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Comparing interview methods with camera trap data to inform occupancy models of hunted mammals in forest habitats

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Abstract

Few studies explicitly assess the robustness and practicality of occupancy analysis informed by local inhabitants, compared to estimates from conventional monitoring methods within different contexts. This study evaluates the efficacy and robustness of occupancy models based on camera trap data, and two locally informed methods: seasonal interviews and hunter diaries, for monitoring 13 hunted mammal species in south-eastern Cameroon. We triangulate estimates of detectability and occupancy to assess the precision and comparability of their estimates for different species, and their cost. Camera trap estimates are comparable with estimates from locally informed methods in 7 of 11 available cases, but produced the lowest detection probabilities for all species in both villages. While camera traps provide robust estimates for abundant species with a high detection probability, locally informed methods can provide estimates of occupancy comparable to camera trap estimates, but at significantly less cost. They are particularly useful where camera trap detection rates (p) are too low to produce robust occupancy model estimates, notably for rare or cryptic species. The methods, survey effort and animals that can be monitored robustly vary between villages. As such, consideration should be given before monitoring commences to ensure that the most effective and informative approach is used.

KEYWORDS

bushmeat, Cameroon, hunting, local ecological knowledge, monitoring, occupancy, wild meat

1 | INTRODUCTION

Widespread species population declines in tropical forests, due to overhunting (Abernethy et al., 2013), highlight the need for rapid, efficient monitoring methods that are both robust and practical over large spatial and temporal scales. Yet, despite the growing prevalence of monitoring programs in tropical forests, knowledge about the relative merits of different mammal monitoring techniques is incomplete (Munari et al., 2011). Monitoring in

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forest environments, commonly using camera traps or line-transects (Beaudrot et al., 2019; Karanth et al., 2011), can be expensive and time-consuming. Further, the probabilities of detecting certain species can be extremely low (MacKenzie et al., 2006), posing a challenge in the context of limited funding for monitoring, both within and even more so outside protected areas. The best field method also depends on several factors, including the target species and the characteristics of the study area (Camino et al., 2020). As such, the most effective and efficient monitoring method in one locality, or for one species, may not be so effective in another. Thus, it is essential to understand which methods will provide high detection probabilities for the focal species in a given locality to improve the survey efficiency (Fragoso et al., 2016; MacKenzie et al., 2006) while also being cost-effective and accurate.

Monitoring program and one-off studies increasingly incorporate local ecological knowledge (LEK) (Danielsen et al., 2009). This work is beginning to show that LEK can be a cost-effective, and potentially reliable method for data collection, drawing on the often-detailed ecological knowledge accumulated by people during their daily lives (Service et al., 2014; Turvey et al., 2013). Several methods exist to gather data from people about species encounters or their use of wildlife, such as interviews (Jones et al., 2008; Parry & Peres, 2015) and diaries, often used to gather self-reported data on hunting patterns or wild meat consumption (Rist et al., 2008; Van Vliet et al., 2015).

All monitoring methods are subject to bias. Camera trap data may result in bias in species trapping rates toward trap-curious species, compelled to return to the camera locations more frequently (Wegge et al., 2004). They may malfunction or be stolen (Burton, 2012; Larrucea et al., 2007), reducing the data available to run robust analysis. Further, unbiased data relies upon accurate placement of cameras, which requires some training and experience to avoid bias (Kolowski & Forrester, 2017). Locally informed monitoring methods are also potentially biased. Several articles have warned against the use of unverifiable data from interviews due to concerns over species misidentification (McKelvey et al., 2008; Molinari-Jobin et al., 2012), which in some studies has resulted in overestimations of occupancy compared to camera trap data (Garrote & Pérez de Ayala, 2015). Bias is sometimes associated with the stakeholder that gathers information. For example, a participant's livelihood, such as whether they hunt or not (Camino et al., 2020), their age (Beaudreau & Levin, 2014) or the frequency with which participants visit the target area (Burgman, 2016) have been found to impact the reliability of the data. Participants may be unable to accurately recall what they have or have not seen when providing information over longer periods of time (Golden et al., 2013). However, in a comparative study with forest resource users in Madagascar, Jones et al. (2008) found no evidence of recall bias, and concluded that rapid seasonal interviews provided reliable information on quantities, effort, and the spatial pattern of harvesting for certain resource types when compared to daily diaries.

To account for possible bias, several studies have combined interviews with occupancy analysis to gather data on rare or wide-ranging species at large-scales (Brittain et al., 2018; Martínez-Martí et al., 2016). Comparative studies that explore the precision, accuracy, and cost of locally informed approaches for estimating species abundance, occurrence, and richness, compared to conventional monitoring methods are useful to assess the real-life applicability of each method for a variety of different species. Camino et al. (2020) carried out a comparison of interviews, locally based surveys, transects, and camera traps for three terrestrial mammals. They found that LEK-based methods increase detection probabilities of the three large terrestrial mammal species, while providing accurate information, compared to standard methods.

While studies evaluating LEK-methods' performance have increased in the last two decades (see Supporting Information S1), few explicitly compare the robustness and practicality of occupancy analysis informed by people with conventional monitoring methods. This is surprising, given the increased application and clear potential of the approach for monitoring, particularly in tropical forests.

Here, we evaluate the efficacy of occupancy models informed by people living adjacent to a Camaroonian biosphere reserve, for monitoring 13 hunted mammal species in two contrasting community forests. We selected species that local inhabitants reported seeing regularly in the community forest (such as porcupines and blue duiker) and those considered to be rare but still present within the community forests (such as forest elephants and gorillas). We focused on mammals as they are the most important group of animals for wild meat hunting, and as such are of local importance. Table 1 shows the species selected for this study.

