





Essays and Perspectives

Comparing local ecological knowledge and camera traps to estimate the abundance of mammals and game birds in the Eastern Amazon

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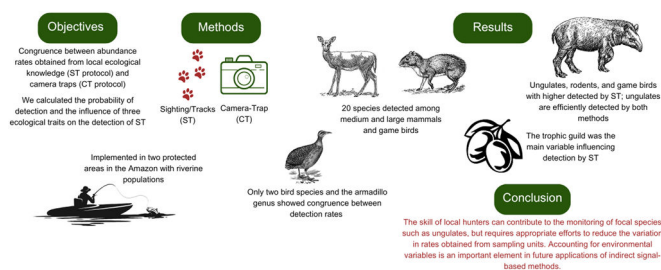
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HIGHLIGHTS

- The use of signs and tracks can detect ungulate species as efficiently as camera traps.
- Common species such as deer and agouti are detected efficiently by both methods.
- Body mass and sociability have little influence on the detection of mammals and birds by local hunters.
- Signals can contribute to monitoring species with large home ranges and vagility, such as the White-lipped Peccary.
- The use of signals requires greater sampling effort to reduce variation in detection rates.

GRAPHICAL ABSTRACT



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ABSTRACT

The choice of appropriate methods to observe population changes of species of interest in environmental monitoring is crucial to ensure the success of long-term programs. Including methods based on local ecological knowledge (LEK) can contribute to the sustainability of monitoring programs in several aspects. We assessed the congruence between detection rates obtained from camera traps and sightings and traces detected through LEK in two protected areas of Eastern Amazonia, comparing detection probabilities and testing the influence of three ecological traits. Only three species showed congruence between the indices, with 10 of the 20 being detected efficiently by both methods, mainly ungulates. The trophic guild was the most important ecological trait influencing species detectability. Our results indicate the effectiveness of LEK in detecting focal species, but limitations in identifying population trends. We recommend collaborative research strategies and the inclusion of

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the knowledge and experience of local populations in monitoring and conservation programs in the Amazon and other tropical systems, which are the regions richest in biological diversity and sociocultural richness.

Introduction

Wildlife monitoring is essential for conservation and requires systematic data collection over time and space to observe population trends (Lindenmayer and Likens, 2010; Rovero and Ahumada, 2017). The selected method must meet the objectives proposed in the monitoring program, due to its efficiency in the detection of focal species (Espartosa et al., 2011; Munari et al., 2011; Fragoso et al., 2016) and the reduced costs that guarantee long-term viability (Seidlitz et al., 2021; Reis and Benchimol, 2023). The ability to detect trends is critical for assessing the conservation status of medium and large vertebrates in neotropical ecosystems (Alves Ribeiro De Carvalho et al., 2024). Terrestrial birds and mammals provide important ecosystem services, such as seed dispersal (Jorge and Peres, 2005; Nuñez-Iturri and Howe, 2007; Jorge et al., 2013), natural population regulation (Ripple et al., 2014), and food security in traditional communities through subsistence hunting (Peres and Palacios, 2007; De Paula et al., 2022). The loss of this diversity implies modifications in ecosystems, including changes in tree community composition and diversity (Nuñez-Iturri and Howe, 2007), trophic cascades due to the loss of top predators or dispersers (Jorge et al., 2013), as well as other phenomena associated with the loss of taxonomic and functional diversity (Bogoni et al., 2020).

Visual census by transects is the most traditional method for sampling and producing indices to monitor these species in the Amazon region (Lopes and Ferrari, 2000; Alves Ribeiro De Carvalho et al., 2024). This method is ideal for recording arboreal and diurnal species, such as primates (Lopes and Ferrari, 2000; Munari et al., 2011); however, it fails to record nocturnal or rare species and is susceptible to missing species that have altered their behavior patterns in response to human disturbance (Fragoso et al., 2016, 2019). Camera traps have evolved to allow the recording of rare and nocturnal species, as they remain active for 24h or longer in the field (Tobler et al., 2008; Munari et al., 2011), in addition to enabling systematic data collection (Rovero and Ahumada, 2017). On the other hand, they require significant upfront investment, maintenance, replacement, and installation costs (Camino et al., 2020; Van Vliet et al., 2023) or limited capture areas due to movement patterns (Sollmann, 2018).

