although higher consensus was found for hunted species, we also found a decent consensus level for several non-hunted species, and this is because hunters also observe these species in their daily lives and activities. For example, when spending time at salt licks—a common practice performed by hunters in the Amazon to hunt animals like tapir and deer—hunters also observe many non-hunted species that visit the site, such as jaguars and spider monkeys (Montenegro, 2004). There is also indirect hunter observation of non-hunted species. For example, in northern Brazil, the Yanomami people constantly decode an elaborate system of sounds connected with the notion of songs, cries and calls of many birds, amphibians and certain insects, which they interpret as acoustic clues for the possible presence of prey, fruits or plants associated with them (Albert, 2016).

We refuted the nature-contact hypothesis. Given that hunters use time-acquired skills to detect animals in the forest, we expected that experienced hunters would have higher consensus compared to less experienced hunters. However, we did not detect any difference between these two groups. This may be related to the interest that all villagers have in talking and sharing experiences about hunted species (Zayonc & Coomes, 2022). Measuring the difference between years of hunting experience and how many years ago the interviewee stopped the activity should be investigated in further studies. We also expected to find a negative association between time absent from the village and personal consensus due to the

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TABLE 2 Details of all generalized linear mixed models elaborated to verify the influence of apparency and hunting level on the consensus obtained for each ecospecies (consensus per ecospecies). Estimated values indicate the coefficients associated with the variable listed on the left. This represents the estimated amount by which the odds (that each response variable would increase if each explanatory variable were one unit higher). *T*-values indicate the degree to which explanatory variables exert a significant effect. Pr (>|*z*) denotes significance levels, in which ***$p \leq 0.001$. AIC, Akaike information criterion; ΔAIC is the difference of AIC of the null model in relation to the selected model.

Response variable	Predictors	Estimate	SE	*t* Value	Pr(>|z|)	AIC	AIC null model	ΔAIC
Consensus per ecospecies	Hunting rate	0.6747	0.0515	13.09	<0.001***	−2934.89	−2725.40	209.49
Consensus per ecospecies	Apparency index	0.3620	0.0412	8.79	<0.001***	−2033.69	−1521.15	512.50

erosion of LEK, as more time in the city means less time in the forest and in direct contact with other local members who know about the forest (Ohmagari & Berkes, 1997; Prado & Murrieta, 2018; Reyes-García et al., 2010; Zent, 2001). This, however, was not confirmed by our findings. Other studies conducted in some of the same villages we surveyed (i.e. within the Amanã Sustainable Development Reserve) found no signs of generational change or erosion of LEK regarding highly hunted species, such as the yellow-footed tortoise (*Chelonoidis denticulatus*) (Tavares et al., 2020). The consistently high consensus level, regardless of time spent away from the village, may stem from our use of the snowball sampling technique, as individuals recommended for interviews were predominantly those recognized for their extensive wildlife knowledge.

We accepted the hypothesis of information transmission, as the consensus among members of villages of smaller population size was greater. This is explained because, in areas with lower human density, the proportion of residents reached by the same information is greater. We highlight that although consensus was lower in villages of larger population sizes, it was high (>0.6) in all villages in our study. This might be explained because personal orality is the main way of disseminating information in all villages, so local knowledge is shared even in larger villages. While one might anticipate a dilution of information in larger villages due to a greater number and diversity of residents, potentially reducing information transmission, the populations of the sampled villages are not notably large, especially when compared to nearby cities.

Worldwide, Indigenous people and local communities manage large tracts of land; Indigenous peoples alone manage around 38 million km^2 of the world, which safeguards biodiversity and mitigates climate change (Estrada et al., 2022; Fa et al., 2020; Garnett et al., 2018; O'Bryan et al., 2020). As a result, there is a growing recognition among researchers and conservationists that LEK systems, perspectives and histories hold globally important conservation lessons. In addition, a substantial proportion of the world's biodiversity inhabits lands managed by local peoples (Indigenous and non-Indigenous) (Fletcher et al., 2021; Piperno et al., 2021; Schuster et al., 2019). Based on a large database gathered over a wide and diverse geographical and cultural scale in different Amazonian societies, we can conclude that the cultural consensus level among villagers is overall high, arising from a long-established and intricate connection between local people and forest environments. Our

