Combining local knowledge and occupancy analysis for a rapid assessment of forest elephants in Cameroon's timber production forests.

Word count: 6673

Stephanie Brittain

Imperial College London, Silwood Park Campus, Buckhurst Road, Sunningdale, SL5 7PY

Current address: Department of Zoology, University of Oxford, New Radcliffe House, Walton Street, Oxford OX2 6AE. Stephanie.brittain@zoo.ox.ac.uk

Madeleine Ngo Bata

Zoological Society of London, Bastos, Yaoundé, Cameroon. Madeleine.Bata@zsl.org

Paul De Ornellas

Africa Conservation Programmes, ZSL London Zoo, Regent's Park, London NW1 4RY. Paul.DeOrnellas@zsl.org

EJ Milner-Gulland

Department of Zoology, University of Oxford, New Radcliffe House, Walton Street, Oxford OX2 6AE. ej.milner-gulland@zoo.ox.ac.uk

Marcus Rowcliffe

Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY marcus.rowcliffe@ioz.ac.uk

Combining local knowledge and occupancy analysis for a rapid assessment of forest elephants in Cameroon's timber production forests.

Abstract

Information on the distribution and abundance of forest elephants must be available in order to appropriately allocate limited resources and set conservation goals. However, monitoring at large scales in forest habitats is complicated, expensive and time consuming. This study explores the potential of applying interview-based occupancy analysis as a tool for the rapid assessment of the distribution and relative abundance of forest elephants (*Loxodonta cyclotis*) in the eastern region of Cameroon.

Models have allowed the covariates that affect occupancy and detectability to be explored and for spatial and temporal patterns in population change and occupancy to be identified. Quantitative and qualitative socio-demographic data provide additional depth and understanding, placing the occupancy analysis in context and providing valuable information to guide conservation action.

Forest elephant detectability has decreased over 6 years, consistent with declining perceived abundance in occupied sites. Forest elephants are occupying areas both outside of protected areas and outside of the current IUCN 'known' elephant range. Critical conservation attention is required to further assess forest elephant populations and threats in these poorly understood areas. We find that that interview-based occupancy analysis is a reliable and suitable method for a rapid assessment of forest elephant occupancy across a large scale, as a complement to, or first stage in, a monitoring process.

Key words

interviews, population monitoring, illegal killing, ivory, logging, Central Africa

Introduction

African forest elephants *(Loxodonta africana cyclotis*) are in danger. Data analysed by the Convention on International Trade in Endangered Species (CITES) Elephant Trade Information System (ETIS) and the Monitoring the Illegal Killing of Elephants (MIKE) programmes demonstrate that the illegal trade of ivory is escalating (Milliken et al. 2009) and that offtake is higher than calculated sustainable levels (CITES, 2015). 2013 was the worst year on record for ivory seizures, with almost 50 tons of ivory seized (Vera et al. 2014). Central Africa remains the sub-region with the highest poaching pressure on the continent (CITES, 2015). While forest elephants are taxonomically and functionally unique, IUCN recognises one species of African elephant *Loxodonta africana*, for which the overall redlist assessment is Vulnerable. Yet, due to the marked geographic variation in threat, a regional assessment lists the central African forest elephant as Endangered (Blanc et al. 2007).

Population status and distribution assessments are required to set goals and measure the effectiveness of management actions (Blanc et al. 2007). Several studies have addressed forest elephant distribution and status (Schuttler et al. 2012; De Boer et al. 2013; Maisels et al. 2013). Yet, due to their cryptic nature, large range within dense forest habitat, and low encounter rates, monitoring their distribution and trends remains a serious challenge (Hedges, 2012). Currently, transect surveys of dung density are the most widely used method. This is arduous and so has been applied to a relatively small part of the species' range, leaving large uncertainties (Barnes, 1997; Blake et al. 2007).