Another approach makes use of indirect signals. It complements data collection in visual censuses (Fragoso, 1998; Carrillo et al., 2000) and allows the detection of cryptic species or those that have changed their behavior (Fragoso et al., 2016). These data can be used for various analyses, including occupancy models (Van Vliet et al., 2023), density estimates through footprints (Esbach, 2023), and individual identification for estimating population abundance (Alibhai et al., 2017). It also allows incorporating local ecological knowledge (LEK) from traditional peoples and communities based on experience acquired through oral transmission and observing species behaviors. Recent studies have highlighted comparisons between traditional methods (transect censuses, camera traps) and LEK regarding species composition and richness, occupancy and abundance indices, ecological traits, temporal patterns, and species distribution (Camino et al., 2020; Braga-Pereira et al., 2022; Ponce-Martins et al., 2022; Van Vliet et al., 2023). Involving participants in the monitoring process provides valuable information on a local scale, empowers local communities in knowledge production, and makes them active in conservation efforts (Danielsen et al., 2005; Benchimol et al., 2017; Camino et al., 2020).

The Brazilian National Biodiversity Monitoring Programme (Programa Monitora) is an integrated system that uses protocols based on transect sampling and camera trapping to assess the population status of medium and large mammals and terrestrial birds (Alves Ribeiro De Carvalho et al., 2024). Most of these protected areas have historically

been inhabited by traditional communities, who assist in data collection as monitors (Dos Anjos Oliveira et al., 2024). However, the capacity of monitors to detect fauna through LEK isn't included in the protocol. Ponce-Martins et al. (2022) demonstrated that local monitors in a protected area in the eastern Amazon could efficiently detect the program's target species through indirect signs, indicating the potential for integrating this knowledge into a comprehensive protocol. However, the study only considered the possibility of LEK in species inventories, not its potential for generating occupancy or abundance indices, which are fundamental parameters for detecting population trends.

In this study, we assessed the congruence between camera trap detection rates and LEK from local monitors in two protected areas in the eastern Amazon, and the influence of ecological traits on the probability of detecting these species. Finally, we discuss how integrated methods based on scientific and traditional knowledge may contribute to understanding abundance patterns and the detection of Amazonian species.

Methodology

Study Area

Our study was carried out at the Terra do Meio Ecological Station (ESECTM), a Protected Area (PA) covering 3371 ha, and the Rio Iriri Extractive Reserve (RERI), a sustainable use PA covering 398,938 ha, located in the middle Xingu region of the eastern Amazon (Fig. 1). Both are part of a larger block of PAs and Indigenous Lands (ILs) that form the Xingu Sociobiodiversity Corridor, encompassing over 27 million ha (Schwartzman et al., 2013; Balee et al., 2020). The resident riverine populations, known as 'Beiradeiros', arrived in the region in the 19th century to harvest rubber from the *Hevea brasiliensis* (Schwartzman et al., 2013). Contact with the indigenous peoples, together with the local experiences of these communities, built up a universe of ecological knowledge of their own, based on hunting, fishing, management, and extraction of forest products, such as the Brazilian nut (*Bertholletia excelsa*) and the babassu coconut (*Attalea speciosa*) (Balée et al., 2020).

Data collection

Camera trap data

The camera trap (CT) data were obtained through the advanced terrestrial vertebrates monitoring protocol implemented by the Monitora Program, developed by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) and supported by the Amazon Protected Areas Program (ARPA) (ICMBio, 2018). The protocol is based on the TEAM (Tropical Ecology Assessment and Monitoring) network for monitoring terrestrial birds and medium-large mammals, with the deployment of camera trap grids with a density of one camera per 2 km² (Rovero and Ahumada, 2017). On average, 60 cameras with passive infrared motion sensors (Bushnell Trophycam) and an interval of 0.6 s between each photograph were installed in 2016, 2017, 2018, and 2023, with a distance of 1.4 km between each camera, between the end of the rainy season and the beginning of the dry season, with a field duration of at least 30 days.