In this study, we wanted to explore the extent to which variables associated with species occupancy in two different social and ecological contexts within the same broad landscape are consistent across different observational methods. As such, we triangulate estimates of detectability and occupancy from locally informed and

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conventional monitoring methods to assess the precision and comparability of their estimates for different species at both the landscape scale (the inter-village levels) and at 1 km^2 site scale (which is the between-site comparisons for a given village). We provide guidance on future use of these methods for monitoring in forest habitats in two contrasting study areas.

We: (1) compare the precision of estimates of detectability and occupancy from interviews, hunter diaries, and camera traps for multiple mammal species at different scales; (2) Identify which environmental and observer variables influence species detectability and occupancy estimates; and finally (3) make recommendations for future use of LEK-informed monitoring methods when monitoring mammals in challenging forest habitats.

We expect landscape level estimates of occupancy from locally informed methods to be broadly comparable with estimates obtained from camera traps (e.g., estimates fall within the confidence intervals of the camera trap estimates) for highly abundant species that are well detected by all methods. Where species are rare and/or of interest to local communities, such as chimpanzees and gorillas, we expect locally informed methods to be more precise and informative than camera-based methods. We predict that species that are of particular interest to hunters, such as pangolins, will be well detected within the hunter diaries. We also expect both locally informed methods to be more cost-effective than camera traps (Garrote & Pérez de Ayala, 2015; Hausser et al., 2017).

TABLE 1 The species included in this study within two community forests adjacent to the Dja Biosphere Reserve in Cameroon, including their IUCN Red List status and Cameroonian hunting class status

Species	IUCN Red List status	Hunting class
Carnivores		
Servaline genet *Genetta servalina*	Least concern	–
Pangolins		
Tree pangolin *Phataginus tricuspis*	Endangered	A
Giant pangolin *Smutsia gigantea*	Endangered	A
Ungulates		
Blue duiker *Philantomba monticola*	Least concern	–
Bongo *Tragelaphus eurycerus*	Near threatened	A
Yellow-backed duiker *Cephalophus silvicultor*	Near threatened	B
Red river hog *Potamochoerus porcus*	Least concern	B
Sitatunga *Tragelaphus spekii*	Least concern	B
Proboscidea		
Forest elephant *Loxodonta cyclotis*	Endangered	A
Primates		
Western lowland gorilla *Gorilla gorilla gorilla*	Critically endangered	A
Central African chimpanzee *Pan troglodytes troglodytes*	Endangered	A
Putty-nosed monkey *Cercopithecus nictitans*[a]	Least concern	–
Rodents		
Brush-tailed porcupine *Atherurus africanus*	Least concern	–

Note: Hunting class A = species protected from hunting for any purpose. Hunting class B = species can be hunted from community forests for subsistence purposes.

[a]Indicates the only arboreal species, included because they are often seen foraging in farms and are viewed by some as a nuisance species.

2 | METHODS

2.1 | Study area

We conducted our study in the Dja Biosphere Reserve (DBR), home to 107 mammal species, several of which are threatened, including the endangered forest elephant (*Loxodonta cyclotis*) and the critically endangered western lowland gorilla (*Gorilla gorilla*). People living around the DBR largely rely on subsistence farming for food security and livelihoods (World Bank, 2013); many rely on wild meat hunting as an additional livelihood and source of protein (Bobo et al., 2015).

Presence/absence data were collected from inhabitants of two rural villages adjacent to the DBR (Figure 1). Both villages have their own community forest which grants hunting rights for non-protected species to community members for subsistence purposes only. Village 1 is small (c. 90 households), remote, and located c. 7 km from the southeastern boundary of the DBR. In 2015, a logging road was built which linked village 1 to the main road network. In contrast, village 2 is larger, consisting of c. 150 households, and located c. 15 km northeast of the reserve, directly on the main road axis that connects to nearby market towns. Timber concessions adjacent to

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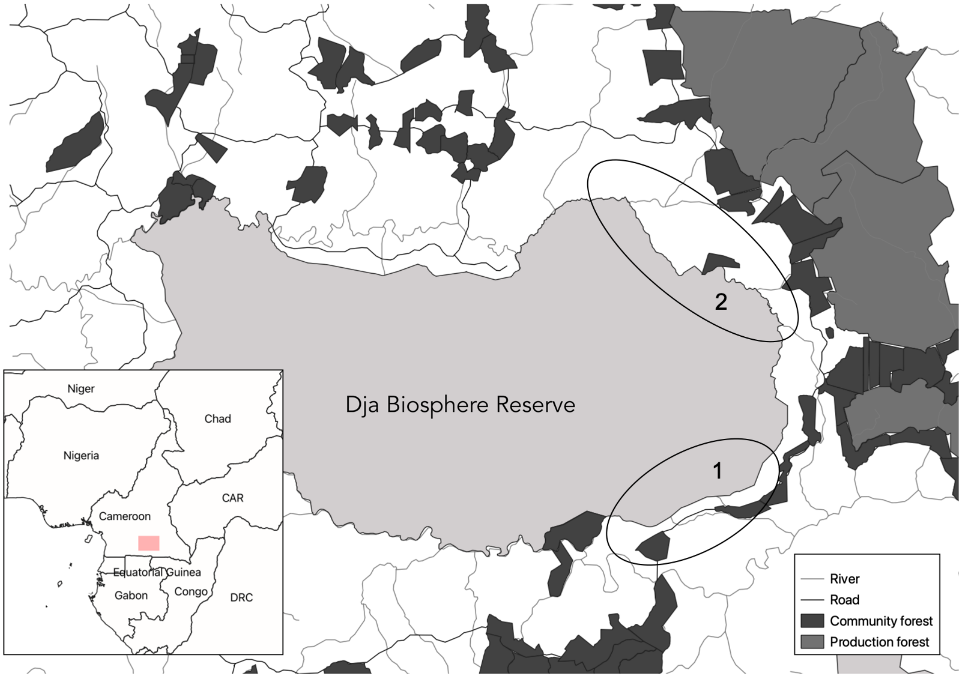