Given these constraints, the scale of forest elephant decline in Central Africa has been difficult to quantify. This lack of information is a key concern for conserving the sub-species (Karanth et al. 2003; Blake & Hedges, 2004; Sutherland et al. 2004; Blake, 2005; Blanc et al. 2007). With 51% of the country's potential range unmonitored, it is vital that Cameroon's forests are surveyed to address this knowledge gap, resolve uncertainty and guide conservation action.

There is great potential for local ecological knowledge to assess forest elephant status and distribution by rapidly gathering data over areas and timescales that cannot be tackled using conventional surveys (Danielsen et al. 2005; Jones et al. 2008; Service et al. 2014; Turvey et al., 2013, 2015; Mohd-Azlan et al. 2013). As local people often frequent large areas that are relatively inaccessible (Service et al. 2014), the likelihood of obtaining species encounter records can be substantially increased by questioning locals, which is especially useful for wide-ranging and elusive species (Service et al. 2014; Turvey, 2013, 2015). Local ecological knowledge can also help to better understand species threats (Abram et al. 2015), resulting in faster decision-making (Danielsen et al. 2010) through increased dialogue (Beland et al. 2013; Mohd-Azlan 2013).

Much published work shows that data collected from local knowledge and conventional methods are comparable (Parry & Peres, 2015; Pan et al. 2015; Daniensen et al. 2005, Turvey et al. 2013, Jones et al. 2008; Meijaard et al. 2011). While all methods are susceptible to biases and uncertainties, it is important to understand these biases to control for them (Jones et al. 2008; Danielsen et al. 2000). Observer and biophysical variables are a concern for most conventional population monitoring methods (Buckland et al. 2001; Nuno et al. 2013; Sethi et al. 2005). Characteristics of observers such as age (Turvey et al, 2010) or experience (Cerqueira et al. 2013) can influence their ability to accurately detect a species. Furthermore, respondent biases, for example driven by social norms, can cause deception or unconscious distortion of responses (Moller et al. 2004). For example, Lunn & Dearden (2006) showed that fishermen may deliberately overestimate their catch, while Moller et al. (2004) found that local people who are adept at finding a species may overestimate its population size if it is considered common.

Heterogeneous habitat type (Tracey et al. 2005), survey time (Cerqueira et al. 2013), seasonality (Blanc et al. 2007), or variations in animal abundance (Royle & Nichols, 2003) can influence the effectiveness of population survey methods by affecting species detectability along gradients that may also influence abundance (Sutherland, 2006). Observer and biophysical variables must therefore be controlled for to reach an unbiased estimate of species distribution and relative abundance.

Occupancy indices are widely used for large-scale monitoring programmes because they are relatively inexpensive and easy to implement compared to estimates of absolute abundance (Royle & Nichols, 2003; Joseph et al. 2006). Occupancy indices also benefit from being able to control for uncertainties associated with detectability, providing unbiased estimates of the likelihood of species presence in time and space (MacKenzie et al. 2006). Occupancy is an estimate of the probability that the species occupies, or uses, a particular sample unit during a specified period of time during which the occupancy state is assumed to be static (Bailey et al. 2004). The maximum likelihood occupancy model allows for both detectability and occupancy to be estimated in a single-model framework by building a detection history (MacKenzie et al. 2002), that potentially includes covariates of occupancy and detectability within the framework (Wintle et al. 2012).

Recently, surveys with local people have been combined with occupancy analysis for the rapid status assessments of multiple species over time (Pillay et al. 2011; D'Souza et al. 2013) and at large spatial scales (Martinez, 2011; Puri et al. 2015). This study combines semi-structured interviews of timber industry employees across Eastern Cameroon (Figure 1) with occupancy analysis to assess large-scale distribution and trends in forest elephant populations over time. We focused on areas classified as 'unknown' by the IUCN African Elephant Database (2012) in order to obtain new information about the range of elephants in these areas (Figure 1).

