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RESEARCH ARTICLE

Congruence of local ecological knowledge (LEK)-based methods and line-transect surveys in estimating wildlife abundance in tropical forests

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Abstract

1. Effective estimation of wildlife population abundance is an important component of population monitoring, and ultimately essential for the development of conservation actions. Diurnal line-transect surveys are one of the most applied methods for abundance estimations. Local ecological knowledge (LEK) is empirically acquired through the observation of ecological processes by local people. LEK-based methods have only been recognized as valid scientific methods for surveying fauna abundance in the last three decades. However, the agreement between both methods has not been extensively analysed.

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2. We compared concomitant abundance data for 91 wild species (mammals, birds and tortoises) from diurnal line transects (9,221 km of trails) and a LEK-based method (291 structured interviews) at 18 sites in Central and Western Amazonia. We used biological and socioecological factors to assess the agreements and divergences between abundance indices obtained from both methods.
3. We found a significant agreement of population abundance indices for diurnal and game species. This relationship was also positive regardless of species sociality (solitary or social), body size and locomotion mode (terrestrial and arboreal); and of sampled forest type (upland and flooded forests). Conversely, we did not find significant abundance covariances for nocturnal and non-game species. Despite the general agreement between methods, line transects were not effective at surveying many species occurring in the area, with 40.2% and 39.8% of all species being rarely and never detected in at least one of the survey sites. On the other hand, these species were widely reported by local informants to occur at intermediate to high abundances.
4. Although LEK-based methods have been long neglected by ecologists, our comparative study demonstrated their effectiveness for estimating vertebrate abundance of a wide diversity of taxa and forest environments. This can be used simultaneously with line-transect surveys to calibrate abundance estimates and record species that are rarely sighted during surveys on foot, but that are often observed by local people during their daily extractive activities. Thus, the combination of local and scientific knowledge is a potential tool to improve our knowledge of tropical forest species and foster the development of effective strategies to meet biodiversity conservation goals.

KEYWORDS
Amazon, citizen science, ethnobiology, ethnozoology, subsistence hunting, traditional knowledge, vertebrates

1 | INTRODUCTION

Abundance is one of the most used indicators to assess wildlife population status, which ultimately enables practitioners to assess the effects of threats on populations and the effectiveness of conservation actions (Kremen et al., 1994; Stephenson, 2019). However, surveying wildlife abundance remains challenging due to financial and logistical limitations, which are more pronounced in long-term studies in poorly accessible areas. In addition, constraints posed by certain species' biological traits may result in underestimated detection through conventional methods (MacKenzie et al., 2006; Nichols & Williams, 2006). While abundant species and those with small home ranges require a moderate sampling effort to estimate their abundance, rare species and those with large home ranges may be difficult to detect, decreasing the accuracy of abundance estimations (Plumptre, 2000). Consequently, methods used in the field can determine the success or failure of abundance surveys (Fragoso et al., 2016). The best method should ideally ensure high detection rates of the target species while also being cost-effective and accurate (Fragoso et al., 2016; Guillera-Arroita, 2016).

Line-transect surveys are frequently used as a method to obtain abundance data of fauna (Plumptre, 2000; Stephenson, 2019). This is mainly because of the broad range of species this method can target, being used to assess the status of populations ranging from whales in the ocean to small invertebrates in forests (de Thoisy et al., 2008; Haugaasen & Peres, 2005; Peres & Cunha, 2012). However, line-transect surveys require intensive sampling effort (de Thoisy et al., 2008) and are often conducted diurnally, resulting in poor estimates of abundance mainly affecting nocturnal and less abundant species (Munari et al., 2011). Even during night surveys, the efficiency of the technique on monitoring nocturnal species is generally low, given the limited human visual capacity and the inability of observers to move in silence (Munari et al., 2011). Line transects can therefore be costly, time- and staff-consuming, and require year-round assessments to adjust for seasonal changes in abundance and behaviour (Fashing & Cords, 2000; Van der Hoeven et al., 2004).

The integration of natural and social science methodologies in conservation studies has gained traction over the past three decades, mainly through the 'citizen science' and the 'ethnoscience' approaches (Berkes, 2017). Both approaches can involve the use of local ecological knowledge (LEK), which is defined as the knowledge and practices of local people regarding ecological relationships that are gained through extensive personal empirical observations of and interactions with local ecosystems, and shared among local resource users (Charnley et al., 2007). As LEK includes traditional, indigenous and local knowledge, we herein use the term LEK instead of traditional or indigenous ecological knowledge. LEK has contributed to research by assisting scientists in locating and collecting information on plants and animals since the 16th century (Alves & Souto, 2015). Currently, LEK-based methods are used to gather information on habitats, extractive uses of biodiversity, human–wildlife conflicts, species ecology and behaviour (Joa et al., 2018; Young et al., 2018), population dynamics over time (Braga-Pereira et al., 2020), and enhance governance (Joa et al., 2018; Vieira et al., 2019).

LEK-based methods have also been applied to develop new scientific methods to overcome previous methodological hurdles (El Bizri et al., 2016; Morcatty et al., 2020; Parry & Peres, 2015) and may provide a cost-effective and robust understanding of natural systems that are likely to equate to or exceed that of conventional scientific knowledge (Gagnon & Berteaux, 2009; Meijaard et al., 2011). Hence, the combination of local knowledge and methods conventionally used by wildlife ecologists could improve species' detection rates, facilitate mutual learning and local empowerment, and contribute to enhance conservation goals (Burgess et al., 2017). To date, studies have focused on the comparison of the two methods regarding the species detection rate for one or a few sets of species (see Anadón et al., 2009; Camino et al., 2020; Madsen et al., 2020; Perez-Peña et al., 2012). In this study, we estimated and compared abundance indices of 91 species of wild vertebrates (including mammals, birds and tortoises) using data collected concomitantly through diurnal line-transect censuses and perceptions of local people through a LEK-based method at 18 sites around indigenous and non-indigenous riverine villages in the Western and Central Amazon. We also examined some biological and socioecological factors that can explain agreements and divergences between both methods to develop a better understanding of their limitations and potentials.

2 | MATERIALS AND METHODS

2.1 | Study area and villages

This study was conducted in 18 sites located in the Brazilian (n = 9) and the Peruvian (n = 9) Amazon. These include eight specific sites in upland forest, four in flooded forest and six in both upland and flooded forests (Figure 1). Eight locations are within indigenous villages, nine are in non-indigenous riverine villages and one site has no human settlement (Supporting Information Table S1). The non-indigenous riverine villages are located in Sustainable Use Protected Areas, which are a legally recognized category of protected area in which traditional people partake in decision-making on natural resource use and management. Hunting remains an important subsistence activity for the residents living within these areas.

2.2 | 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; 29092-3; 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.

