Integrating local and scientific ecological knowledge to assess African forest elephant (*Loxodonta cyclotis*) populations in a data-deficient region, eastern DR Congo

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Introduction

Effective wildlife management requires monitoring changes in the spatial distribution of species, their population size and population trends (Sinclair et al. 2006). However, obtaining this data, particularly for rare and elusive species such as forest elephants (*Loxodonta cyclotis*), is not a trivial task. Surveys designed to collect the relevant data are often challenged by environmental factors (weather, land cover) and animal behaviours that can cause imperfect detection of all individuals, leading to estimates that are biased and/or imprecise (Williams et al. 2002). Moreover, methods currently used for assessing wildlife density in rainforests are time-consuming and expensive, or not suitable to cover large areas, at least on a regular basis (Hoeven et al. 2004; Zhou and Griffiths 2007). Significant research effort continues to be directed at developing reliable, cost-effective monitoring methods for rare and elusive species (Thompson 2004; Conroy et al. 2008; Royle et al. 2013). However, field data with which to assess the forest elephant's status and population trends across its geographical range remain limited, and recent field surveys using standard ecological field techniques have typically failed to detect wild individuals (Camino et al. 2020).

Conventional methods predominantly used to study wildlife populations include transect and point count surveys using distance sampling techniques, and camera trap surveys (Paddock et al. 2020). These methods require researchers to follow standard protocols and assumptions, which if incorrect leads to misleading measurements and erroneous inferences about the population under study (Mathai et al. 2013). However, the difficult terrain of the sampling unit often hinders the ability of observers to carry out detections efficiently over long distances, undermining the reliability of results obtained (Mathai et al. 2013). Moreover, estimating wildlife densities often requires collecting data over long time periods, which, when using these traditional methods, requires significant resources in terms of equipment, finance, and personnel.

In order to overcome such difficulties inherent in using conventional contemporary wildlife survey methods, conservationists and wildlife managers have used social surveys as a complimentary tool to study wildlife populations (White et al. 2005). In addition, researchers have called for incorporating local knowledge from communities living close to wildlife to help tropical biodiversity conservation (Gilchrist et al. 2005; Bawa et al. 2006; Danielsen et al. 2014). Though once considered anecdotal, local ecological knowledge (LEK) is now used routinely to guide the management of conservation programmes (Gilchrist et al. 2005; White et al. 2005, Sandbrook et al. 2013; Peñaherrera-Palma et al. 2018).

LEK extends back in time over generations. Therefore, in addition to constituting a valuable source of information on the current situation, LEK has been successfully used to track historical changes in species distribution (Huntington et al. 2011). Collecting LEK involves collaboration with local communities, which creates the scope to engage such communities and grassroots conservation NGOs in the conservation process and promote their commitment to continued action (Sheil and Lawrence 2004; Schewe et al. 2020).

There is a need to carefully compare results obtained from LEK with those obtained from field surveys, because they reflect independent sources of information which could either corroborate or refute each of the findings. Such a comparison could also increase confidence and depth of knowledge in both approaches (Huntington et al. 2000). While the agreement between results obtained by the two methods has not been extensively analysed, studies indicate that data collected from local knowledge are comparable with those collected using conventional methods (Jones 2011; Parry and Peres 2015). Our study aims to confirm the validity of these conclusions for the case of the African forest elephant. Thus, the research question is: Does the combination of local and scientific knowledge provide a potential tool to improve our knowledge of African forest elephant and foster the development of effective wildlife management strategies to meet biodiversity conservation goals?

Methodology

Study site

The study area is located in Itombwe Massif Forest in the Albertine Rift region in eastern Democratic Republic of Congo (DRC), to the west of the northern tip of Lake Tanganyika (Fig. 1). It extends between 2° 51.286’ and 4° 00.690’ south, and between 28° 09.889’ and 28° 58.511’ east. The area holds the largest and most remote block of intact montane forest (>1,500 m elevation) in Africa and is one of the most biologically diverse sites in Sub-Saharan Africa. The massif lies at the intersection of three phytogeographical regions: the Guineo-Congolian, Afro-Montane and Zambezian regional centres of endemism. This location, at the crossroads of three regions, partly explains the vegetational diversity (Omari et al. 1999). The Massif is recognized as a sanctuary for endangered forest elephants, gorillas (*Gorilla gorilla graueri*), and many other rare and endangered mammal, reptile, amphibian, bird and fish species, as well as invertebrates and plants. (Omari et al. 1999).