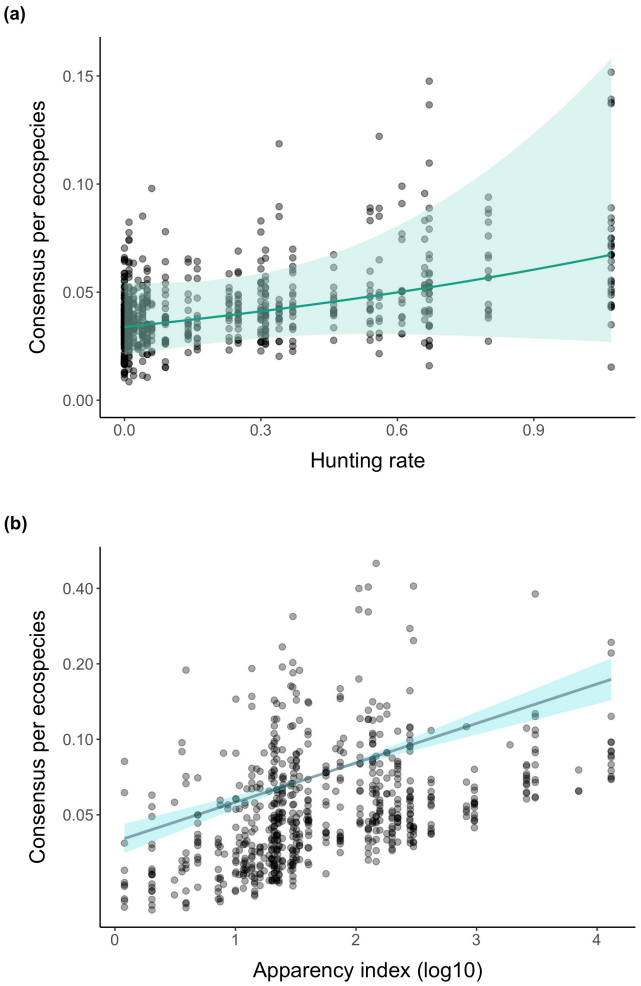

FIGURE 5 Relationship between consensus value per ecospecies and (a) hunting rate (number of individuals hunted per person per year) and (b) apparency index. The shaded area represents 95% CIs, and points are residuals of the model. The *Y*-axis in (b) is logarithmized (natural log) plotted in the original scale, while the *X*-axis is transformed into log10.

findings reinforce the importance of LEK-based methods for research, such as the estimation of the status of species populations with different bioecological characteristics. LEK can also be used to generate novel methods that are often more efficient in detecting

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and estimating species abundances than conventional methods (e.g. El Bizri et al., 2016; Morcatty et al., 2020). Finally, the accuracy of data obtained from interviews can be verified analysing the data per itself, rather than comparing the interview data to data obtained from other collection methods.

All people living in Amazon rainforests have accumulated a profound body of experience with Amazonian wildlife and their environments over very long periods of time. The immense value of this knowledge reservoir must be recognized by academics and management agencies to improve their integration into research and conservation programs, as increasingly demanded by international bodies (IUCN, 2021; UN Office of the High Commissioner for Human Rights (OHCHR), 2013). The inclusion of local, non-Indigenous and Indigenous peoples in protecting areas of global importance such as the Amazon must go beyond information gathering and move into clear joint decision-making processes that encourage decolonisation (Trisos et al., 2021) and incorporate varied perspectives, approaches and interpretations of the natural world.

AUTHOR CONTRIBUTIONS

Pedro Mayor, Thais Q. Morcatty, Pedro E. Pérez-Peña, Mark T. Bowler and Hani R. El Bizri conceived the ideas and designed the methodology. Franciany Braga-Pereira, Pedro Mayor, Thais Q. Morcatty, Pedro E. Pérez-Peña, Mark T. Bowler, Marina A. R. de Mattos Vieira, Aline S. Tavares, Carla Mere-Roncal, Carolina Bertsch, Claudia Ramos Rodriguez, Claudio Bardales-Alvites, Eduardo von Muhlen, Fernanda Pozzan Paim, Jhancy Segura Tamayo, João Valsecchi, Jonas Gonçalves, Leon Torres-Oyarce, Lísley Pereira Lemos, Michael P. Gilmore, Miguel Antúnez Correa, Natalia Carolina Angulo Perez, Pablo Puertas and Hani R. El Bizri collected and compiled the data. Franciany Braga-Pereira, Thais Q. Morcatty, Carlos A. Peres, Carlos González-Crespo and Hani R. El Bizri analysed the data. Franciany Braga-Pereira wrote the original draft. Franciany Braga-Pereira, Pedro Mayor, Thais Q. Morcatty, Mark T. Bowler, Marina A. R. de Mattos Vieira, Rômulo Romeu da Nóbrega Alves, Julia E. Fa and Hani R. El Bizri edited the manuscript. All authors gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

We declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data are available on https://doi.org/10.5061/dryad.v9s4mw733.

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SUPPORTING INFORMATION

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

Figure S1. Examples of the set of species images of the illustrated checklist used during the structured interviews which provided visual stimulation with drawings of species presumably present in each study areas.

Figure S2. Relationship between (A) Personal consensus and years of hunting experience; (B) Personal consensus and percentage of time spent outside the village; and (C) Personal consensus and age.

Figure S3. Relationship between village consensus and forest type.

Figure S4. Consensus values per ecospecies.

Figure S5. Simulation of seeds referring to the number of individuals of each species in a site.

Figure S6. Likert scale of relative abundance.

Table S1. Species included in the interviews per village.

Table S2. List of species considered in this study with their respective biological and socioecological information.

Table S3. Information on areas studied in the Brazilian and Peruvian Amazon.

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