Sightings and tracks data

During the installation of camera traps between 2016 and 2018 and in 2023, data collection was carried out simultaneously through sightings and tracks (ST) of animal presence, the so-called "Beiradeiro Protocol". We used the path opened for the installation of the cameras as a sampling transect, with 4.5 km, associated with each camera in 700-

meter sections. Indirect records include footprints, sounds, burrows, feces, feathers, nests, and other traces identified by local monitors. Only traces identified from the LEK estimated to be less than a week old were considered for analysis. Data were recorded by a smartphone equipped with CyberTracker software.

Species traits

We selected three ecological traits as predictor variables to assess their influence on detection: species body mass, sociability (solitary or social animals), and trophic guild (Animalivore, Omnivore, and Herbivore/Frugivore). We chose mass and sociability as predictors because

we expect that larger species and social species have a higher probability of detection (Tobler et al., 2008; Treves et al., 2010) and that the trophic guild is related to behavior patterns that leave traces (Ponce-Martins et al., 2022). The mass values were extracted from Peres and Palacios (2007). The trophic guild was extracted from the diet description of Emmons (1990), following the organization of Robinson and Redford (1986) for mammals, and Peres and Palacios (2007) for birds. Given the presence of anteater species (giant armadillo), we grouped them with carnivores in the “Animalivore” category (Voss et al., 2001).