2.3 | Data collection

Between 2011 and 2017, we surveyed the abundance of a set of species through line transects, and through interviews with local people from 17 different indigenous and non-indigenous riverine villages. All villages were settled in or near the sites where transects were surveyed, and local people use these sites for different purposes (hunting, harvesting of forest products, etc.); therefore, each village offered information about at least one correspondent site. In all, 16 villages informed LEK about a single correspondent site, and 1 village informed LEK for 2 correspondent sites. Interviews and line transects within each study area were conducted in a mean lapse time of 8.6 months, ranging from 0 to 24 months.

The species considered in this study did not necessarily occur in all study sites, and each sampling was conducted considering the species known to occur in a given region from previous studies. In total, we surveyed the abundance of 91 species, with a median of 35 species (range = 14–45) per site. This number included 45% Primates (number of species = 41), 13.2% birds (n = 12), 13.2% Carnivora (n = 12), 8.8% Rodentia (n = 8), 6.6% Pilosa (n = 6), 5.5% Artiodactyla (n = 5), 3.3% Cingulata (n = 3), 2.2% Didelphimorphia (n = 2), 1.1% Perissodactyla (n = 1) and 1.1% Testudines (n = 1; Supporting Information Table S2). All bird species considered in this study consist of gamebirds.

2.4 | Line transects

We estimated the population abundance of each species from direct diurnal sightings conducted on 31 line transects, with a total surveyed distance of 9,221 km (ranging from 42 to 2,687 km surveyed per site; mean = 512 km, SD = 707; Supporting Information Table S1). Each transect was randomly positioned in all study areas and transects were opened prior to the surveys. Two observers (at least one of them was a local monitor) walked the trails between 6:00 and 15:00 hr at an average speed of 1.5 km/hr. When a group of animals was encountered, the number of individuals and species was recorded. From the collected data, we calculated the sighting

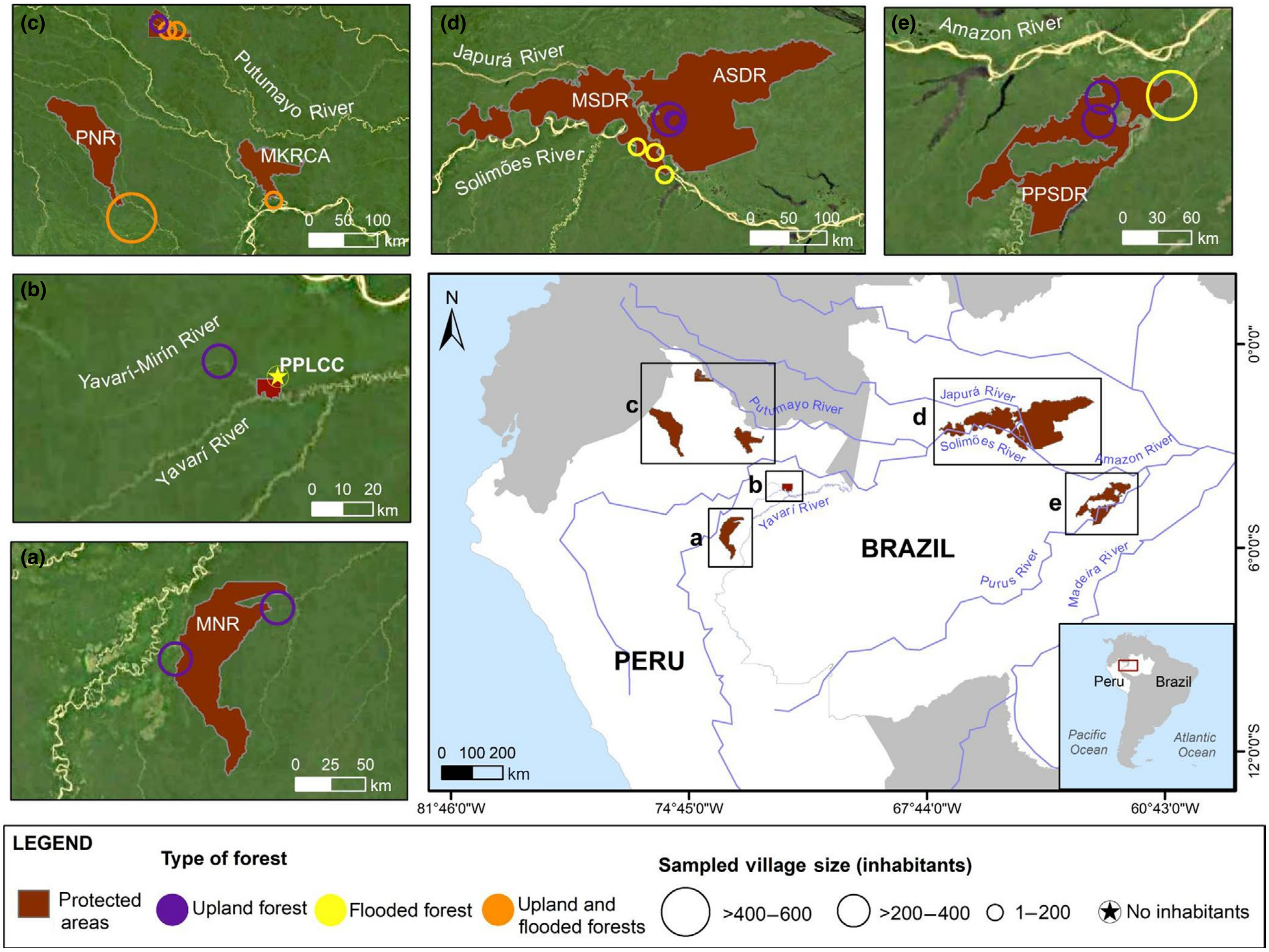

FIGURE 1 Map of the study area portraying the 18 sites in Central and Western Amazonia. Brown background areas represent protected areas. Letters (a–e) provide close-up views of the sampled regions and study areas; MNR: Matsés National; PPLCC: Lago Preto and Paredón Conservation Concession; PNR: Reserve; Pucacuro National Reserve; MKRCA: Maijuna-Kichwa Regional Conservation Area; MSDR: Mamirauá Sustainable Development Reserve; ASDR: Amanã Sustainable Development Reserve; PPSDR: Piagaçu-Purus Sustainable Development Reserve. Map generated using ArcGIS 10.3.1; Datum: WGS84 Source: ESRI, Edited in Adobe Photoshop and Elaborated by Nadia Zamboni and Franciany Braga-Pereira in December 2020

rates (individuals/km, calculated as the total number of individuals observed divided by the total effort in km travelled on any given transect during all seasons), which were used as our abundance index since higher abundance increases species detections (e.g. Paim et al., 2019). The value of zero was assigned to species whose occurrence is confirmed in the area but that were not detected on any transect sampled near that village.

2.5 | Local ecological knowledge

We interviewed 291 local people from the sampled villages (average interviewees per village = 16.16, *SD* = 6.62) using a snowball sampling technique (Bailey, 1994) through the indication by each interviewee of another local expert on fauna. The interviewees' ages ranged between 16 and 75 years old (average = 37.75; *SD* = 13.29). We conducted interviews individually to collect the interviewee perception of the abundance through a LEK-based method of each species that occur in the area in which the interviewee lives. Interviews did not require local translators as both the interviewers and the interviewee, including those from indigenous territories, were fluent in Portuguese or Spanish. All researchers conducting the interviews were already working in each site and had built relationships of trust in the communities.