FIGURE 1 The location of the Dja Biosphere Reserve and approximate location of the study villages 1 & 2 in southeastern Cameroon, with surrounding production and community forests

village 2, with long-term contracts of 25+ years, mean that noise and habitat disturbance has occurred over prolonged periods of time, with possible implications for the wildlife surrounding village 2. Additionally, a higher local population with greater access to markets where meat can be sold, may result in higher hunting pressure in village 2 compared to village 1. As such, our expectation is that village 1's community forest will have both higher mammal occupancy and detectability than village 2, which in turn may have result in differences in the most effective and cost-efficient methods to use between the two villages.

2.2 | Data collection—surveys to detect focal species

Our objective was to determine the performance of LEK-methods in two contrasting villages for detecting 13 mammal species hunted for wild meat, compared to camera traps across the same area and time. We used semi-structured interviews with village inhabitants, hunter diaries with local hunters, and camera-traps to gather data on focal species presence/absence within the community forests of both villages. For each method, we estimated the occupancy and detection probabilities, compared the variables that most influence species occupancy and compared their cost.

2.3 | Data collection

Each data collection method presents different strengths and potential biases; efforts were made in the survey design to account for and control these biases (Supporting Information S2). See Table 2 for the survey effort undertaken for each of the three survey methods.

2.3.1 | Camera-trapping survey

We conducted camera-trapping surveys in August–November 2017 in village 1 and April–June 2018 in village 2. Thirty Bushnell Aggressor cameras were placed in a grid set 1 km apart, one camera within each 1 km^2 site, capturing a gradient from each village to toward the reserve, but remaining within the limits of the community forest. The cameras were placed 30–45 cm off the ground, angled horizontally, and no attractants were used. Suitable places to position the cameras were chosen within 100 m of each grid point, that were close to frequently used animal trails (Amin et al., 2015) or possible feeding spots. Once a suitable place was identified, the cameras were attached to trees located about 4 m from the trails. To avoid low sunlight interfering with the cameras, they were set facing north or south (Bruce et al., 2018). Tall grass and foliage that could have caused an obstruction were cleared from in front of the cameras.

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TABLE 2 The survey effort undertaken for data collection using camera traps, hunter diaries and semi-structured interviews in villages 1 and 2

	Village 1			Village 2		
Method	Spatial scale (km^2)	Temporal scale (occasion)	Total number of traps and observers	Spatial scale (km^2)	Temporal scale (occasion)	Total number of traps and observers
Camera traps	26	2.5 months (15 5-day occasions per site)	26	22	2.5 months (15 5-day occasions per site)	24
Diaries	13	2.5 months (76 1-day occasions per site)	10	12	2.5 months (76 1-day occasions per site)	10
Semi-structured interviews	26	2.5 months (4 observers per site)	141	24	2.5 months (4 observers per site)	109

Note: The table displays the area covered by each survey method in km^2 (spatial scale), the period of time over which data collection took place (temporal scale) and the number of camera traps and people interviewed for the hunter diaries and semi-structured interviews (observers/traps).

2.4 | Locally based methods

2.4.1 | Participatory mapping of species detections

Prior to carrying out the interviews and hunter diaries, maps of both community forests were made to allow species detections to be mapped. Participatory mapping exercises with mixed gender and age groups were held to identify and map key landmarks and land uses. Features were ground-truthed with GPS, and combined with existing GIS data on major roads and land use designations (e.g., protected area, village locations, adjacent timber concessions, rivers) resulting in maps that were both representative of areas of local importance and spatially accurate, to help participants accurately identify where species were detected (Corbett, 2009).

To facilitate comparison of site-level (e.g., 1 km^2) estimates of occupancy between the camera trap and interview methods, the spatial sampling unit used on the participatory map for the interviews and daily diaries reflected the same 1 km^2 grid used for the camera trapping. The participatory map was used during the seasonal interviews and with the hunter diaries to identify in which 1 km^2 site the species had been seen, and the associated grid reference number was recorded.

2.4.2 | Seasonal interviews

Prior to the interviews taking place, all interview participants were shown a series of photos of the target species, plus some species that are not present in the area, to assess whether the participant would correctly identify each species and to reduce possible misidentification bias. Fewer than 3% of participants incorrectly identified a species, and none stated that a species was present in the area when it is known not to exist there. Only data from participants who correctly identified the focal species from the photos were included in the final analysis.

We conducted semi-structured interviews once a season (e.g., four times a year), over the course of 1 year (from May 2017 to July 2018). These interviews comprised of simple questions about the presence/absence of the target mammal species during that particular season. Detections were mapped onto the participatory map during the interview. Semi-structured interviews were informal conversations performed by two trained team members. Interviews were undertaken in French, and lasted 20 min–1.5 h. A targeted non-probability sampling strategy was employed, interviewing all willing adults within the village, aiming for at least one adult per household.