The forests of the Itombwe Mountains are subject to intense human pressure. Causes of deforestation and forest degradation include cattle ranching (particularly at higher altitudes) gold mining, shifting slash-and-burn agriculture, small-scale commercial forestry plantations (such as oil palm), felling of trees for firewood and construction, and hunting.

The study area comprises the wildlife corridor linking two protected areas (PAs) within the Itombwe Massif, the Itombwe Natural Reserve (NR) and the Luama Hunting Domain (Figs. 1 and 2). This wildlife corridor comprises 1,712 km^2 of mainly forested landscapes, representing a gradient of disturbance from undisturbed primary forest to unlogged but hunted natural forest, 30-year-old secondary forest and forest gardens. The study area is subject to the same pressures as other parts of the massif. Evidence of earlier agricultural clearing was recorded in most survey areas, and settlement relocation continues at the present time. Gardens in the west of the survey zone were small (< 0.5–2.0 ha), with manioc being the principal crop. Most active gardens were opened in previously cleared areas with few located in primary forest.

The paper compares results of two studies carried out to estimate elephant populations in the study area: a field inventory of dung counts using line transects in 2018, and interviews with local subsistence hunters (who use arrows, traps and dogs) carried out in 2019. Both studies focused on sample areas in the vicinity of nine villages where the hunters we interviewed lived. For analysis, the survey area was divided into a northern Compartment 1 comprising villages 1, 2 and 3, central Compartment 2 comprising villages 4, 5 and 6, and southern Compartment 3 comprising villages 7, 8 and 9 (Fig 2). For comparative analysis of the two survey methods, data from each line transect were assigned to the nearest village.

Field inventory

Often, elephants cannot be counted directly in forests because they are difficult to see in the thick undergrowth. Therefore, the census was based on dung counts, which have been used successfully elsewhere in Africa where visibility is limited (Buckland et al. 2001). The census was carried out during July–August 2018 by Leonard Mubalama (MK-L) and three local assistants. Surveys were conducted using line transects (Buckland et al. 2001) coupled with

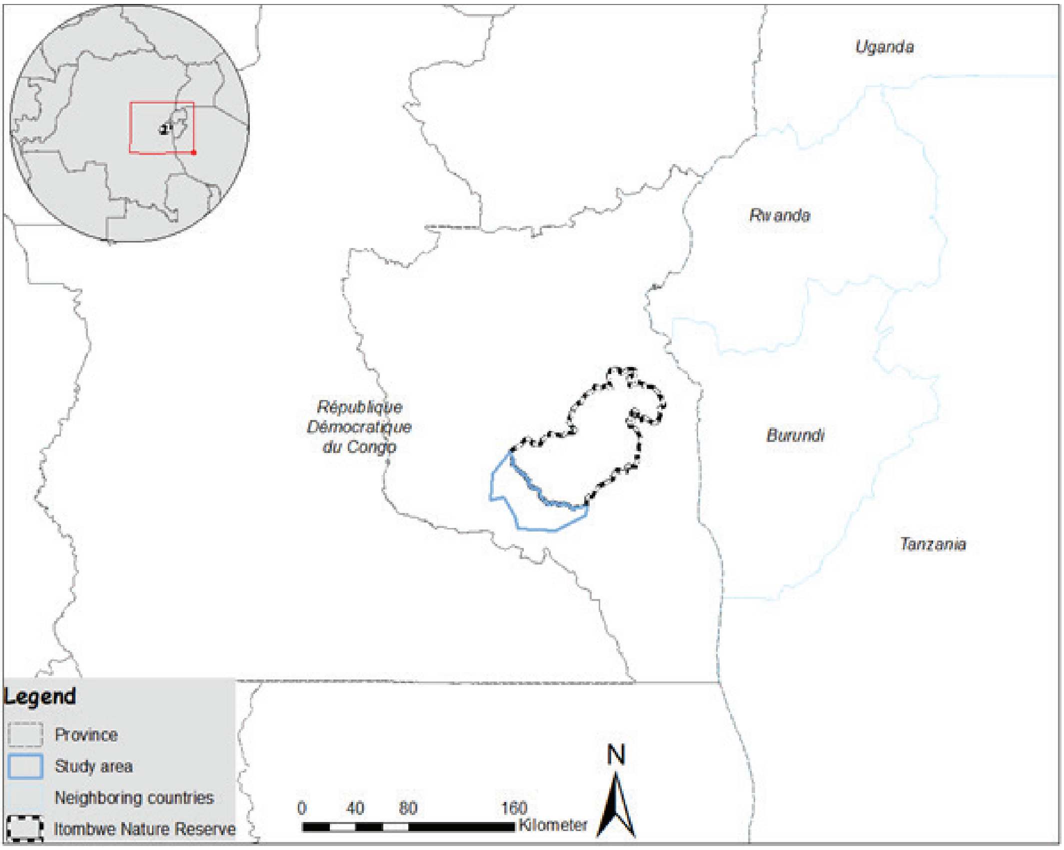

Figure 1. Location of the study area in Itombwe Massif Forest in eastern DR Congo.