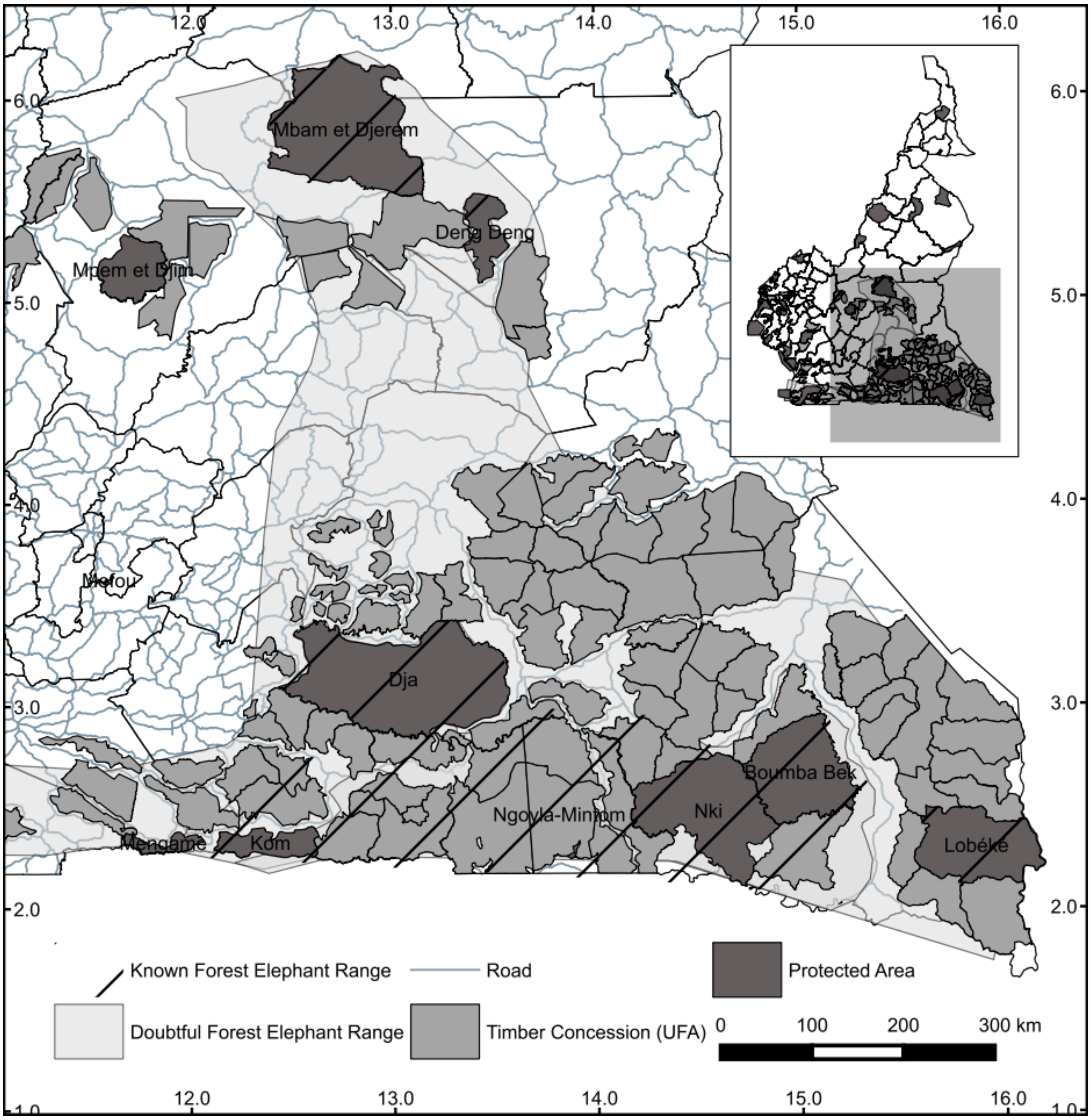


Figure 1. Map of study site: The Eastern Region of Cameroon.

Timber concessions are an important, and under-researched habitat for elephants, comprising 60-80% of the eastern region (Bikie et al. 2000). We aimed to i) assess the distribution and trends in forest elephant populations over six years across 30,000 km^2 of eastern Cameroon using interview-based occupancy analysis, ii) Assess the reliability and suitability of this method of rapid assessment in the context of forest elephants in Africa and iii) Make recommendations for conservation action in the study area.