2.4.3 | Hunter diaries

Data from the hunter diaries were collected by 10 hunters in each village, who were trained to keep image-based daily diaries of the species they detected during their daily activities, providing information on the species detected, where the species was detected, the habitat type and date (following Rist et al., 2008).

A key contact was employed within each village to collate the datasheets. The key contacts were involved in the creation of the community forests as a community representative, were familiar with reading maps and as such were able to assist hunters with the mapping of species detections onto the participatory map. The accuracy of data collection was checked by the team with opportunistic hunter follows (see Rist et al., 2008) at the start of the data collection ($n = 9$) and the key contact was in weekly contact with the research team, to feedback on progress.

2.5 | Ethics

Free, prior, and informed consent was obtained by all participants involved in this study. Personal anonymity was assured, and village locations were not recorded to ensure anonymity at the community level (St. John et al., 2016). Hunters completing the daily diaries were given a small compensation for their participation (equivalent to £0.10p a day), and interview respondents were given small gifts. However, the compensation was such that it did not incentivize participants to falsify data (e.g., hunters who recorded no detections were compensated the same as those who had recorded many sightings). The research was approved by the University of Oxfords Central University Research Ethics Committee (CUREC) (R45771/RE001).

2.6 | Data analysis

In our analysis, we used a subset of the interview and hunter diary data gathered that temporally and spatially matched the camera-trapping data to enable robust comparison between methods in both villages (Camino et al., 2016; MacKenzie et al., 2006), and also reduce recall bias from the seasonal interviews.

Species detection histories were created by arranging the data into presence/absence (1/0) of a species during repeat visits to a site. For camera traps, the sampling occasion was set at 5 days, a compromise between model stability and ensuring an adequate number of repeat visits to each site (Burton et al., 2015). Following Martínez-Martí et al. (2016), individual interviewees from the interview and hunter diaries were treated as repeat spatial and temporal surveys within each 1 km^2 site. Occupancy was defined as area used, rather than area occupied, due to the different home range sizes of the species included in this study.

We included four sociodemographic covariates that we felt could plausibly influence the ability of participants to detect the species when employing the interviews and daily diaries in the comparative analysis: participant age, gender, their frequency of visits to the community forest, and time spent in the forest per visit. Additionally, we included six environmental covariates that we expect can help explain variation in ψ (occupancy) for all methods: habitat type, distance (km) of each detection from the reserve, roads, rivers, and village. For camera traps, these variables were also used instead of the socio-demographic covariates as detection covariates (p), with the addition of slope. Village was not included as a variable because the two villages are over 100 km apart and vary greatly in their context. As such, we expected that the animals that could be robustly monitored and the most appropriate method for doing so could vary greatly between villages, which would not be identified in the results if village were simply included as a variable. We used the Euclidean distance tool in QGIS 3.0.2 to extract distances (QGIS Development Team, 2018), and Pearson tests for correlation between environmental covariates, none of which were highly correlated. Covariates were standardized before modeling to aid comparisons and model convergence (Reilly et al., 2017).

The MacKenzie and Bailey (2004) goodness-of-fit test was conducted on each global model to produce a c-hat value, indicative of over-dispersion. Where the c-hat value was >1, models were compared using the second-order quasi-Akaike Information Criterion (QAICc), to account for small sample sizes (Burnham & Anderson, 2002; Mackenzie & Bailey, 2004). Single species, single-season occupancy models, originally designed by MacKenzie et al. (2002), were performed using the package "unmarked" in R version 3.4.2 (Fiske & Chandler, 2011). Because we intend to explore differences in the drivers of occupancy and detection between villages and methods, rather than to test specific hypotheses, our candidate model set included all combinations of the variables that we expect to affect species occupancy or detection (see Doherty et al., 2012; Hegyi & Garamszegi, 2011; Tredennick et al., 2021). Minimal adequate models were selected from the global model with the "dredge" function (package MuMIn), which searches all predictor combinations and selects models by comparing values of Akaike's information criterion (AICc or QAIC if c-hat >1) (Barton, 2012). Models that did not converge or produced estimates of $p < .15$ and $\psi = 1$ due to too few detections were excluded, because here the model cannot clearly distinguish between genuine and false species absence (MacKenzie et al., 2002). The top-ranked models were those with Δ(Q)AICc <2 (MacKenzie et al., 2006). When there was more than one model, we conducted model-averaging with the "AICcmodavg" package for R (Burnham & Anderson, 2002). The weight of evidence for each covariate was calculated by summing the AIC weights across candidate models containing that covariate (Burnham & Anderson, 2002). The power of each model to detect change with 80% power was calculated following Guillera-Arroita and Lahoz-Monfort (2012), accounting for imperfect detection.

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See Supporting Information S3 for the justification behind variable selection and SI4 for the power of each model to detect change in occupancy.

Comparisons of occupancy were drawn between the two villages at both the village level (i.e., the overall estimate of occupancy across the whole 30 km^2 area) and at the site level (i.e., the estimated occupancy within each individual 1 km^2 site grid). Estimates with the smallest CI's were deemed the most precise, while agreement was defined as cases where estimates for one method fall within the CI's of either of the other methods.

To compare estimates of occupancy at the 1 km^2 site scale, we used the "predict" function (package unmarked) to obtain 1 km^2 site-level predicted estimates of occupancy across the 30 km^2 area, in each village. Only species that produced robust occupancy estimates from all three survey methods were compared at the 1 km^2 site level. Pearson correlation tests compared the predicted 1 km^2 site occupancy estimates between all three survey methods.