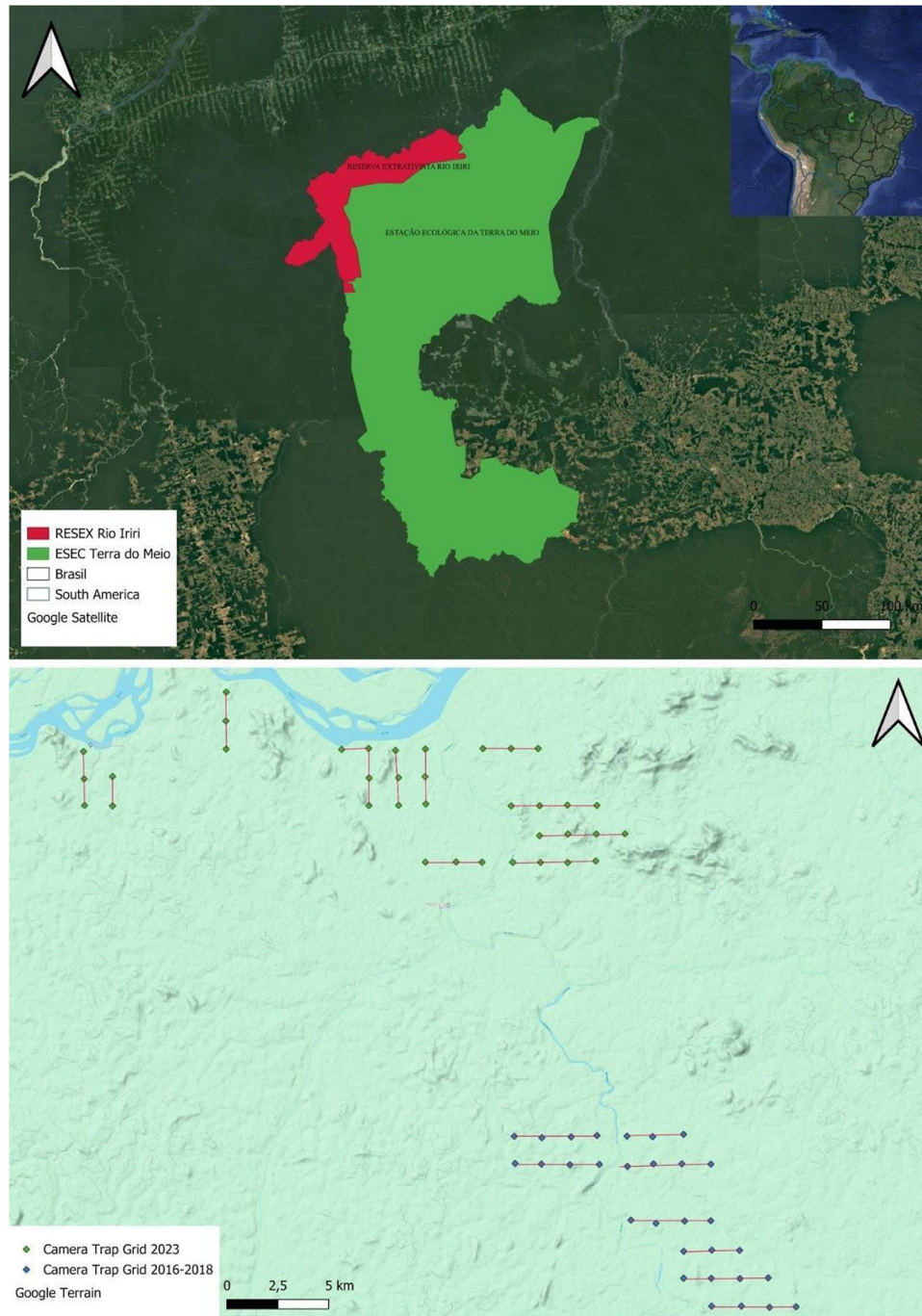


Fig. 1. Above, a map of the two protected areas where the Monitora Program operates. Below are the transects made on the ICMBio camera trails. In blue are the cameras deployed between 2016 and 2018, and in green are those deployed in 2023.

Data analysis

We performed paired analyses to assess the degree of congruence between the detection rates (DR) obtained by each method: rate of independent records per CT (>60 min), being the sum of records from cameras grouped by sampled transect * 100, divided by the accumulated effort of the cameras; and number of records by ST * 10 divided by the walked effort by transect. We assumed 60 min due to the continuous presence of some species in front of the equipment for long periods (Tobler et al., 2008). We also assume that detection is constant, based on the basic premise that the detection rate of camera traps is linear to animal abundance (Sollmann et al., 2013; Parsons et al., 2017).

We performed Spearman correlation (Rho, $p < 0.05$) by species. Only

species detected by both methods were selected for analysis, excluding exclusively arboreal species such as primates. In the case of a transect where a species was observed using one method but not the other, we assigned it a value of zero for correlation. We only selected transects sampled by both methods. 33 transects were carried out, totaling 148.5 km traveled over the four years. The camera trap effort was 6115 camera-days. We calculated the percentage of sites where the species was detected by each method and its probability of detection (p) from a model of detection/non-detection (total number of registers/total number of transects), assuming constant detection.

We fitted a series of Generalized Linear Mixed Models (GLMMs) to select the best model considering the different combinations of predictor variables. We use the negative binomial distribution for overdispersed