Data were collected through structured interviews with an illustrated checklist, which provided colour plates of species expected in each study area (Supporting Information Table S1). During each interview, we asked the local vernacular name for each species illustration, often corresponding to the species common nomenclature in Portuguese or Spanish. For each species, we asked the interviewee to estimate their abundance on a Likert scale: 0 (when the species was 'absent'), 1 (low abundance), 2 (medium abundance) and 3 (high abundance; Van Holt et al., 2010, 2016). The value assigned by each interviewee for each species was considered as our abundance index for the LEK-based method. The value of zero was assigned only to species whose occurrence is expected for the area by previous studies but was mentioned as absent by a specific interviewee. We validated the consistency of the responses through a cultural consensus analysis (Borgatti & Halgin, 2011), which consists in a multivariate test based on the degree of similarity between respondents' answers. Respondents showed a personal consensus higher than 0.6, indicating a high consensus regarding the abundance indices of each species population.

2.6 | Covariates

2.6.1 | Species traits

Species traits were used to help explain the agreement and divergence between abundance values obtained through line transects and the LEK-based method. These included body mass, sociality (solitary/social—with two or more individuals), habit (diurnal/nocturnal) and locomotion mode (arboreal/terrestrial). For some analysis, we also used body mass categories: small (less than 1 kg), medium-sized (between 1 kg and 5 kg) and large-sized (exceeding 5 kg) species, considering adult average body mass (Emmons & Feer, 1990).

2.6.2 | Hunting rate

We used data in Peres (2000) to obtain information on the hunting rate (in number of individuals hunted per person per year) of each species across the Amazon; if a species was not listed by Peres (2000), we considered a hunting rate of 0. For some analyses, we also divided the distribution of hunting rate values of all species into quantiles, forming the following hunting rate ordinal classes: no hunting (0), low hunting (until 0.05), moderate hunting (between 0.05 and 0.35) and heavy hunting (until 1).

2.6.3 | Forest type

We used the forest type of each surveyed site as a covariate. The studied sites were either in upland forest and/or white-water flooded forest. Upland forest (*terra-firme*) is a non-flooded forest located in sites with higher elevation within the Amazon rainforest. White-water flooded forest (*várzea*) is a seasonal floodplain forest inundated by white-water rivers that flow within the Amazon rainforest.

2.7 | Data analysis

2.7.1 | Drivers of abundance for line transects and LEK-based method

We examined the effect of species traits, hunting rate and forest type on line transect and LEK-based abundance indices. For the transect data analysis, we used GLMM with the negative binomial distribution. We considered (a) line-transect abundance index values as a response variable; (b) species traits, hunting rate and forest type as predictor variables of fixed effects and (c) species as a random variable.

For the LEK-based method data analysis, we used cumulative link mixed model (CLMM) because the data of the perceived abundance are ordinal, ranging from 0 to 3. For this model, we considered (a) LEK-based abundance index as a response variable; (b) species traits, hunting rate and forest type as predictor variables of fixed effects and (c) sites and species as random variables. In this case, abundance indices collected in each interview were compared per species within a particular site.

There was no collinearity ($p > 0.05$) among predictor variables. For GLMM and CLMM, we used residual checks to verify whether our models were, in principle, suitable or not. We used the Akaike information criterion to select models of interest if ΔAIC values >6 (ΔAIC obtained from the difference between a null and complete 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, 2019), MuMin e lme4 (Oksanen et al., 2013) packages.

2.7.2 | Comparison of abundance indices obtained through line transect and LEK-based method

We conducted generalized linear mixed models (GLMMs) to examine the relationship between the abundance indices from the two methods, comparing the within-species abundance index from each interviewee and the abundance index obtained through line transects at each site. We considered (a) line-transect abundance index as a response variable; (b) LEK-based method abundance index as a predictor variable of fixed effects and (c) site and species as random variables following Zuur et al. (2007). In this analysis, we nested the effect of each species within each particular site (see Supporting Information Table S1).

First, we analysed the entire dataset in one initial model. Then, we stratified the dataset into different sets considering the following groups in different models: diurnal, nocturnal, arboreal, terrestrial, solitary, social, small, medium and large-sized body; none, low, medium and high hunting rate; upland and flooded forests. We did this stratification to clarify the relationship between abundance indices from transect and LEK-based method according to different biological and socioecological factors (Supporting Information Table S1).

Given that line-transect abundances consist of over-dispersed count data, we used the negative binomial distribution. We used frequentist statistics to evaluate the relationships between variables, presenting in each case p-values (<0.05), confidence intervals, F-values, degrees of freedom and adjusted r squared values (>0.6).

We used pairwise Pearson correlations to examine the strength and direction of species-specific correlation coefficients between abundance indices based either on the LEK-based method or line-transect censuses. Here, we calculated the mean and the error (±95% CIs) of correlation coefficients for each species. For these correlations, we excluded all species occurring at fewer than four of all 18 sites. To boost sample sizes and the number of species included in the analysis, we pooled all taxonomic species into ecological analogues or functional groups (hereafter, ecospecies), typically defined as closely related parapatric species or congeners that replace one another across geographical boundaries (see Peres & Palacios, 2007). Considering that our sampling unit (number of interviewees) is ~300, a correlation value $r > 0.113$ can be considered highly significant at alpha = 0.05 (see Statistics Solutions, 2021).

3 | RESULTS

3.1 | Abundance estimates using line transects and the LEK-based method

For line-transect surveys, most species were either undetected (39.8%) or yielded an abundance below 0.1 individuals per kilometre walked (40.2%; Figure 2; Supporting Information Figure S2). Many of no- or low-detection species during surveys on foot had been widely recorded through the LEK-based method as having medium (44%) or high (41%) abundance in the area. For example, *Coendou* spp., *Pipile cumanensis*, *Bradypus tridactylus*, *Cheracebus torquatus* and *Choleopus didactylus* were not recorded in any transect but were reported as occurring in all interviews. Conversely, the distribution of species abundance indices in the histogram according to LEK-based method had only 4.7% of the data representing species that are supposedly absent in the area, and 17.9%, 28.7% and 48.6%, representing species with low, medium and high abundance indices, respectively (Figure 3). In 90.3% of the occasions when an interviewee reported that a species was absent in the village, the species was also not detected in the area through line-transect surveys. Conversely, only on five occasions did interviewees say that a species recorded during line-transect surveys were absent in the area (twice for *Sciurus* sp. and *Pithecia albicans*, and once for *Lagothrix poeppigii*).