2.6.1 | Cost analysis

We estimated the time invested in staff cost including the data collection, entry and analysis, essential resources for the fieldwork, and the time commitment required to carry out each survey method, for one single trip, and over the course of 1 year.

3 | RESULTS

3.1 | Survey effort summary

In village 1, 141 people participated in the seasonal interviews. Each 1 km^2 site was visited a mean of 106 times over 75 days (range = 42–139, median = 135). Ten hunters completed the hunter diaries over the same time period and each 1 km^2 site was visited a mean of 3.93 times (range = 2–10, median = 3). Of the 30 cameras set, four malfunctioned or were damaged. In total, 26 cameras over 75 days resulted in a survey effort of 1950 camera trap days.

In village 2, 109 people participated in the seasonal interviews. Each 1 km^2 site was visited a mean of 16 times over 75 days (range = 2–71, median = 8). Ten hunters completed the hunter diaries over the same time period and the 1 km^2 sites were visited a mean of 2.1 times (range = 1.4–12.6, median = 2). Of the 30 cameras set, six malfunctioned or were damaged. In total, 24 cameras over 75 days resulted in a survey effort of 1800 survey days.

3.2 | Village-level comparisons of predicted occupancy and detection

Interviews, diaries, and camera traps produced survey estimates of occupancy for 13, 6, and 7 species, respectively in village 1 (Figure 2a). Although detected, gorilla was recorded by only one camera, insufficient for occupancy analyses for these species. Interview data agreed with at least one other method for seven of the available comparative estimates ($n = 8$). Interview and camera trap estimates agreed for four of the seven species where comparisons were possible (e.g., brush-tailed porcupine, red river hog, tree pangolin, and yellow-backed duiker). Camera traps resulted in the highest estimate of occupancy in four of the seven cases; however, detection rates from the camera traps were low, notably for the Central African chimpanzee (*Pan troglodytes troglodytes*; $p = .04$) and yellow-backed duiker ($p = .02$), both rare or cryptic species, resulting in wide confidence intervals. Camera trap detection rates were also low for red river hog (*Potamochoerus porcus*; $p = .10$), tree pangolin (*Phataginus tricuspis;* $p = .03$), and servaline genet (*Genetta servalina*; $p = .05$). Camera trap data produced the lowest detection probabilities for all species.

Interviews, diaries, and camera traps produced estimates of occupancy for five, eight, and four species respectively in village 2 (Figure 2b). Chimpanzee and red river hog were detected by cameras, although insufficiently for occupancy analysis to be successful. Interview data were in agreement with at least one other method where a comparison was available ($n = 3$). Camera trap data agreed with either the interview or diary data in the three cases where camera trap data provided a comparable estimate: blue duiker (*Philantomba monticola*), brush-tailed porcupine, and yellow-backed duiker. However, large confidence intervals for camera trap estimates for blue duiker, and interview estimates for putty-nosed monkey, make inference about comparisons more challenging for these species in village 2. As with village 1, camera trap data produced the lowest detection probabilities for all species.

3.3 | Comparing predicted occupancy and detection at the site level

Here, we discuss the weight of evidence for the variables from the top and averaged top models for which species estimates were produced from all three monitoring methods, so that a full comparison of estimates between methods could be completed. For a summary of all species occupancy models and directions of effects, see the Supporting Information S5–S7. Complete sets of

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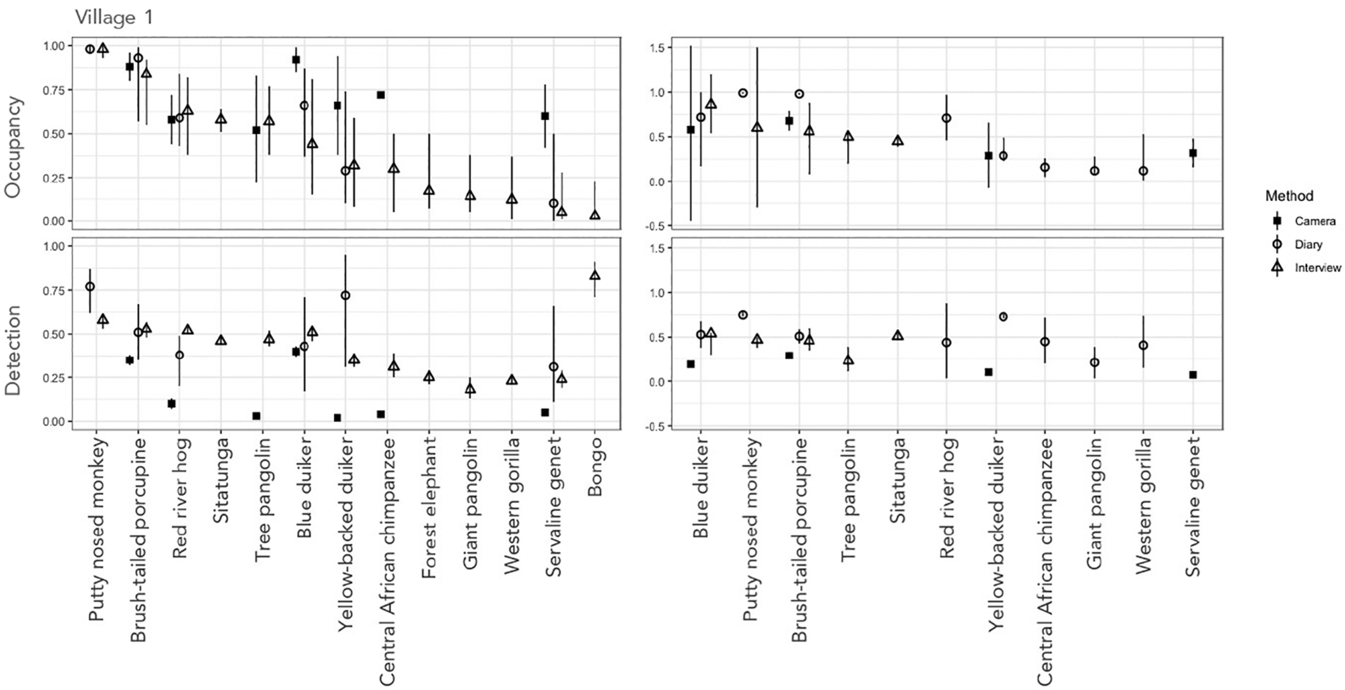