reconnaissance transects (recce.) following the path of least resistance, a tried and tested method for surveying animal populations in dense forest habitats (Walsh and White 1999). A total of 38 transects of 1000 m were established, at least 500 m apart, with 12, 16 and 10 transects in the northern, central and southern compartments, respectively. Each transect was walked in the morning (07.30–12.30) and afternoon (13.00–17.00). For each direct encounter of an elephant sign (dung), we measured the perpendicular distance from the sign to the transect. At each encounter location, we noted the habitat type (as either primary forest, natural forest, secondary forest or forest garden) and recorded other vegetation parameters. As measures of forest disturbance, we counted human trails and hunting traps encountered along each transect and measured the distance from the starting point of each transect to the nearest village.

Interviews

In July–August 2019, we conducted participatory rural appraisals covering a wide range of issues with the participation of a total of 496 people from the nine villages, and in-depth interviews with a stratified random sample of 50 local hunters ranging in age from 25 to 78 drawn from the three forest compartments (Table 1). Hunters interviewed included both bushmeat hunters, using arrows, traps and bows, and commercial hunters using snares and, in some cases, shotguns.

Interviewees spoke a variety of local languages (Fang, Lega, and Bembe, as well as Kiswahili). Interpreters were used to help with interviews, in order to use the local vernacular whenever possible in those communities where traditional languages are still spoken. Using local dialects is advantageous because much of the detailed traditional ecological knowledge is best conceptualized and more thoroughly expressed in the local vernacular (Maffi 2001), while community and individual rights are respected (Mubalama 2001).