The most detected taxa on line transects were Primates, followed by gamebirds and Carnivora, which corresponded to 85%, 5% and 5% in the total sum of all detected individuals ($N = 22{,}908$), respectively. Tortoises and Didelphimorphia species

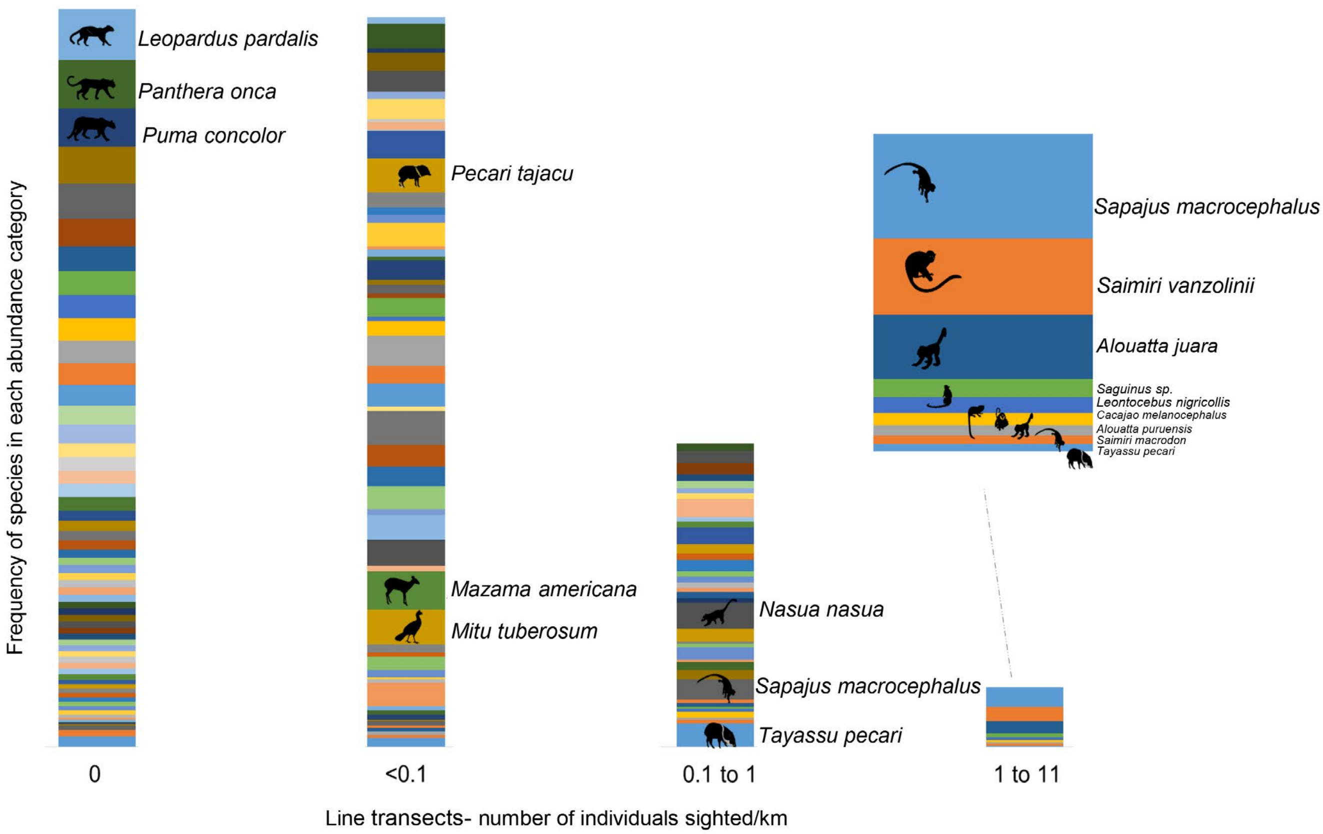

FIGURE 2 Distribution of species abundance according to linear transect. Abundance values were grouped into four categories (*x*-axis): 0 (when the species was never recorded on transects of a specific village); <0.1 individual per km; from 0.1 to 1 individual per km and from 1 to 11 individuals per km. Each coloured box represents a species and box sizes represent the number of sites in which the species was detected with that abundance category. *Y*-axis represents the frequency with which each species was recorded in each abundance category. A close-up was performed on the last category for better visualization of the most registered species. Species can occur in more than one category because the graph is based on the number of sites with a certain abundance category for each species. We included a silhouette and the scientific name of the species in the box of the most registered species in each category

were never recorded using line transects. In agreement with line transects, the most abundant taxa recorded through LEK-based method were Primates, gamebirds and Carnivora which corresponded to 30%, 17% and 15% in the total sum of all abundance data estimated by all interviewees (N = 20,282), respectively. The abundance of tortoises and Didelphimorphia species within the total of LEK-based abundance indices were 2% and 0.4%, respectively (Figure 4).

3.2 | Correlates of abundance estimated by line transects and the LEK-based method

When each method was analysed separately, the most abundant species on line transect were those that live in larger groups and with diurnal habit. In addition, the abundance of populations in flooded forests were higher than in upland forests using line transects (Figure 5a; Supporting Information Table S4). For the LEK-based method, species that live in larger groups were also estimated to have a higher abundance; all other variables did not have a significant effect on the LEK-based abundance (Figure 5b; Supporting Information Table S5).

3.3 | Comparisons of abundance estimates using line transect and the LEK-based method

For 30 of all 54 ecospecies, we found a significantly positive correlation ($r \geq 0.113$) between abundance indices based on the LEK-based method and direct field surveys on line transects, with only two species showing a significantly negative correlation. All group-living species with group sizes ≥ eight individuals showed a positive correlation (Figure 6).

Considering all species (the entire dataset in our initial model), we found a consistent and significant relationship between the abundance indices obtained through transects and the LEK-based method ($p < 0.001$; Supporting Information Table S3). However, when we stratified the dataset, our models revealed that this relationship is dependent on biological and socioecological factors. We found a consistent and significant relationship between the abundance indices for species that are diurnal (Figure 7a; Supporting Information Figure S3) and hunted at an intermediate level (Figure 7e); and independently of sociality (7B), body size (Figure 7c), locomotion mode (Figure 7d) and forest type (Figure 7f). On the other hand, we did not find a significant relationship for species that are nocturnal (Figure 7a; Supporting Information Figure S3) and non-hunted