FIGURE 2 Species- and village-specific estimates of occupancy probability (top row) and detection probability (bottom row). Estimates are derived from the top and averaged top models summarized in Table 3. Error bars show 95% confidence intervals

estimates of occupancy from all three monitoring methods were produced for five species in village 1 and two species in village 2.

Distance from road was the most important variable for blue duiker, brush-trailed porcupine, and red-river hog occupancy in village 1, while distance from village and distance from road were important for diaries for blue duiker and red river hog. Distance from village had the greatest weight of evidence for estimating brush-tailed porcupine occupancy in both villages. In village 2, distance from river had the greatest weight of evidence for both blue duiker and porcupine occupancy.

There is strong evidence for the impact of gender on species detectability using both interview and diaries in village 1; detection rates were higher for women in all cases. Distance from the reserve was most likely to affect detection by camera traps in village 1; blue and yellow-backed duiker detection decreased while genet and porcupine increased with distance from the reserve. In village 2, brush-trailed porcupine and blue duiker detection using interviews and diaries was most affected by the time respondents spent in the forest (Table 3).

We found strong and significant positive correlation between site-level predicted occupancy based on the top and averaged top interview and diary models for brush-tailed porcupine (.46, $p = .008$), and between diary and camera estimates for blue duiker (.58, $p = .006$). Further, we found strong and significant correlations for brush-tailed porcupine estimates of site-level occupancy in village 2 from diary and interview data (.46, $p = <.05$) and from diary and camera trap data for blue duiker (.58, $p = .01$), however 80% power to detect change in occupancy was not achieved for camera trap data from village 2 (see Supporting Information S4). Significant site-level occupancy correlations were not found for any other species and no significant correlations were found between interview and camera trap data.

3.4 | What methods are most cost and time efficient?

Survey methods are only beneficial if they are both robust and affordable for sustained periods of time. In this study, the number of staff required for camera trap surveys meant that the total number of staff days required exceeded that of interview and hunter diary surveys. This is despite the high number of return trips for the hunter diary surveys, because the return check-up visits did not require a full research team. In this study, interviews were the cheapest to conduct in both villages. Costs per trip were lowest for hunter diaries, but due to the regular return visits and check-ins with local key contacts and

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TABLE 3 Akaike information criterion weight (Q)AICcWt of each covariate for each species, calculated by summing the (Q)AICcWt for each model in which the covariate occurred in the model selection process

	Method	*Ψ* road	*Ψ* river	*Ψ* village	*Ψ* reserve	*Ψ* habitat	*p* gender	*p* age	*p* trips	*p* time	*p* slope	*p* road	*p* reserve
Village 1													
Blue duiker	Interviews	**0.86**		0.26	0.13		**1**		.48				
	Diaries		0.05	**0.24**	0.17		**1**	**1**	**1**	**1**			
	Cameras	0.19	**0.37**		0.13	0.18					.21	.32	**1**
Servaline genet	Interviews					**1**	**1**						
	Diaries	**0.43**		0.19		0.16	**1**	**1**	**1**	**1**			
	Cameras	0.21	**0.24**			0.08					.21	.22	**.8**
Brush-tailed porcupine	Interviews	**0.56**			0.06	0.1	**1**		.05	.1			
	Diaries			**0.19**	0.17	0.15				**1**			
	Cameras	0.18	0.35		**0.42**						.33	**1**	.96
Red river hog	Interviews	**0.34**	0.06			**0.64**							
	Diaries	**0.37**			0.15	**1**		**1**	.05	**1**			
	Cameras	0.18	0.03		**0.23**	0.18					.51	**.58**	.18
Yellow-backed duiker	Interviews		0.14		**0.18**	**1**	**1**						
	Diaries	**0.34**		0.13	0.12			**.25**					
	Cameras	**0.28**	0.19			0.23					.21	.23	**.8**
Village 2													
Blue duiker	Interviews	0.66	**1**	0.8	0.65		.13	.26	.47	**1**			
	Diaries	0.2		0.17	0.28	**0.35**							
	Cameras			0.12		**0.19**					**.71**		
Brush-tailed porcupine	Interviews	0.27	**0.94**	0.33	0.3		.23	.11		**1**			
	Diaries	**1**	0.32	**1**	**1**	1		**1**	.68	**1**			
	Cameras			**0.59**	0.13						**.59**		

Note: Result is blank when the covariate did not appear in any of the final models because all models with the covariate were poor according to the goodness of fit test/produced an occupancy estimate of 1 and $p < .15$/did not converge. See Supporting Information S5–S7 for all top models. Values in bold represent the occupancy and detectability variables with the greatest weight.