Methods

Timber concessions are split into Forest Management Units (UFAs), which are well-defined and demarcated areas (FAO, 1997). Each forest management unit (UFA) is divided into 30 Annual Allowable Cuts (AACs), of which one can be exploited each year over the course of 30 years. Sites were defined as AACs as they are familiar to respondents and roughly equal in size (c. 5km^2). Maps of the UFAs were obtained prior to interview and the site's year of exploitation was clearly marked on each map. This enabled the respondents to state in which site they had worked, in what year and if they had or had not seen signs of elephant, helping them to recall fine-scale temporal and spatial data relevant to a particular site.

Interviews were conducted with timber concession workers, villagers and administrative authorities. A targeted, opportunistic sampling strategy was used to select respondents. While the external validity of the data obtained through this strategy is low (Sapsford & Jupp, 1996), the extent of concessions and their potential value as conservation land (Lamb et al. 2005) means that timber concession workers are a valuable source of knowledge.

In order to triangulate the data collected from timber concession workers and to obtain data on incidents of poaching, qualitative interviews were also held with administrative authorities. MINFOF (The Ministry of Forests and Wildlife) is the governmental department responsible for the protection of forested areas and its biodiversity in Cameroon. Chefs de poste (CDP) are theoretically aware of any reported poaching and can therefore give a different perspective on the research questions. Managers of the Department of Fauna, the managers of the eastern region departments and the CDP from MINFOF were interviewed at the regional and departmental level.

The research team designed and administered a simple questionnaire for timber concession workers and authorities from 12th May to 30th June 2013, in order to elicit their observations of elephants over the period 2008 to 2013 (Figure S3). The interviews were designed to be easily replicated and administered, whilst retaining standardisation. The combination of closed and open-ended questions enabled quantitative and qualitative analysis, strengthening the results by drawing on the information gathered from each.

A pared down version of the semi-structured interview used for timber concession workers was used to guide interviews with administrative authorities, skipping to the sections on estimated abundance, distribution and threats in order to collect qualitative data. Informal interviews are normal conversations with individuals or groups of people as they go about their lives (Newing et al., 2011). Informal interviews, composed of open-ended questions were conducted on several occasions to gather qualitative information on forest elephant population changes, threats and attitudes towards elephants. The direction of the conversation was led by the interviewee, with some questions asked by the interviewer to either guide conversation or probe an interesting point. Notes of key points were taken immediately after the conversation so as not to forget the detail of the conversation.

Efforts were made both in the design of the survey and the interview process to minimise or control for respondent bias. For each participating timber concession, an initial meeting was held with the site manager who helped us to identify what teams entered the forest on foot and did not operate machinery, and so had the best chance of spotting and correctly identifying signs of elephant presence. In order to select a subset of the most reliable UFA workers from within the identified teams, focus groups comprising of a series of short questions were used to eliminate unsuitable respondents (Figure S2).

Selected respondents were interviewed individually to prevent audience effect bias. Questions were phrased neutrally to reduce deference effect bias (Newing et al., 2011) and respondents were asked to report on their own experience only. No specific reference to elephants was made at the start of the interview so as to reduce order effect bias and care was taken to use the 'interview funnel' approach (Newing et al., 2011). The reliability of reported detections was validated by asking respondents to repeat both their detection and non-detection responses at the end of the interview and to describe the reported signs to ensure that the species had been correctly identified. If the respondent appeared unsure or gave different responses, the response was removed from analysis.