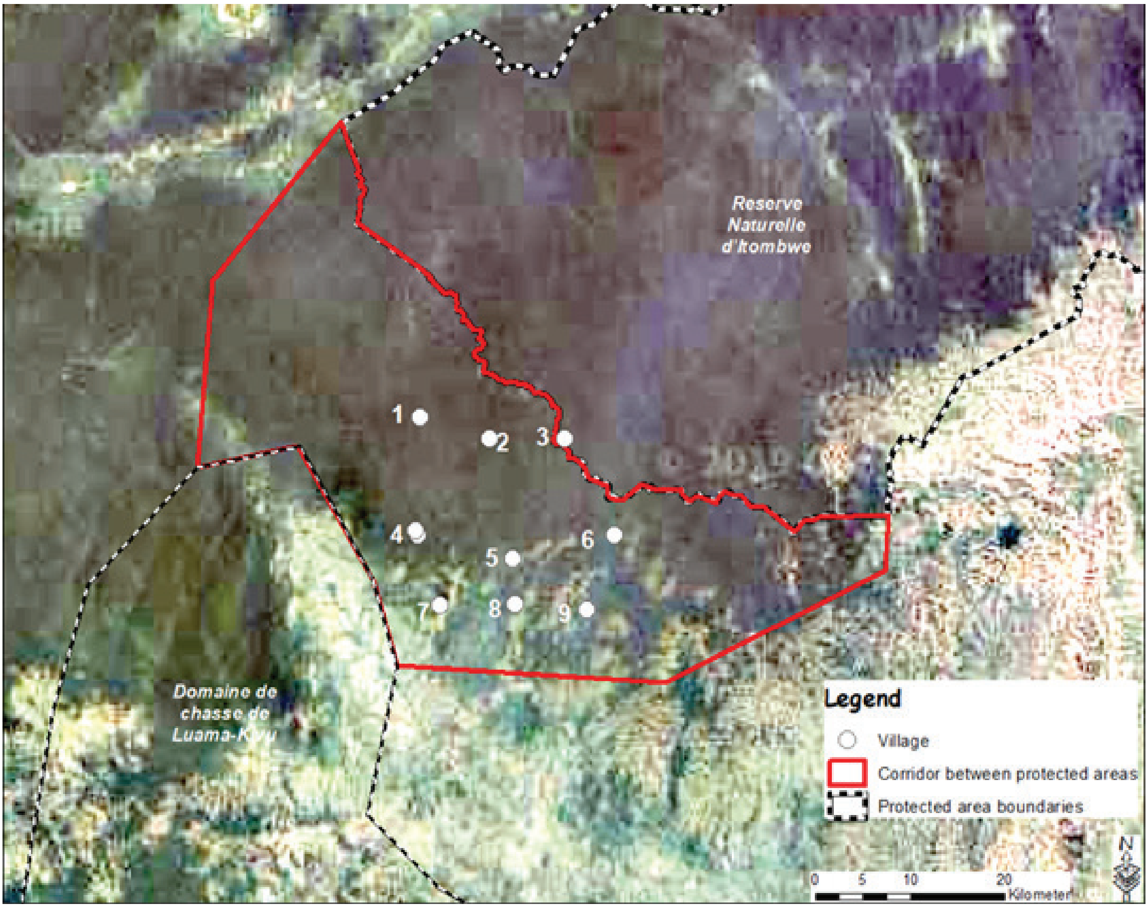

Figure 2. Location of the nine villages in the study area in the corridor between Itombwe Nature Reserve and south Kivu Luama Hunting Domain.

Table 1. The three forest compartments in the Itombwe-Luama Forest landscape, with number of villages, number of households in 2019, total number of interviewees, and the number of hunters whose in-depth interviews provided data on elephant populations and trends

Area	Number of villages	Number of households	Number of interviewees	Number of hunters
Compartment 1	3	23	192	15
Compartment 2	3	32	183	20
Compartment 3	3	16	121	15
Total	9	71	496	50

All interviews were structured with open-ended questions within an informal and flexible framework. A concerted effort was made to avoid potentially leading questions or to pre-empt the conversation. Maps, calendars, animal picture cards and multiple-choice options were used to aid understanding of the questions by hunters and to maintain interest and enthusiasm during the interview.

Hunters were asked for personal details such as age, education, and marital status; whether they had been born in the study area or elsewhere; previous and current alternative livelihoods; and previous and current hunting activity. To elicit information about current hunting activity, interviewees were asked about reasons for hunting, species targeted, traps and hunting gear used, and hunting locations. Based on this experience, they were asked to estimate the numbers of elephants and other key species in the areas where they hunted. Hunt locations were assigned to numbered zones on the map of the villages.

Conversations regarding elephants encompassed local language names; aspects of the species' ecology (i.e. habitat, shelter, diet, breeding biology, behaviour); whether the elephant is traditionally (and is still) used as a food or for other purposes; and the locations the species is or was found in three general time periods: in the past when the participant was a young man (nominally more than 20 years ago), in the recent past (up to 20 years ago) and the current status. For each period, participants were asked to indicate whether the species was common (many individuals seen often), present in low numbers (some individuals seen occasionally) or absent. By analysing and comparing information provided by the interviewees we estimated, for hunting areas around each village, general trends over time; and, for the current period, numbers of sites where elephants were found and the minimum number of elephants in each area (see Table 2 below).

As is evident from the above description, the interviews yielded a wide range of rich LEK about elephants, as well as other animal species. In this field note we focus on information provided about elephant populations, including distribution and trends, for the purpose of comparison with results of the field survey.

Data analysis

Data from the field inventory were analysed using single individual signs as the sampling unit. We used geometric mean regression to test the relationship between the transect dung pile encounter rate and the dung pile encounter rate of recce samples. Results showed that the transect dung pile encounter rate was not significantly different from the recce encounter rate ($p < 0.0001$). We used DISTANCE v. 6.2 (Buckland et al. 2001) to model a global detection probability, and the detection probability in hunting areas around each village, (average size: Between 25 and 31.25 km^2) and used these probabilities to estimate the number of elephants in each area. We used habitat as a covariate to estimate elephant density for each habitat. The Kruskal–Wallis test (one-way ANOVA; SPSS 2007), with p-values adjusted using the Bonferroni correction, was used to assess differences between the results of the field inventory and the surveys, and the differences in the abundance of elephants among areas, as well as differences in vegetation parameters across habitats. We also assessed bivariate relationships between elephant abundance and vegetation variables, using Spearman rank correlations.

Results

Evidence of the presence of elephants was found or reported in every sample area during each survey period. The field inventory in 2018 identified 249 locations with dung samples in transects around the nine villages (average 27.66 per village). Interviews with hunters in 2019 identified 210 locations where elephants were known to be present (23.33 per village). The minimum number of elephants in the nine hunting areas was estimated at 155 by the field study in 2018 and at 161 in 2019, based on information provided by the hunters we interviewed (Table 2).

The differences between the numbers of locations where elephants were present based on LEK compared to results of the field inventory were not statistically significant (ANOVA: $F = 1.51$, df = 1, $p = 0.24$).