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TABLE 4 Table of the staff, time, and travel costs required per trip and over the course of 1 year for monitoring with each method in villages 1 and 2

Fieldwork costs	Village 1			Village 2		
	Interview	Diary	Camera	Interview	Diary	Camera
Monitoring fieldwork details						
Number of staff needed per trip, (a)	3	1	6	3	1	6
(×) Days staff are in the field per trip, (b)	17	5	23	15	3	21
(×) Total trips needed, (c)	1	4	2	1	4	2
= Total days staff are in the field to complete fieldwork ([a × b] × c)	204	60	276	180	36	252
Staff costs per day £9[d]						
Staff costs per trip (£GDP) ([a × b] × d)	£459	£45	£1242	£405	£27	£1134
Staff costs for all fieldwork (£GDP) ([a × b] × c × d)	£459	£180	£2484	£405	£108	£2268
Spending (£GDP) on essential resources per trip (e)	446.9	315.5	1046	282.80	175.5	856
Essential resources include the following: Interviews: Participant gifts, photocopying, petrol, accommodation Daily diaries: Salary for local key contacts and participants, photocopying, petrol, accommodation Camera trap surveys: Petrol, accommodation, batteries						
Spending (£GDP) on essential resources to complete fieldwork (f [e × c])	£446.9	£1262	£2092	£282.80	£702	£1712
Total spend (£GDP) for one survey trip ([a × b] × d + e)	£905.9	£360.5	£2288	£687.8	£202.5	£1990
Total spend (£GDP) for all fieldwork ([b × c] × d + f)	£905.9	£1442	£4576	£687.8	£810	£3980
Total spend (£GDP) for all fieldwork, inclusive of camera trap start-up costs (£180 per camera × 30 cameras = £5400)			£9976			£9380

Note: See Table 2 for the survey effort undertaken for each method in villages 1 and 2.

participants, the costs for hunter diaries exceeded those of interviews over the whole survey period. Camera trapping was the most expensive overall, due to the high staff time and effort required to set and collect camera traps, and the cost of the equipment required for long-term monitoring (Table 4).

4 | DISCUSSION

Effective conservation action requires an understanding of biodiversity trends, over appropriate temporal and spatial scales. In challenging contexts, where monitoring is difficult and funding is tight (such as Cameroon's forests), methods must be both cost-effective and robust. This study assesses the robustness and cost-effectiveness of occupancy analysis informed by local inhabitants through seasonal interviews and hunter diaries, compared with camera traps, for multiple tropical forest mammals.

The best field method for a particular monitoring study depends on several factors, including the target species and the characteristics of the study area (Camino et al., 2020). As expected, species detection was lower in village 2 than village 1, which often limited the capacity of camera traps to produce robust and informative estimates with the resources available to us. However, where detection was sufficient, the camera trap data were also valuable. A key message of our work is that the methods and survey effort and animals that can be monitored robustly vary from village to village. As such, consideration should be given before monitoring commences to ensure that the most effective and informative approach is used in each instance, rather than adopting a blanket approach.

We show that LEK-based methods can be efficient and robust tools for detecting the presence and estimating the occupancy of hunted mammals in tropical forests. In particular, our findings support previous research showing that interviews can be used for detecting rare

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species (e.g., giant pangolin, gorilla, and chimpanzee). Where camera trap data are available, estimates of occupancy informed by both hunter diaries and interviews often agree with estimates derived from camera traps at the village scale (e.g., estimates fall within the CIs of the camera trap estimates). As such, our findings contradict those of Garrote and Pérez de Ayala (2015) who found that estimates from interviews overestimate occurrence and distribution (Garrote & Pérez de Ayala, 2015).

Village-scale estimates of occupancy were often comparable between methods, with evidence of site-level agreement between interview and diary data and diary and camera trap data for blue duiker and porcupine species in both villages. However, the lack of site-level agreement in predicted occupancy for all other species has implications for future occupancy studies; if a study aims to obtain an overall estimate of occupancy at a village or landscape scale, then locally sourced data may be an effective and economical way to do this. However, if the aim is to obtain estimates of the likelihood of occupancy at the site level (here, at a resolution of 1 km^2), to predict habitat preferences or identify areas of conservation priority, for example, then more research is needed to understand how and why results may differ between methods. Site-level predictions are possible; for example, Brittain et al. (2018) used local knowledge gathered from interviews with forest-concession workers, combined with occupancy analysis, to identify areas of conservation priority for forest elephants across the eastern region of Cameroon. The resulting maps of predicted occupancy were in line with up-to-date estimates of forest elephant density and distribution from scientific surveys. It may be that in this particular study, limiting the data to the same 30 km^2 area to ensure spatial comparability across all three methods resulted in a smaller sample size, rendering the variability in occupancy and detection harder to ascertain and predict, especially for species such as chimpanzee whose home ranges often extend to 15 km^2 (Bryson-Morrison et al., 2017).

Species-level differences in the effectiveness of monitoring methods were identified. While cameras yielded insufficient data to estimate occupancy for some species (i.e., gorilla in village 1 and chimpanzee in village 2), locally informed data allowed occupancy estimation for these species. There are several potential reasons for this. First, chimpanzees and gorillas are easily identifiable, making easily recognizable calls and nests, increasing detectability by people in a way that does not apply to camera traps. Second, the locally informed detection rates for these species may be high because they each hold a cultural or economic interest, a phenomenon that has also been reported in other studies (Camino et al., 2020; Martínez-Martí et al., 2016). More "eyes on the ground" from such methods increases the likelihood of detection, which has also been shown to be especially useful where species densities are low (Martínez-Martí et al., 2016; Turvey et al., 2015). Whatever the driver, the result is in line with previous studies that have also found estimates of primate population trends from local inhabitants to be robust (van der Hoeven et al., 2004). Therefore, in the face of a lack of data or low budgets, local knowledge can provide informative estimates of occupancy for some important species.