Occupancy models were constructed with the response variable being whether the interviewee had observed elephants or their sign in a given AAC at any point in the study period. Due to the rotational nature of exploitation within UFAs, repeat data from the same site over different years were not collected frequently enough to conduct multi-season occupancy analysis (MacKenzie et al. 2003). Therefore, single-season occupancy analysis was carried out, by treating each site-by-year combination as a site in the detection matrix. Year could then be included as a covariate in the occupancy analysis to identify trends in detectability and occupancy over time, with a year considered to be the closure period, over which occupancy was assumed to be constant. The study period of 2008-13 was chosen because the volume of reliable data dropped off sharply prior to 2008 (respondents were unsure when asked to repeat their responses at the end of the interview), and the number of respondents who had been in that job long enough reduced meaning that there was not enough data pre-2008 to conduct analysis. Following Martinez (2011), individual interviewees were treated as effective repeat surveys for occupancy analysis. The number of respondents varied greatly between concessions. Although occupancy analysis accounts for missing data, sites with only 1 respondent were discarded from analysis and sites that did not meet the minimum of 4 replicates were treated with caution during analysis and discussion (Mackenzie et al. 2002).

UFA group was included as a factor in analysis, allowing for comparisons of occupancy and detectability between groups (Figure S1). The UFA groups are spatially distinct, separated by well used roads and villages. Data on reported elephant tracks, broken branches, dung, carcasses and direct sightings were included in analysis to build a detection history for each site. Respondents who reported having seen a sign were asked to describe what they saw as a means of verification. Only signs or direct sightings seen by the interviewee were included as sightings related by others were considered hearsay and unreliable for this study.

Owing to the easily identifiable signs of forest elephants and the controls put in place to ensure the reliability of the respondents selected, false positives were not thought to be likely, so were not included in the models. Given the sample unit size relative to elephant home range in this study, occupancy estimates cannot be seen as reflecting probability of long term residence. Rather we interpret occupancy as the proportion of area used (Martinez, 2011; MacKenzie & Royle, 2005).

Maps of site-level occupancy covariates were prepared using ArcGIS 10.0 (ESRI, 2011), while the respondent detectability covariates were obtained from each interview. Pairwise correlations were conducted to examine the independence of variables and eliminate any covariates that were too closely associated to be modelled together. Spearman's rank and Shapiro-Wilk tests checked for normal distribution of the continuous geographic variables. Spearman's correlation coefficient tested the relationship between the non-normally distributed variables. Pearson's correlation coefficient for parametric data were used for the remaining normally distributed variables. There was a strong positive correlation between the detectability variables respondent age and number of trips made to the forest (ρ=0.98) and between the number of years the respondent had worked in the concession and number of trips made to the forest (ρ=0.91; Table S1). The variable 'number of trips' was therefore not included in the models. There were no significant correlations between the covariates for the occupancy part of the model (Table S2). Year of observation and UFA group were included as covariates for both occupancy and detectability to control for UFA-level variation in detectability (MacKenzie, 2006). Other covariates were included based on their hypothesised relationship with occupancy or detectability (Table S3).

Akaike Information Criteria (AIC) (Burnham & Anderson, 2002) was used to identify the best fit-models that account for detectability (ρ), keeping the global model for occupancy (ψ) (Table S4). Then, using the best fit model for p, occupancy was modelled to find the best fit model for both ρ and ψ. The MacKenzie & Bailey (2014) goodness-of-fit bootstrap test was run to evaluate the best-fit model. And for inferences to be drawn to best explain the effect of the covariates on ρ and ψ. All occupancy analysis was conducted in R (R Core Team 2017), using package 'unmarked' package (Fiske & Chandler, 2011).

Change in relative abundance over time was calculated based on the relationship between individual animal detection probability, r, site population size, N, and per-visit detection probability, p, proposed by Royle & Nichols (2003):

$p = 1 - (1 - r)^N$.

Given detection probabilities estimated in years i = 1,2,…6, year specific populations are given by:

$N_i = \log(1-p_i) / \log(1-r)$.

Assuming constant r, population size in year i relative to year 1 is therefore given by:

$N_i / N_1 = \log(1-p_i) / \log(1-p_1)$.