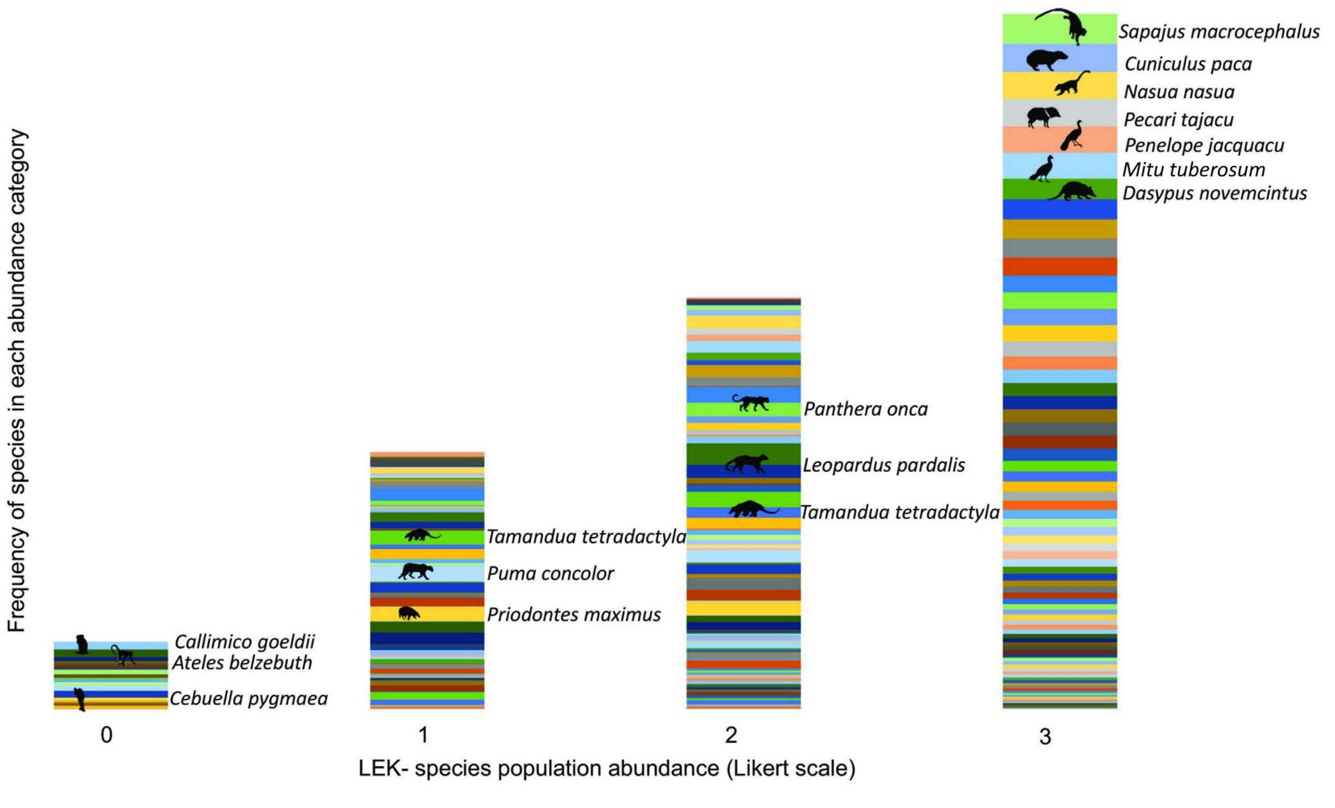

FIGURE 3 Distribution of species abundance according to the LEK-based method. Abundance indices were grouped into four categories (x-axis): when the species was perceived as 'absent' (0); 'low abundance' (1); 'medium abundance' (2) and 'high abundance' (3) by each interviewee. Each coloured box represents a species and box sizes represent the number of interviewees reporting a certain abundance category for each species. Y-axis represents the frequency with which each species was recorded in each abundance category. Species can occur in more than one category because the graph is based on the number of interviewees indicating a certain abundance category for each species. We included a silhouette and the scientific name of the species in the box of species with higher number of reports in each category

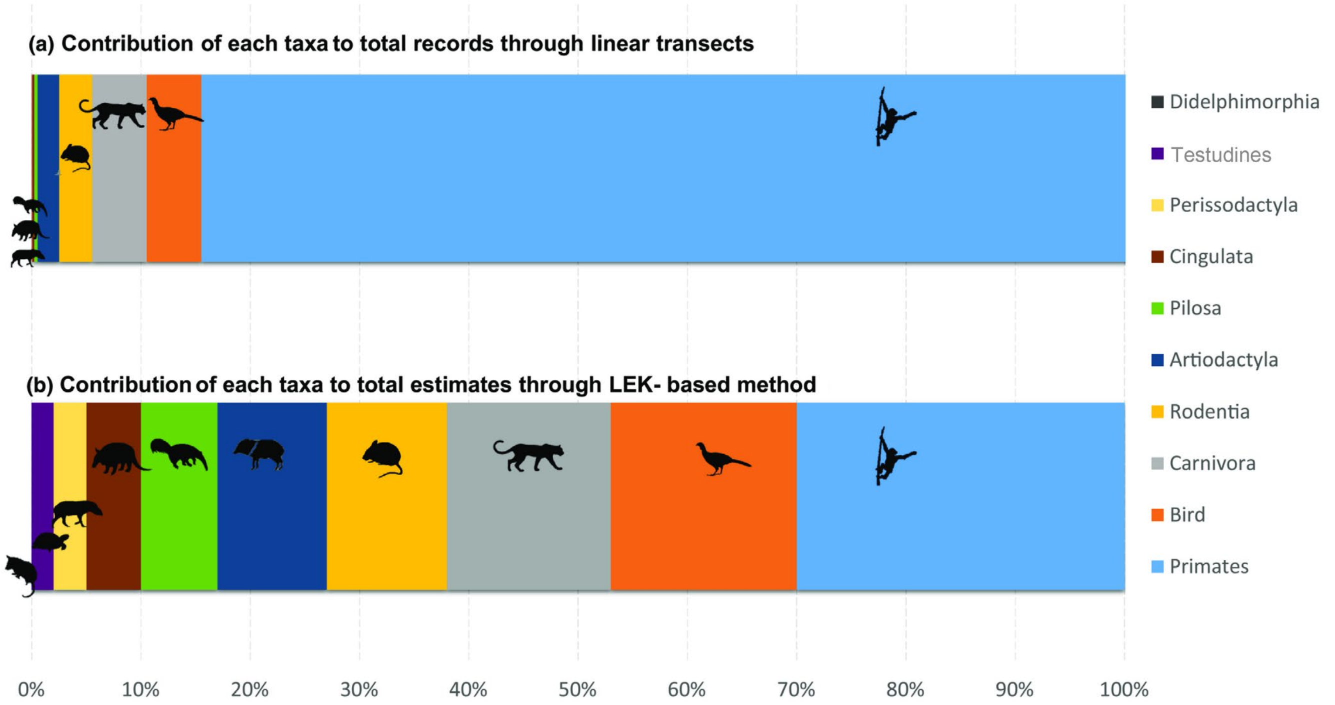

FIGURE 4 Representation of each taxa in the total sum of (a) all individuals detected on linear transects and (b) the abundances estimated by all interviewees through the LEK-based method. Both methods include the same number of species per taxa. The percentages for each method were calculated by summing all the abundance indices of all species for each taxon, thereby deriving the percentage of that summed value for the total abundance indices