The two survey methods also produced strikingly similar estimates of elephant presence and elephant populations across the study area (Table 2). Comparative analysis of differences among villages and forest compartments found by the field survey showed that elephants were most abundant in the central region of the study area. There were statistically significant differences between the study areas in central sector and those in southern and northern study areas, in terms of both the number of locations where elephants were present (one-way ANOVA: $F = 9.03$, df = 1, $p = 0.0005$ between central and northern study areas; $F = 4.14$, df = 1, $p = 0.05$ between central and southern study areas) and the minimum numbers of elephants (central vs. northern: $F = 8.83$, df = 1, $p = 0.006$; central vs. southern: $F = 5.24$, df = 1, $p = 0.03$). There were no significant differences in the abundance of elephants between the south and the north (locations: $F = 0.91$, df. = 1, $p = 0.35$; numbers of elephants: $F = 0.22$, df = 1, $p = 0.64$). Clear differences were also evident between hunting areas (villages) within the forest compartments, with elephants being most abundant in hunting areas around villages 4 and 6 (Table 2).

With regard to population trends, 97% of hunters we interviewed reported that populations of elephant have declined during the last 20 years. The majority of respondents believed that this is predominantly a consequence of hunting pressure (62%), resulting in elephant migrating away from visited areas (66%), as well the incidental entangling of animals in pitfalls used for hunting forest species (54%) (Fig. 3). Conservation problems identified by hunters as contributing to this decline included growing human population; illegal elephant hunting (poaching and for bushmeat); deforestation, and mining. (Hunting is not illegal outside protected areas, except when involving totally protected species such as elephant). Perceptions of conservation problems were broadly similar across the study area, except that mining was mentioned less often by respondents in the central forest compartment (Compartment 2).

Data from a single field survey cannot provide information about population trends. However, analysis of differences in elephant abundance between habitats supported hunters' assertions that human disturbance was the principal driver of elephant population decline. Forest elephant abundance, measured as the number of encounters per transect differed significantly between habitats ($H = 21.49$, df = 3, n = 58, $p < 0.01$). However, this difference was mainly accounted for by the difference between encounter rates in primary forest and all other habitats (natural forest, secondary forest and forest gardens), where mean encounter rates were similar. To further elucidate these findings, we analysed habitat characteristics in terms of vegetation parameters and the presences of human activities (Table 3). Abundance was positively correlated with vegetation parameters associated with primary forest, i.e. canopy cover ($r_4 = 0.76$, $p < 0.05$), and tree height and diameter ($r_4 = 0.52$, $p < 0.05$ and $r_4 = 0.57$, $p < 0.05$, respectively). In contrast, elephant abundance was negatively correlated with variables indicating human presence, i.e. wildlife traps ($r_4 = -0.67$, $p < 0.05$), human trails ($r_4 = -0.78$, $p < 0.05$), and positively correlated with mean distance to the nearest village ($r_4 = 0.62$, $p < 0.05$). Elephant abundance was also negatively correlated with indicators of disturbed habitats, i.e. understorey vegetation cover ($r_4 = -0.60$, $p < 0.05$) and ground vegetation cover ($r_4 = -0.67$, $p < 0.05$).

While undertaking the field survey we also encountered direct evidence of the effects of one of the factors mentioned by commercial hunters, namely, poaching. We found three poached elephant carcasses during our survey, all of which were adjacent to roads in each of the 3 blocks, indicating that poachers are profiting from the road networks to penetrate deeper into the forest away from human settlements to hunt wildlife. (No tusks were recovered by us, however the management of the Itombwe NR was informed).

Discussion and conclusion

Realistic estimates 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. Supporting the findings of previous studies (Jones 2011; Parry and Peres 2015), our study suggests that LEK-based methods can be efficient and accurate for detecting large terrestrial mammals in large, remote areas and have been reliable if not vital for tracking megafauna for many decades (Maxwell 1924). Furthermore, our study confirms, as noted by Huntington et al. (2011), that LEK can provide complementary information on historical trends and drivers of change that is difficult to obtain from conventional field survey methods. This

Table 2. Number of locations in hunting areas around each village where elephants were present, based on findings of the field inventory and hunters' reports (interviews), and estimated minimum numbers of elephants using each survey technique