The ethical guidelines offered by the Social Research Association (2003) were followed throughout. The interview team (Stephanie Brittain and Madeleine Ngo Bata) spoke French to ensure accurate communication. Confidentiality and anonymity was guaranteed to all respondents and free, prior, informed consent was obtained. Interviews were recorded if permission was given (>95% of respondents agreed). Where permission to record was not granted, notes were taken and transcribed immediately post interview. Due to the sensitive nature of the topic, no-one was asked if they had taken part in any illegal activities.

Pilot study

A pilot study (4th -11th May 2013) involved trialing the methodologies and sampling strategy, aiming to make any necessary adjustments to the approach and assess the reliability of the responses. The pilot study was conducted in a timber concession where prior robust data on elephant presence was available.

Results

Of the 182 respondents originally interviewed, 161 were timber concession workers, 16 were administrative authorities and 5 informal interviews were conducted with researchers, poachers and hunting zone owners. Prior to analysis, 7 timber concession workers (4%) were deemed unreliable and were removed, leaving a total of 175 respondents, of which 154 were timber concession workers, 16 were administrative authorities and 5 were informal interviews.

Survey responses suggested that interviewees were likely to be able to distinguish elephant signs in the field; 96% of respondents were raised in rural villages and 76% felt they owed their knowledge of animal signs to their fathers or upbringing. Respondents gave information about elephant observations in 342 sites within 34 UFAs. The number of respondents per site visit ranged from 1 to 25 per site, with a mean of 4.82. Figure 2 shows the naïve distribution of detections and non-detections, suggesting that forest elephant range extends further north and east of the current IUCN known elephant range. There is a higher proportion of sites with reported detections in the South-West and South-East UFA groups than in the Central and North groups.