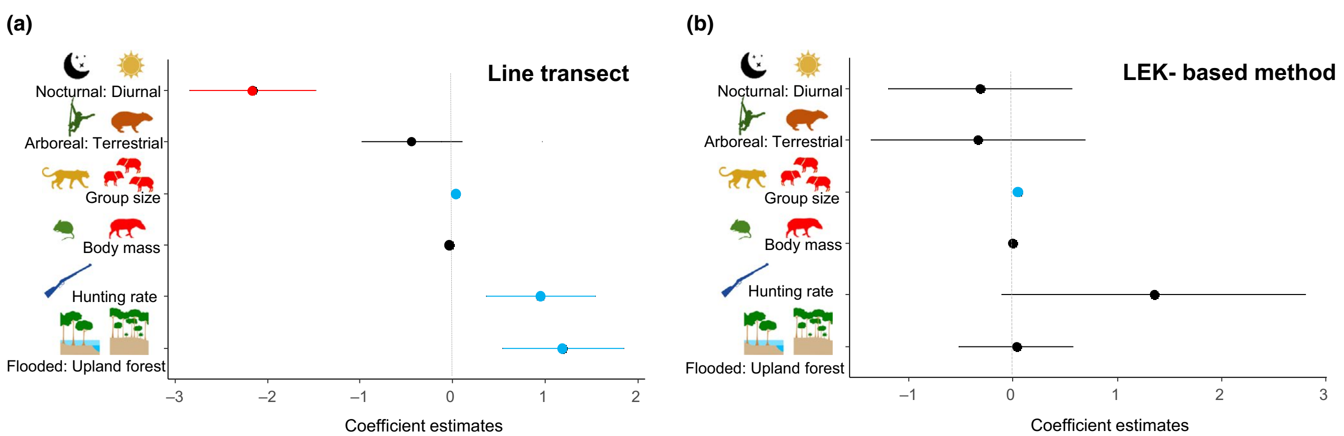

FIGURE 5 Linear coefficient estimates (±95% confidence intervals) showing the magnitude and direction of biological and socioecological effects on the abundance indices obtained through the line transect (a) and LEK-based method (b), when analysed separately. Blue and red solid dots represent either significantly positive or significantly negative effects, respectively; and black solid dots represent non-significant effects. Silhouette credits: Franciany Braga-Pereira. Flooded and Upland forest illustration credits: Andrew Abraham

or with a high level of hunting (Figure 7d; Supporting Information Table S3).

4 | DISCUSSION

Population abundance estimates are essential to assess the population status of wild species as well as facilitate decision-making regarding their conservation and management. The effectiveness of management decisions is dependent on the accuracy and timeliness of abundance estimates, meaning that improvements to data collection may herald improved management actions (Hodgson et al., 2018). In this study, we compared two methods of abundance data acquisition, which arise from two distinct systems of knowledge. Line-transect surveys are based on theoretical scientific knowledge, characterized by being systematic, controlled and based on hypotheses; which provides objectivity, verifiability, and, when properly applied, precision and accuracy (Rodríguez & Pérez, 2017). On the

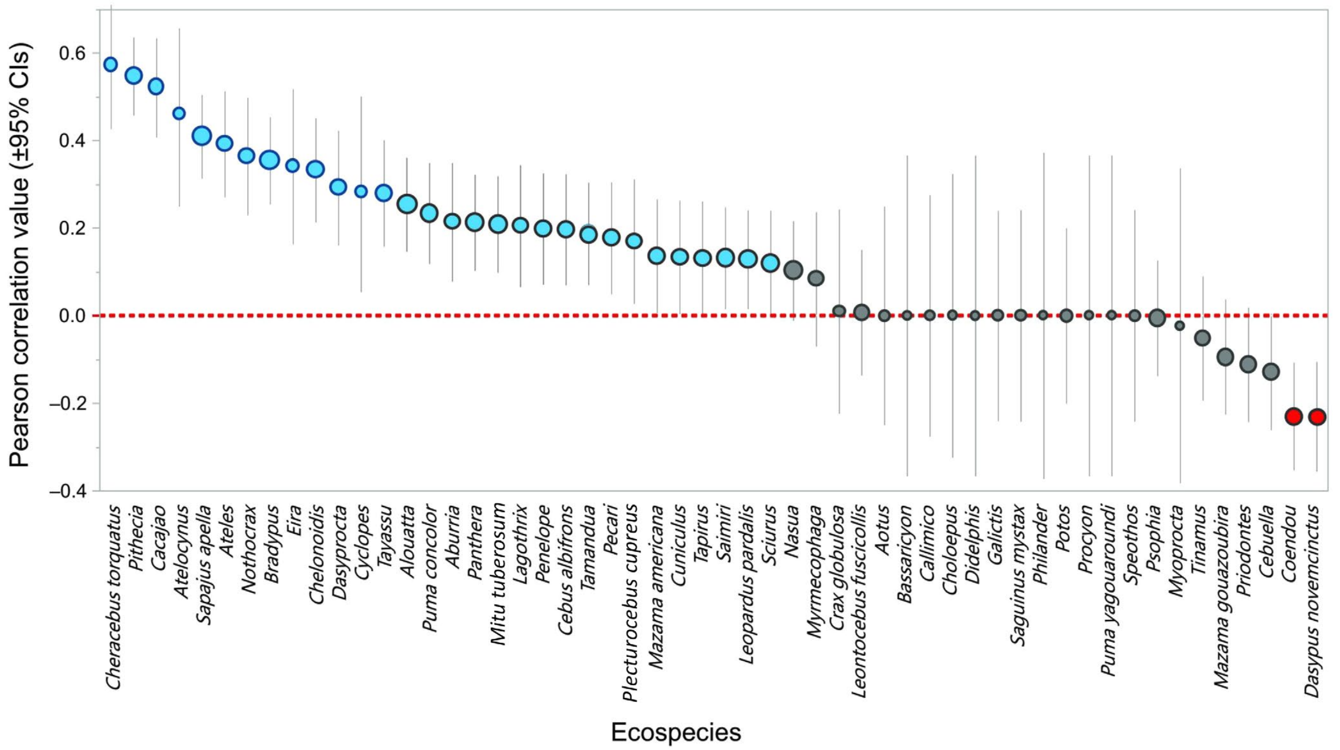

FIGURE 6 Ecospecies-specific abundance correlation between the LEK-based method and line transect. Considering that our sampling unit (the number of interviewees) is ~300, correlations >0.113 (for $p < 0.05$) was considered significant. Circle sizes are proportional to counts (number of interviews). Point colours denote correlation level: blue—positive correlation, grey—without correlation, and red—negative correlation. Here we pooled all taxonomic species into ecological analogues or functional groups (ecospecies)