Village number	Locations where elephants were present		Estimated minimum number of elephants	
	2018 (Field inventory)	2019 (Interviews)	2018 (Field inventory)	2019 (Interviews)
1	12	11	3	3
2	14	12	4	4
3	23	27	10	12
4	57	36	53	54
5	13	16	8	8
6	85	58	66	68
7	15	19	4	4
8	15	16	3	4
9	15	15	4	4
Totals	**249**	**210**	**155**	**161**
Mean	**27.67**	**23.33**		

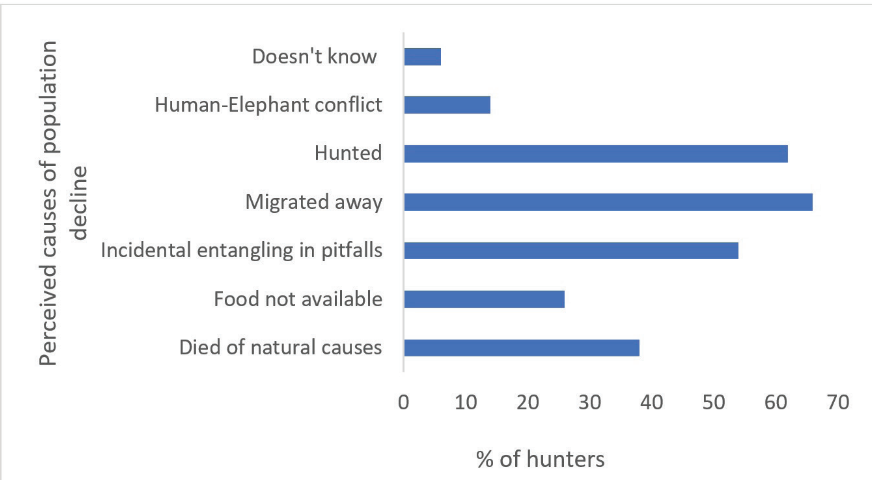

Figure 3. Perceptions about why the forest elephant is becoming rare, as determined from interviews with 50 local hunters.

also supports the results of previous studies that information provided by local resource users on species-specific depletion can be consistent with current scientific knowledge (Turvey et al. 2015).

With regard to efficiency, in our study, we estimated that around USD 161,368 would be spent to conduct a single full linear transect survey of the study area, considering travel expenses to transect sites from the field stations, food supplies, and the cost of a technician (USD 50 per day) and a local assistant (USD 20 per day). In comparison, considering two technician interviewers (USD 50 per day) for each of the nine villages sampled, we estimate that the LEK-based method would cost USD 1,700 to obtain comparatively reliable abundance indices. This supports the findings of previous studies (Gardner et al. 2008) that participatory approaches provide cost-effective monitoring of the distribution and abundance over large spatiotemporal scales even for rare and cryptic species (Stephenson 2019).

With regard to accuracy, a possible limitation of LEK-based research methods is that respondent biases, for example driven by social norms, can cause deception or unconscious distortion of responses (Moller et al. 2004). In our study, these could arise from the fact that commercial hunting is a major income-generating activity in the villages, while agriculture and fishing are not. There is a clear gender split: men are the main income-earners in the villages and commercial hunting is an exclusively male activity. Agriculture is predominantly for subsistence and mostly carried out by women. In these circumstances, hunters may be reluctant to provide information that indicates they are breaking hunting laws, or that may be used to formulate policies that further restrict their freedom to hunt.

A case in point relates to hunting in PAs. The wildlife corridor which corresponds to the study area is a legal hunting zone, while hunting is prohibited in the adjacent PAs. Since the hunters knew that we worked in close collaboration with the wildlife authorities managing both the Itombwe NR and the Luama Hunting Domain, they refrained from revealing that they also operate in these PAs for fear of being prosecuted in the future by Ecoguards. However, intelligence work carried out separately by our field assistants (who are native to the study region) subsequently identified 15 respondents who hunt in zones located within the two reserves.

Similarly, several hunters were extremely reticent about providing information on elephants, as they were aware of the Provincial Decree of 10 April 2015 banning the trade in ivory and similar products in the Province of South Kivu where the study zone is located. We were largely able to overcome this reluctance through the use of local languages and assistants familiar with the area who were trusted by respondents. However, we cannot know whether the hunters we interviewed were themselves involved in killing elephants. Shotguns, which are sometimes used to kill elephants, were recorded in all survey

Table 3. Mean values of canopy cover, understorey cover, ground cover, tree height, diameter at breast height (DBH), numbers of water courses, human trails and hunting traps for each of the four habitat types studied. p-values indicate significant different in vegetation parameters across habitat types