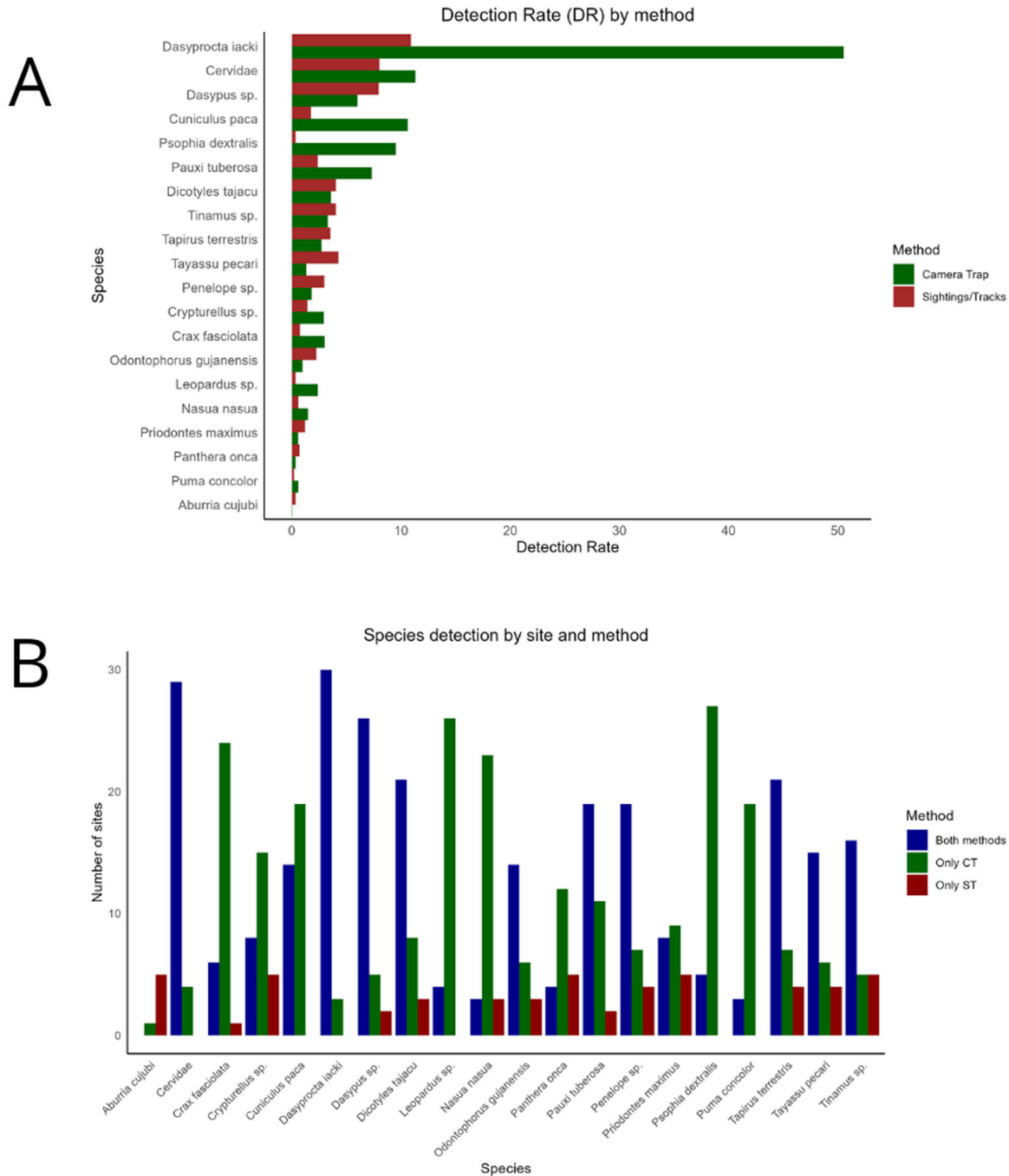


Fig. 2. A) Detection rate by method. B) Detection by method and site. The blue bar indicates the sites where the species was detected by both methods, the green bar exclusively by camera trap (CT), and the red bar exclusively by Sightings and Tracks (ST).

data, using the number of records per km as the response variable, independent records obtained by camera trap, and species traits (session 2.3) as predictor variables. We converted the body mass values (in grams) into logarithmic values to reduce the discrepancy between the masses. We added species as a random variable to assess whether the difference in records between taxa affected the model's response. To fit the candidate models, we used the “lme4” package (Bates et al., 2015) in R (R Core Team, 2025). We selected the best models using the corrected Akaike information criterion (AICc) for small sample sizes, with a delta value of less than 2.0 (Burnham et al., 2002) from the package “AICcmodavg” (Mazerolle, 2020).