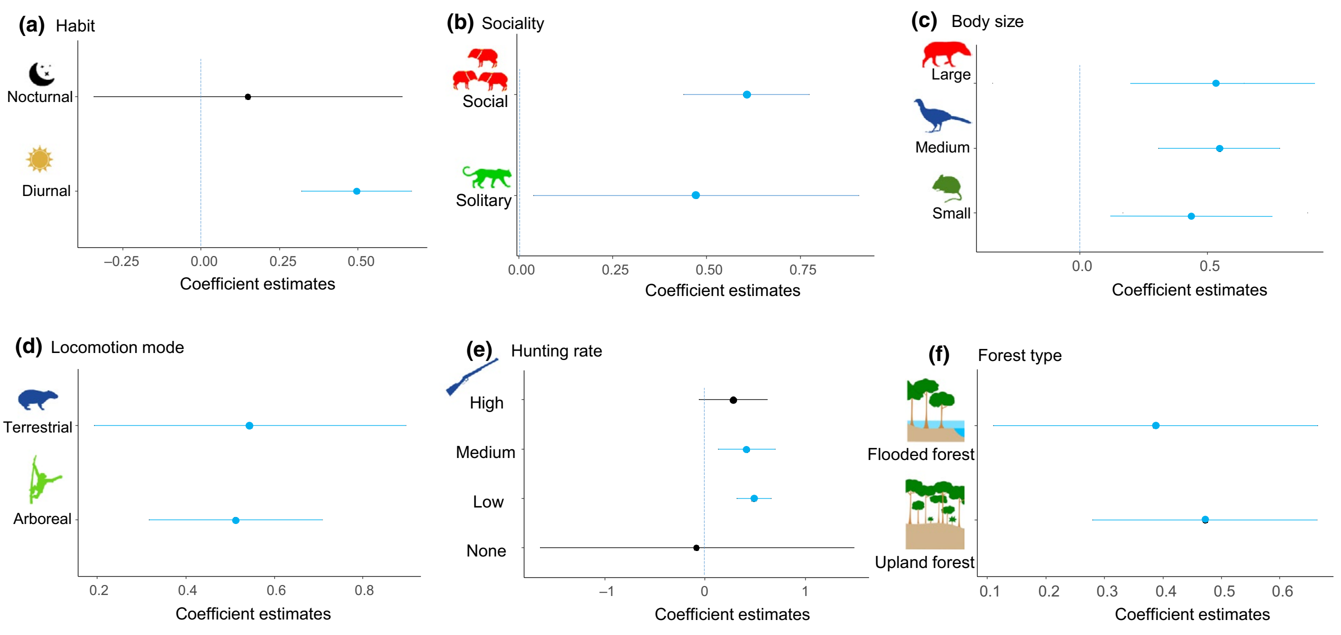

FIGURE 7 Linear coefficient estimates (±95% confidence intervals) showing the magnitude and direction of effects on the relationship between the abundance indices obtained through line transects and the LEK-based method for species according to their habit (a); sociality (b); body mass (small—to 1 kg; medium—from 1 to 5 kg; large—exceeding 5 kg) (c); locomotion mode (d); hunting rate (no hunting (0), low hunting (until 0.05), medium hunting (between 0.05 and 0.35) and high hunting (until 1)) (e); and forest type (f). Blue and black solid dots represent significantly positive and non-significant effects, respectively. Silhouette credits: Franciany Braga-Pereira. Flooded and upland forest illustration credits: Andrew Abraham

other hand, LEK arises from day-to-day practices and empirical knowledge embedded within specific worldviews beyond the nature/culture divide (Congretel & Pinton, 2020; Rodríguez & Pérez, 2017). LEK has direct practical applications and is considered more inductive and tacit (Congretel & Pinton, 2020).

In this study, abundance indices obtained from line transects and a LEK-based method were comparable for species that are diurnal, and independently of the species locomotion mode, sociality, body mass and forest type. The fact that both methods were congruent in terms of abundance estimates shows that conventional survey techniques based on direct sampling of populations can be substituted or, in some circumstances, be improved by LEK-based methods. On the other hand, we found that line transect may underreport, and even fail to report species with specific traits (such as nocturnal or rare species) as, according to previous studies, all species considered in this research potentially occur in the study areas. In constrast, LEK widely recorded most species that occurred in the area. In accordance with our results, wildlife abundances estimated by shepherds in Southeastern Spain were similar to those from line-transect surveys, but shepherds' ecological knowledge yielded abundance estimates across a broader range of species than linear transects, which only detected the species in the upper abundance range (Anadón et al., 2009). Records and memory recalls of neotropical vertebrate species occupancy by long-term residents at dozens to hundreds of forest fragments are also far more complete than those derived from short-term surveys (Canale et al., 2012; Peres & Michalski, 2006). In addition, the ability to identify the occurrence and variations in populations of some species through LEK has been found to be more accurate for ungulates compared to line transects and camera trapping (Camino et al., 2020) and for Tayassuidae when comparing LEK to line transects (Perez-Peña et al., 2012). Overreporting through LEK could be expected for species involved in psycho-attitudes of human–wildlife conflicts, such as large felids (Treves & Karanth, 2003). Because of these conflicts, the perceived abundance by locals could be magnified. However, the abundance of large felids was perceived as low or intermediate by most interviewees.

In some cases, the cause for low detection of species through diurnal line-transect surveys may be the reduced effort. However, we highlight that the effort applied during line transect surveys in our study—a total of 9,221 km walked—far exceeds the average effort often applied in Neotropical forests, which usually ranges from 40 to 600 km (de Thoisy et al., 2008). Our low record of many species was therefore not a result of limited effort, and we claim that line transects could be an inappropriate method to survey several but not all species. For example, ecospecies yielding non-significant correlation values between the two types of abundance estimates are primarily those that are rarely detected along diurnal surveys on foot. For instance, porcupines were never recorded along transects, and *Dasypus novemcinctus* either failed to be recorded or its survey-based abundance was very low (0.002 ind. per km). Conversely, both small- and large-group-living Pitheciinae primates (*Pithecia* and *Cacajao*) showed highly positive correlation values because in villages where these taxa were not detected, interviewees also perceived them as absent, whereas in villages where they were frequently detected along transects, all informants indicated intermediate to high abundance. Some ecospecies failed to yield significantly positive correlations, but this does not necessarily mean that either one of the two methods is inefficient. For example, large tinamids (*Tinamus*) are frequently recorded along transects but are subject to high variance in detection rates, whereas interviewees consistently reported high abundance values.

In general, line-transect surveys cover <0.5% of a given study area, which is often too scarce to reliably estimate species' abundance (Matthews & Matthews, 2002; Van der Hoeven et al., 2004). On the other hand, LEK is arguably a compelling method because the observer performance and overall survey effort of hunters surely exceed those of conventional biodiversity surveys. In addition, the effort of LEK is multi-scale, given that local forest observers are generally present at all times of the day and year-around, accounting for different circadian rhythms and seasons, and in multiple areas when conducting their habitual activities, such as hunting, fishing, farming and harvest of timber and non-timber products. Even the same specific activity can include diverse practices. For example, local people use many techniques to hunt nocturnal or diurnal species, such as waiting on trees, traps and baits, sweeping the forest floor or spotlighting along the riverbanks from a canoe across different landscape types (Tavares et al., 2020; Vieira et al., 2019). The repetition of such practices results in a systemic knowledge of their surroundings, including natural environments and the perception of wildlife population changes, which are ultimately reflected on species abundance estimates over different time-scales (Braga-Pereira et al., 2020).