	Primary forest	Natural forest	Secondary forest	Forest garden	Kruskal–Wallis p
Canopy cover (%)	76.44 ± 6.65	73.3 ± 7.95	65.41 ± 4.92	26.4 ± 7.01	<0.01
Understorey (%)	41.0 ± 5.94	45.85 ± 5.88	51.0 ± 8.70	54.7 ± 5.72	0.01
Tree height (m)	21.69 ± 1.65	17.53 ± 2.12	15.92 ± 2.72	10 ± 1.63	<0.01
DBH (cm)	31.3 ± 3.82	27.65 ± 4.55	25.66 ± 4.88	14.83 ± 3.55	<0.01
Water course	4.34 ± 2.02	3.43 ± 1.86	2.88 ± 1.29	0.5 ± 0.87	<0.01
Human trails	0.18 ± 0.37	0.72 ± 0.71	1.26 ± 0.85	1.92 ± 0.59	<0.01
Hunting traps	0	0.5 ± 0.53	0.65 ± 0.82	0.81 ± 0.75	0.05

sectors, although these were used less frequently than snares. Poachers with access to military arms are reported to have killed elephants in the area over the last 15 years, although this appears to occur infrequently at present because elephant population numbers are now extremely low. However, we found direct evidence (see Results) that elephant poaching for the illegal ivory trade, continues in the area.

Bearing in mind these possible limitations, our findings confirm that LEK is an invaluable source of information for monitoring hunted species in data-poor environments. Using a combination of LEK and field surveys to monitor populations can greatly assist co-management for sustainable customary wildlife harvests by indigenous people (Moller et al. 2004). However, improved management is more likely when local stakeholders are empowered to monitor and co-manage their own resources (Raymond et al. 2010), highlighting a weakness of rapid surveys. Therefore, we suggest that future studies should engage with local people, not only as sources of information, but as potential partners and possibly engaging the hunters as rangers for the conservation of endangered forest elephants against commercial poaching.

In conclusion, although LEK-based methods have been long neglected by ecologists, our comparative study demonstrated their effectiveness for estimating elephant abundance in forest environments. This can be used simultaneously with line-transect surveys to calibrate abundance estimates and trends, and record elephants and other species that are rarely sighted during surveys on foot, but are often observed by local people during their daily extractive activities. The methodology is simple and it can be incorporated into many tropical biodiversity and conservation projects. It can also be used for long-term monitoring of wildlife status in a given area. In contrast with classical methods, the combination of LEK and scientific field data is low in cost and ensures local ownership of the results (Hoeven et al. 2004). 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 achieve biodiversity conservation goals. This study was carried out as part of a project whose wider goal is to involve local people in wildlife conservation.

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References

Bawa K, Kress W, Nadkarni N, Lele S. 2006. Beyond paradise–meeting the challenges in tropical biology in the 21st century. *Biotropica* 36: 276–284.

Buckland ST, Anderson DR, Burhham KP, Laake JL, Borchers, DL, Thomas L. 2001. *Introduction to distance sampling: estimating abundance of biological populations*. Oxford University Press, Oxford.

Camino M, Thompson J, Andrade L, Cortez S, Matteucci SD, Altrichter M. 2020. Using local ecological knowledge to improve large terrestrial mammal surveys, build local capacity and increase conservation opportunities. *Biology and Conservation* 244: 108450.

CITES Secretariat 2021. Monitoring the Illegal Killing of Elephants (MIKE): PIKE trend analysis 2003–2020. [14 December 2021]

Conroy MJ, Runge JP, Barker RJ, Schofield MR, Fonnesbeck CJ. 2008. Efficient estimation of abundance for patchily distributed populations via two-phase, adaptive sampling. *Ecology* 89: 3,362–3,370.

Danielsen F, Topp-Jørgensen E, Levermann N, Løvstrøm P, Schiøtz M, Enghoff M. Jacobsen P. 2014. Counting what counts: using local knowledge to improve Arctic resource management. *Polar Geography* 37: 69–91.

Gardner TA, Barlow J, Araujo IS, Ávila-Pires TC et al. 2008. The cost-effectiveness of biodiversity surveys in tropical forests. *Ecology Letters* 11: 139–150.

Gilchrist G, Mallory M, Merkel F. 2005. Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society* 10 (1): 20.

van der Hoeven CA, de Boer WF, Prins HHT. 2004. Pooling local expert opinions for estimating mammal densities in tropical rainforests. *Journal of Natural Conservation* 12: 193–204.

Huntington HP, Gearheard S, Mahoney AR, Salomon AK. 2011. Integrating traditional and scientific knowledge through collaborative natural science field research: identifying elements for success. *Arctic* 64: 437–445.