Results

Both methods detected 20 taxa, 13 larger and medium mammals and seven terrestrial birds (Fig. 2). The most common species recorded by the Sighting/Tracking (ST) method was Agouti (*Dasyprocta iacki*), with a rate of 10.9 ST /10 km (±10.9), followed by Cervidae family (*Mazama americana* and *Passalites nemorivagus*) with 8.0 ST /10 km (±6.9), armadillo genus *Dasyopus* sp. (7.9 ± 8.3), White-lipped Peccary (*Tayassu pecari*) (4.24 ± 6.24), Tinamous (*Tinamus* sp.) (4.04 ± 4.39) and Collared Peccary (*Dicotyles tajacu*) (4.03 ± 4.39). Agouti was also the most common species detected by CTs (50.53 ± 28.2), followed by the Cervidae (11.3 ± 10.9), Paca (*Cuniculus paca*) (10.5 ± 12.07), Olive-winged Trumpeter (*Psophia dextralis*) (9.7 ± 7.02), and Razor-Billed Curassow (*Pauxi tuberosa*) (7.3 ± 5.06) (Fig. 2A).

The Agouti had the highest detection probability for Sighting/Tracks ($p = 0.909$), followed by Cervidae ($p = 0.879$), *Dasyopus* sp. ($p = 0.848$), Lowland Tapir ($p = 0.758$), and Collared Peccary ($p = 0.727$). The agouti also had the highest probability of detection from CTs, detected at all sites ($p = 1$), the same result for Cervidae and paca ($p = 1$), followed by Olive-Winged Trumpeter ($p = 0.970$) and *Dasyopus* spp. genus ($p = 0.939$) (Fig. 2B).

When we analyzed the relationship between the number of detections per transect depending on the method, we found that Agouti

was the most common species, observed in all sites, with 90,9% of the sites detected by both methods. Only 9.09% of the sites were detected exclusively by CT. Cervidae (87%), genus *Dasyopus* (78.8%), *Pauxi tuberosa* (57%), genus *Penelope* (57%), and *Tapirus terrestris* (63.6%) were the only species detected in more than 50% sites by both methods. The Olive-Winged-Trumpeter (*P. dextralis*) was mostly detected by camera traps (81.8%), with no site exclusively observed or recorded by sightings/tracks. Only the genus *Tinamus* was detected equally by each method (16% of sites each).

Only three taxa showed significant correlations between methods: the genus *Dasyopus* (Rho = 0.3, $p = 0.03$), *Odontophorus gujanensis* (Rho = 0.43, $p = 0.01$), and the genus *Tinamus* (Rho = 0.35, $p = 0.04$) (Fig. 3).

The model that best explained the influence of ecological traits on detection included all variables ($\Delta AICc = 0.00$; weight 0.30), with two other models ($\Delta AICc = 0.48$ and 0.53, respectively) including mass and sociability (Table 1). The trophic guild was the most important variable, retained in all models and with the highest relative importance (sum of

Table 1
Models ranked according to Akaike's information criterion corrected for small samples.

Model	AICc	$\Delta AICc$	ω_i
Soc + BM + TG + SP	1800.03	0.00	0.38
BM + TG + SP	1800.51	0.48	0.30
TG + SP	1800.57	0.53	0.29
Soc + SP	1806.78	6.74	0.01
BM + SP	1806.88	6.84	0.01
Soc + BM	1808.74	8.71	0.00

Predictors: TG = trophic guild (Herbivore/Frugivore, Omnivore, and Annimivore); Order = order taxa level; Soc. = sociability (Gregariousness or Solitary); BM = body mass value log transformed. AICc = Akaike information criterion adjusted for small sample bias; $\Delta AICc$ = difference between a given model and the best model; ω_i = Akaike weights. All models included camera trap records as a predictor.