We did not find agreement in abundance indices of non-hunted or heavily hunted species comparing the two methods in the same model. The non-agreement about non-hunted species is possibly biased by the non-detection of 83% of these species during transect surveys, while these same species were mentioned as present in 84% of LEK interviews. This lower detectability of non-hunted species, which are generally rare (Bodmer, 1995), during line-transect surveys, reinforces the inappropriate use of this method to detect rare species. Regarding hunted species, they can be elusive and therefore less detected during the transect sampling through direct sighting. However, hunters holistically consider other signs left by animals (such as footprints, scratches, urine trails, faeces, odours, animal vocalizations and other specific noises) for estimating their abundance. As much as these signs could also be identified during line transects, the record usually just occurs when the individual animal is visualized (Fragoso et al., 2016), which reduces the number of individuals detected during transect sampling.

Upland forests are more species rich, including more forest habitat specialists than flooded forests, while the average population biomass density is higher in seasonally flooded forests along white-water rivers (Haugaasen & Peres, 2005; Peres, 1997). Although we expected greater abundance in flooded forests in relation to upland, we did not detect differences on abundance indices related to forest type through LEK when the two methods were analysed separately. We believe that estimates using the nominal ordinal scale of abundance were probably inappropriate to capture differences in wildlife abundance between forest types. This is because nominal ordinal classification is subject to how each nominal level (low, medium and high) is perceived by each person, which reduces the efficiency of comparisons among different sites. The use of LEK-based methods with nominal scales, as used in this study, could be used to provide reliable comparisons over time within a site, in a way that abundance trends can be detected, but they are less reliable to make comparisons among people living in different sites, as local people use different levels of reference based on local natural abundance to give their responses. Although this index may be less reliable to make comparisons over long periods of time, as more recent situations may become the new baseline for people's perceptions on animal abundance, LEK not only takes information from one's own experience but also from other individuals (e.g. their ancestors) in their environment over time (Mazzocchi, 2006). For this reason, it is possible to ask about animal abundance from long ago or if population abundances have changed over time (Braga-Pereira et al., 2020; Van Holt et al., 2016).

To improve the accuracy of LEK-based methods, we recommend the adoption of quantitative methods during interviews for the estimation of wildlife abundance, in which participants would estimate the number of individuals occurring in a certain area. Using quantitative visual scales (Braga-Pereira et al., 2020) or physical units (i.e. seeds; Chaves et al., 2020) that allow the informant to indicate the number of specimens they perceive to live in a certain area would therefore be more efficient to detect differences between environments and across long periods of time (see Supporting Information Figure S4). Quantitative visual scales may be more useful when interviews about animal relative abundance are targeted at a larger number of species, thus optimizing interview time. Estimates of numbers of individuals could also be used to estimate population density, especially of those species for which interviewees are most effective in measuring their numbers within a given area, as in the case of game species (Van der Hoeven et al., 2004). For species that are of less interest to local people, line transects may provide more accurate population density estimates, because survey efforts would be directed to a particular species. Another advantage of line transects is that they can provide accurate information to compare population densities among sites and over time, as they are performed in a systematic manner. However, we advocate that even when using linear transects, LEK-based methods should be used to calibrate and ensure that the non-detection of a given species is not a result of underreporting.

An efficient way to refine population studies would be to first conduct interviews at an early stage of monitoring to obtain a preliminary overview of the abundance of species in the area, and improve study design on line-transect surveys. Second, studies could involve local people in monitoring line transects so they can help inform on species that remain undetected during sampling, but may be observed elsewhere using other methods. In addition, the perception of local monitors is multisensory, involving hearing, smell and indirect visual signals, such as tracks and scratches, which increase detection probability along transects. Community-based wildlife monitoring (where locals record and interpret their own data) can provide more than a contribution to science, e.g. contributing to long-term sustainability by the empowerment of local stakeholders to better manage their own natural resources (Constantino et al., 2012; Danielsen et al., 2009; Luzar et al., 2011), building local capacity, and developing legitimate and successful conservation initiatives (Fragoso et al., 2016).

Local ecological knowledge plus training in community-based wildlife monitoring can be an empowering method that can be performed and continued regardless, for example, of international or national crises, such as the COVID-19 pandemic, during which many protected areas remained closed to external researchers. Furthermore, participatory approaches have proven to provide cost-effective monitoring of the distribution and abundance over large spatiotemporal scales even for rare, nocturnal and cryptic species (Farhadinia et al., 2018; Silvertown, 2009; Van Damme et al., 2015). In our study, considering travel expenses to transect sites from the field stations, food supplies, and the cost of a technician (US$50/day) and a local assistant (US$20/day) (Gardner et al., 2008) to survey a typical transect each day, we estimate that around US$161,368 would be spent to conduct all linear transect surveys. In comparison, considering two technician interviewers (US$50/day) for each of the 17 villages sampled, we estimate that the LEK-based method would cost US$1,700 to obtain comparatively reliable abundance indices.

Using a large dataset collected at a large spatial scale from different regions, we compared wildlife abundance estimates obtained from two sampling methods for a range of species and environments, and more importantly assessed the effect of several socioecological and biological factors on the congruence and divergence between these methods. Given that interviews with local experts optimize sampling effort and reduce monetary costs, this method may overcome the lack of resource for continued and large-scale reassessments, another major constraint in environmental research and conservation projects. We strongly recommend the use of LEK-based methods to manage and monitor wildlife populations. As local people have accumulated a profound body of knowledge about wildlife and the environment, it is urgent that local and scientific knowledge-based methods be combined and shared reciprocally. This combination not only benefits the scale (Gagnon & Berteaux, 2009) and budget of the monitoring (or research; Farhadinia et al., 2018; Silvertown, 2009; Van Damme et al., 2015), but also promotes the collaboration between local people and external researchers in wildlife management initiatives (Constantino et al., 2012). We claim that this is a leading alternative to develop effective strategies in social-ecological systems to meet biodiversity monitoring and conservation goals.

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CONFLICT OF INTEREST

We declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

T.Q.M., H.R.E.B., P.E.P.-P. and P.M. conceived the ideas and designed the methodology; F.B.-P., T.Q.M., H.R.E.B., A.S.T., C.M.-R., C.B., C.R.R., C.B.-A., E.M.v.M., F.P.P., G.F.B.-R., J.S.T., J.V., J.G., L.T.-O., L.P.L., M.A.R.d.M.V., M.B., M.P.G., N.C.A.P., P.E.P.-P. and P.M. collected and compiled the data; F.B.-P., T.Q.M., H.R.E.B., C.G.-C. and C.A.P. analysed the data; F.B.-P. wrote the original draft; F.B.-P., T.Q.M., H.R.E.B., C.M.-R., F.P.P., L.P.L., M.A.R.d.M.V., M.B., M.P.G., R.R.d.N.A., C.A.P., P.E.P.-P. and P.M. edited the manuscript. All authors gave final approval for publication.

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DATA AVAILABILITY STATEMENT

Data deposited in the Dryad Repository http://datadryad.org/resource/ https://doi.org/10.5061/dryad.905qfttms (Braga-Pereira et al., 2021).

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