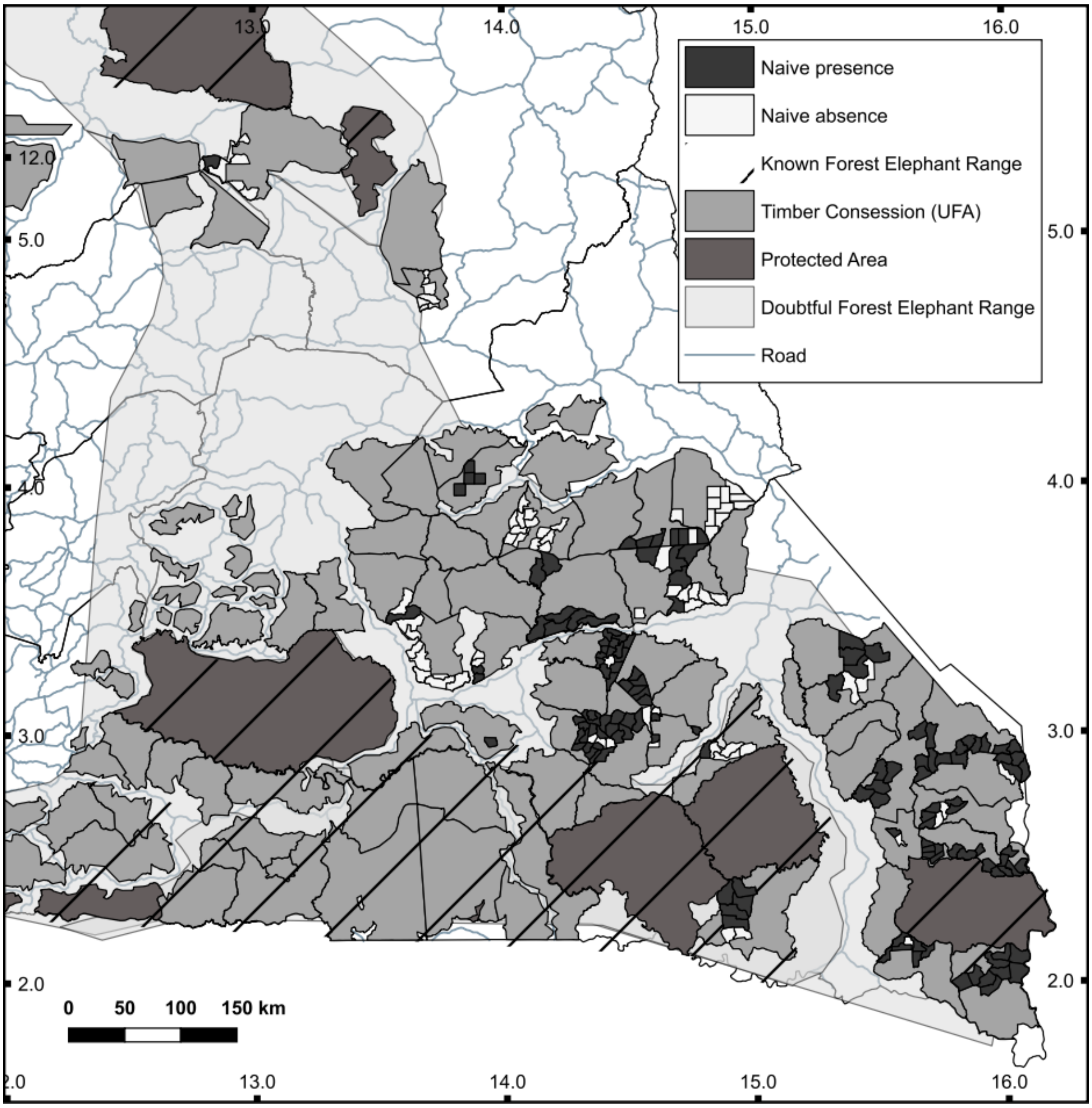


Figure 2. Distribution of sites with reported naïve presence and absence.

The null model, assuming constant occupancy and detectability, estimated occupancy (Ψ; probability that a given site was used by elephants) as 0.76, and detectability (*p*; probability that use of a UFA by elephants would be detected by a respondent) at 0.58 (Table S6).

The most parsimonious model with covariates that best described occupancy and detectability included, for detectability, the number of nights that the respondent camped in the forest when working, the number of years they had worked in the concession, the UFA group and year (Table 2). The occupancy variables included were the distance of the village from the centre of each AAC, the AAC's distance from the nearest river and road, and its elevation, as well as the UFA group. A goodness-of-fit test found no significant lack of fit (p=0.8).

Table 2: Summary of best fitting models with an ΔAIC of <4.

MODEL	AIC	ΔAIC	WI	Ψ SE	p SE
p(C+YW+G+Y) Ψ (V+Ri+Ro+E+G)	1349.16	0.00	24%	0.73	0.42
p(C+YW+G+Y) Ψ(V+Ri+Ro+E+S+G)	1349.57	0.41	20%	0.7	0.4
p(C+YW+G+Y) Ψ(V+Ri+Ro+E+S)	1350.16	1.00	15%	0.29	0.35
p(C+YW+G+Y) Ψ (V+Ri+Ro+E)	1350.24	1.08	14%	0.28	0.36
p(C+YW+G+Y) Ψ(V+Ri+Ro+S)	1350.29	1.14	14%	0.3	0.35
p(C+YW+G+Y) Ψ(T+V+Ri+Ro+S)	1350.34	1.19	13%	0.3	0.35

KEY TO SYMBOLS

AIC: Akaike Information Criterion

ΔAIC: Akaike difference

Ψ: probability of occupancy, p: probability of detection

C: Nights Camped, YW: Years Worked, G: UFA Group, Y: Year T: Distance from Towns, V: Distance from Village, Ri: Distance from River, Ro: Distance from Road, E: Elevation, S: Slope