Gender played an important role in accounting for detectability in the interview data in village 1, with women reporting more detections than men. This contradicts findings from several previous studies, which found that men were likely to overestimate, either because of social norms, or because they are adept at finding a species and may overestimate detections as a result of seeing the species more frequently than others (Burgman et al., 2011; Hemming et al., 2017). It may be that the species better detected by women in this study are of greater interest for women than men, and therefore noticed more readily by women. Alternatively, it may be that men generally travel further from the community forest, and therefore women, who remained closer to the village during the period of time the camera traps were set, had a higher detection rate for animals in the community forest area, although this heterogeneity should have been captured by the environmental variables in the occupancy models.

The inclusion of observer-based and environmental variables in the models highlights the importance of accounting for variation in both occupancy and detection (Van Strien et al., 2013). In their large-scale comparison of wildlife distribution data between interviews with local people and camera traps, Caruso et al. (2016) found that interviews cannot be adequately relied upon. However, as Petracca and Frair (2017a,) pointed out, their study did not account for differences in site size and location, violated the closure assumption and did not conduct repeat surveys at each site. As such, they are unable to control for variable detectability, which we show must be accounted for to produce reliable estimates.

Some biases exist that occupancy analysis cannot account for, such as reporting or recall bias, which may affect diary and interview data in different ways. For example, participants may be unwilling to report directly to a researcher when they have hunted or detected a protected species, due to social desirability biases (Nuno & St John, 2014). Completing anonymous diaries may therefore allow participants to feel more comfortable compared to direct interviews. However, so long as the reporting probability is not too low, occupancy analysis can still give unbiased results by adjusting detectability appropriately. The results from this study do not suggest that

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respondents held back from reporting species detections in either the hunter diaries or the interviews, given that observations of protected species were reported in both.

Within the financial and logistical constraints of fieldwork, we show that local sourcing can be a reliable, rapid and cost-effective method of gathering occupancy data at the village scale in poorly understood systems. Our findings support those of Camino et al., 2020, that interviews are cheaper and faster than hunter diaries, and in particular for covering large areas. However, hunters may be better placed to detect certain species that they regularly hunt or are important to them, supporting the idea that hunters may have specialist knowledge about species of conservation interest.

Although the comparison conducted in this study was over a small spatial scale of 30 km^2, it enabled a direct spatial comparison of estimates derived from camera traps, diaries and interviews. Estimates of occupancy were robustly comparable across methods because we matched sites both spatially and temporally, over a period of time short enough not to violate the closure assumption.

Camera traps were selected as the comparison method because although they have their own biases, they remove the observer-based biases that are associated with both interviews and diaries. However, camera traps can also be unreliable. In this case, a lack of reliable estimates from the camera traps, especially in village 2, limited our ability to undertake more extensive comparisons between species. A greater camera trapping effort may be required in future comparative research, to increase the detection of endangered and cryptic species that may avoid community forest areas. However, increasing survey effort has budgetary implications (Guillera-Arroita & Lahoz-Monfort, 2012). While we do not assume that the camera traps in this study represent the "truth," as in other comparison studies (e.g., Caruso et al., 2016), future studies in locations where true occupancy is known (e.g., Moore et al., 2011) would be beneficial to assess the robustness of each method. However, this will remain challenging in situations in which local sourcing of data is likely to be of most benefit.

As well as being cost-effective and potentially more informative than camera trap data, locally informed methods also provide co-benefits to communities' which camera traps cannot. Locally led surveys such as the hunter diaries used in this study may increase local capacity and empower local communities, raising legitimacy of conservation actions, and their chances of success (Danielsen et al., 2009; Dolrenry et al., 2016). This is important, because communities are often excluded from conservation, management, and economic initiatives (Bennett, 2016).

However, locally informed methods only work well if well applied (Camino et al., 2020). Before establishing a mammal monitoring program that draws on local knowledge, we recommend piloting the interview process to ensure that participants can reliably identify the target species. Developing the participatory map was a time intensive but vital part of the research, which enabled the species detections to be accurately mapped. Mobile data collection platforms such as Sapelli (Stevens et al., 2013) is an alternative option to enable working with nonliterate users and accurately map detections. However, both mobile platforms and participatory mapping approaches require significant time, resources, and expertise to develop these protocols alongside communities, which must be accounted for before monitoring starts.

Our comparison of mammal occupancy at the village and site-level identified sources of uncertainty and precision between three different monitoring methods and for multiple mammal species. We demonstrated the potential of locally informed methods for providing robust and cost-effective occupancy estimates at the village scale, in particular for species with detection rates too low for camera trap data to provide reliable occupancy estimates. Our findings add to the growing body of literature studying the relevance of LEK-informed methods, and in particular comparing its performance against other more conventional methods.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

AUTHOR CONTRIBUTIONS

Stephanie Brittain, E. J. Milner-Gulland, and Marcus J. Rowcliffe conceived the ideas. Stephanie Brittain, Fabrice Kentatchime, and Cedric Thibaut Kamogne-Tagne collected the data. Stephanie Brittain and Sophie Jane Tudge analyzed the data. Stephanie Brittain led the writing. All authors reviewed the manuscript.

DATA AVAILABILITY STATEMENT

Data are available upon request form the lead author, Stephanie Brittain (stephanie.brittain@zoo.ox.ac.uk).

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