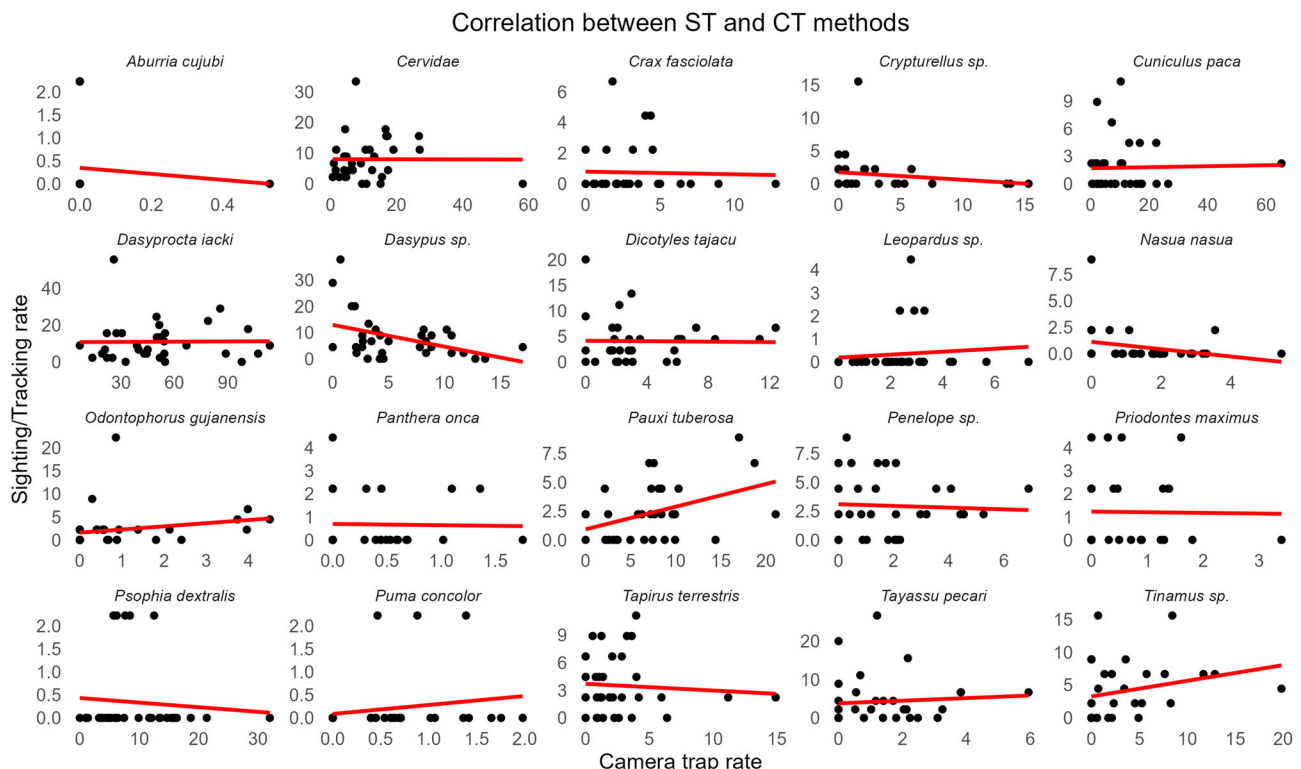


Fig. 3. Spearman correlation results for each taxa.

Akaike weights >0.9; Table 1).

Discussion

The faunal composition observed by both methods is similar to that found in other upland sites in Amazonia (Munari et al., 2011; Benchimol et al., 2017). Two ground-dwelling bird taxa showed a significant correlation between the methods: *Odontophorus gujanensis* and the genus *Tinamus*, which are abundant in upland sites (Alves Ribeiro De Carvalho et al., 2024), and *Tinamus* sp., in particular, is often detected through visual censuses and camera traps (Mere Roncal et al., 2019; Alves Ribeiro De Carvalho et al., 2024). Both are easily detected by sightings and tracks by local monitors (Ponce-Martins et al., 2022).

Our data observed similar patterns proportionally between the rates of both methods. Both agoutis and deer (*M. americana* and *P. nemorivagus*) were the most abundant and detected simultaneously at most of the sampled sites (Fig. 2A and B). The agouti is usually one of the most abundant mammals in assemblages sampled by visual censuses and camera traps, but here, most records are based on partially eaten babassu coconuts. Local monitors distinguish between fruits eaten by agoutis and pacas based on the tooth marks left on the fruit, noting that pacas gather the fruits together, while agoutis consume them one at a time. This same knowledge is cited by hunters from the Awá and Gua-jajara peoples in the eastern Amazon (Leão-Vulcão, pers. comm.).