Huntington HP. 2000. Using traditional ecological knowledge in science: methods and applications. *Ecology Applied* 10: 12701274.

Jones JPG. 2011. Monitoring species abundance and distribution at the landscape scale. *Journal of Applied Ecology* 48: 9–13.

Maffi L. 2001. (Ed.). *On biological diversity: linking language, knowledge and the environment*. Smithsonian Institution Press, Washington. ebook: https://bit.ly/3sAgEh3

Mathai J, Jathanna D, Duckworth JW. 2013. How useful are transect surveys for studying carnivores in the tropical rainforests of Borneo? *Raffles Bulletin of Zoology* 28: 9–20.

Maxwell M. 1924. *Stalking big game with a camera in equatorial Africa: with a monograph on the African Elephant*. Century Co., New York & London.

Moller HF, Berkes PO, Lyver Kislalioglu M. 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society* 9 (3): 2.

Mubalama L. 2001. The development and management of protected tropical areas: the need for a code of ethics to guide collaborative research in Africa: a case study from the Republique Démocratique du Congo. In: Potvin C, Kraenzel M, Seutin G (Eds.). Protecting biological diversity: roles and responsibilities. McGill-Queen’s University Press, Montreal.

Omari I, Hart J. Butynski T, Birhashirwa N, Upoki A, M’keyo Y, Bagurubumwe N. 1999. The Itombwe Massif, Democratic Republic of Congo: biological surveys and conservation, with an emphasis on Grauer's gorilla and birds endemic to the Albertine Rift. *Oryx* 33 (4): 301–322.

Paddock C, Michael, Bruford W, Gráinne, Mccabe M. 2020. Estimating the population size of the Sanje mangabey Cercocebus sanjei using acoustic distance sampling. *American Journal of Primates* 82: e23083.

Peñaherrera-Palma C. 2018. Evaluating abundance trends of iconic species using local ecological knowledge. *Biology Conservation* 225: 197–207.

Parry L and Peres CA. 2015. Evaluating the use of local ecological knowledge to monitor hunted tropical-forest wildlife over large spatial scales. *Ecology and Society* 20 (3): 15.

Raymond CM, Fazey I, Reed MS, Stringer LC, Robinson GM, Evely, AC. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management* 91: 1,766–1,777.

Royle JA, Chandler RB, Sun CC. Fuller AK. 2013. Integrating resource selection information with spatial capture-recapture. D Warton (Eds.). *Methods in Ecology and Evolution* 4: 520–530.

Sandbrook C, William MA, Bram B, Bhaskar V. 2013. Social research and biodiversity conservation. *Conservation Biology* 27: 1,487–1,490.

Sinclair ARE, Fryxell JM, Caughley G. 2006. *Wildlife Ecology, Conservation, and Management*, 2nd edn. Wiley-Blackwell, Oxford.

Schewe R, Hoffman D, Witt J, Shoup B, Freeman M. 2020. Citizen-science and participatory research as a means to improve stakeholder engagement in resource management: a case study of Vietnamese American Fishers on the US Gulf Coast. *Environmental Management* 65: 74–87.

Sheil D and Lawrence A. 2004. Tropical biologists, local people and conservation: new opportunities for collaboration. *Trends in Ecological Evolution* 19: 634–638.

SPSS Inc. 2007. SPSS for Windows, Version 16.0. SPSS, Chicago

Stephenson PJ. 2019. Integrating remote sensing into wildlife monitoring for conservation. *Environmental Conservation* 46 (3): 181–183.

Thompson WL. 2004. Future directions in estimating abundance of rare or elusive species. In: Thompson WL. (Ed.). *Sampling rare or elusive species*. Island Press, Washington DC, USA.

Turvey ST, Trung CT, Quyet VD, Nhu HV. 2015. Interview-based sighting histories can inform regional conservation prioritization for highly threatened cryptic species. *Journal of Applied Ecology* 52: 422–433.

Walsh PD and White LJT. 1999. What it will take to monitor forest elephant populations? *Conservation Biology* 13 (5): 1,194–1,202.

White P, Jennings N, Renwick A, Barker N. 2005. Questionnaires in ecology: a review of past use and recommendations for best practice. *Journal of Applied Ecology* 42: 421–430.

Williams BK, Nichols JD, Conroy MJ. 2002. *Analysis and management of animal populations*. Academic Press, San Diego, CA.

Zhou S, Griffiths SP. 2007. Estimating abundance from detection–non-detection data for randomly distributed or aggregated elusive populations. *Ecography* 30: 537–549.