Deer, along with other ungulates, make up a significant part of the diet of local communities in the region (De Paula et al., 2022). Our results point to high efficiency in detecting these species, with simultaneous detection for most sites by both methods (Fig. 2B). Tracking ability is built on the development and testing of hypotheses based on observation of the animals and their tracks to maximize the efficiency of capturing the target animal (Liebenberg et al., 2017). Therefore, it is expected that the ability to detect traces of these animals is extremely refined in experienced traditional hunters.

Because they live in low densities, large carnivores are rarely detected by visual censuses and even by camera traps (Tobler and Powell, 2013; Fragoso et al., 2019), requiring considerable time and space to detect them. Both methods had low detectability for big cats, but *P. onca* was detected more frequently through traces. This may be because the species leaves traces that are more recognizable to monitors, such as scratches and larger footprints. The inclusion of these signs increases the chance of detection, being efficient for generating occupancy data in an area larger than that sampled by camera trap protocols (Hines et al., 2010).

The models show that body size and sociability have little influence on the ability of local monitors to detect a species, mainly based on tracks, with trophic guild being the main explanatory variable. The results found here can be explained by the skills of the monitors, which are based mainly on traces left by animals, associated with behaviors involving movement, foraging, territorial marking, or digging (Ponce-Martins et al., 2022). This facilitates access to nocturnal and cryptic species, such as *Priodontes maximus*, through the identification of burrows throughout the space.

Larger species are more easily detected by camera traps than smaller ones due to the ease of activating the equipment (Tobler et al., 2008; Marcus Rowcliffe et al., 2011), and this pattern has also been observed for tracks (Silveira et al., 2003). However, smaller species (< 10 kg), such as agoutis, armadillos, and birds of the Tinamidae family, were among the most common, implying that this pattern is not maintained here. While formal biologists rely mainly on footprints, which are imprinted on the ground due to the quality of the terrain and the mass of the animal, riverine communities are also able to distinguish smells, hairs, and traces that do not depend directly on the size of the animal.

Species with large social groups, such as *T. pecari* and *P. dextralis*, responded differently to the two methods. In particular, *P. dextralis* was barely detected by ST but was abundant in camera traps. In this case, this may be due to the lack of physical tracks left in the environment

compared to other birds, which reduces the ability to detect them indirectly. Since sampling took place in more enclosed areas and this species flees from human approach, there may be a sampling bias of lower visual detection. This explains why the species was rare in our sampling, but was more easily detected on open trails where there is greater visual acuity (De Souza Fialho et al., 2025). *T. pecari*, on the other hand, was detected similarly by both methodologies. It has a large distribution area through which it moves in a semi-nomadic pattern (Fragoso, 1998; Keuroghlian et al., 2004), which requires longer sampling times for detecting herds. This movement pattern leaves distinct physical evidence, such as long tracks of footprints and chewed fruit, which are easily detectable by local hunters.

These results raise important questions for applications of this methodology. Firstly, our results highlight the ability of local monitors to detect focal species for monitoring, such as ungulates, quickly, but the difficulty in producing metrics congruent with camera traps. Physical characteristics of the environment, such as litter and soil quality, can hinder the detection of some species (Espartosa et al., 2011; Esbach, 2023) and should be considered. Second, the variation in rates per transect may be a product of the sampling effort (Esbach, 2023). The limited number of transects sampled (33) may have been responsible for the large variation in the detection of species less likely to leave tracks, such as large carnivores, making it impossible to produce reliable abundance metrics. One way around this problem is to use occupancy models to generate detection/nondetection data, but with an appropriate sampling design and effort to generate detection histories over time or space (Sollmann, 2018). Tracking animals can also be fundamental for monitoring species targeted by hunters with high seasonal vagility, such as *T. pecari*, through a monitoring network at different locations in protected areas. The implementation of this method must take into account long-term cost-effectiveness, a limiting factor for the success of monitoring programs (Reis and Benchimol, 2023), and the ability to engage communities, based on a sense of governance and empowerment, to ensure rapid responses at the local level for the conservation of threatened species (Danielsen et al., 2005).

Declaration of competing interest

The authors report no declaration of interest.

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