W_i: Akaike model weight

Occupancy was not strongly affected by any of the explanatory variables, but as expected (Table S4), it was higher in areas further from villages and roads, and closer to rivers. It did not vary significantly between UFA groups. Detectability, however, had a number of strong associations, including that those who camped for up to a week at a time in the forest were more likely to detect elephants than those who didn't camp, or who camped for longer; that the detectability was much higher in the south-west and south-east UFA groups, and that there was a strong and consistent decline in detectability over time (Table 1). In this study, all sites share the same forest environment; therefore, any spatial variation in the ability to detect the species cannot be explained by changes in habitat type and visibility. The same measures are put in place in each concession to assure the reliability and quality of respondents and the competence of the individual to detect signs is controlled for in the model. Therefore, we do not expect that spatiotemporal changes in detectability are due to spatial or temporal variations in the responders' ability to detect elephants. In that case, it is likely that variation in the detectability of forest elephants is a valid proxy for variation in abundance, rather than variation in an ability to detect elephant signs. Site-level detectability, therefore, may be a signal of the relative abundance of elephants in occupied sites, suggesting that elephants are more abundant in the south-west and south-east UFA groups than elsewhere (Figure S1), but that abundance may be decreasing over time in the study site as a whole (Table 1, Fig 3).

Table 1: Beta summary of best fitting model p(C+YW+G+Y) Ψ (V+Ri+Ro+E+G) with detectability and occupancy covariates.

OCCUPANCY ψ	Estimate	SE	Z	P(>|z|)
Intercept (G = Central)	2.47	0.65	3.82	< 0.001
Distance from village (V)	0.80	0.31	2.47	0.06
Distance from road(Ro)	0.94	0.49	2.37	0.02
Distance from river(Ri)	-0.48	0.22	2.30	0.03
Elevation (E)	-1.06	0.49	1.64	0.02
UFA group (G contrast SW)	0.74	0.72	1.01	0.31
UFA group (G contrast SE)	-1.4	1.05	1.26	0.17
UFA group (G contrast N)	-3.75	2.16	1.91	0.07

DETECTION p				
Intercept (C= >8 nights, YW=>10 years, G=Central, Y=2008)	0.98	0.36	2.70	0.006
Nights camped (C contrast 1-7)	-1.16	0.22	4.97	< 0.001
Years worked (YW contrast <10)	-0.09	0.16	0.60	0.54
UFA group (G contrast SW)	0.745	0.20	4.00	0.00
UFA group (G contrast SE)	2.34	0.18	12.73	0.00
UFA group (G contrast N)	-0.84	1.63	1.20	0.61
Year (Y contrast 2009)	-0.77	0.41	1.93	0.06
Year (Y contrast 2010)	-0.86	0.38	2.37	0.02
Year (Y contrast 2011)	-1.02	0.36	2.86	0.01
Year (Y contrast 2012)	-1.28	0.35	3.73	0.00
Year (Y contrast 2013)	-1.07	0.36	3.06	0.003

Detectability reduced by about 30% between 2008 and 2013, which can be translated into a potential reduction in relative abundance of around 40% (Figure 3).

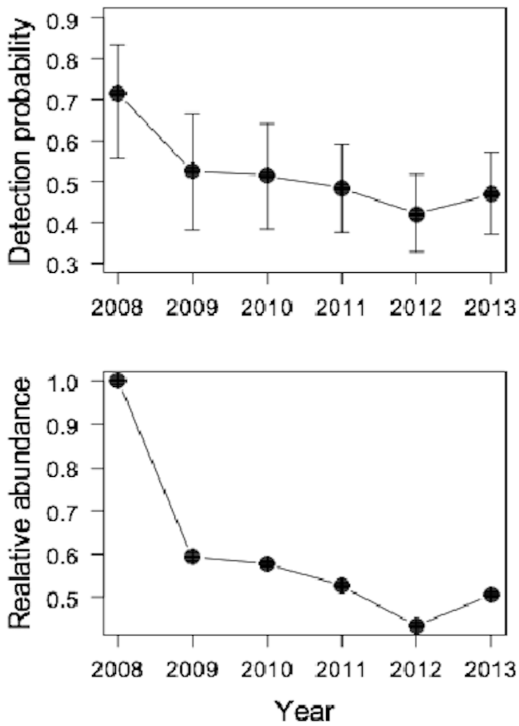


Figure 3: Changes in forest elephant detection probability and relative abundance from 2008 to 2013

Although the model shows no significant different in occupancy related to the UFA groups, there is a significant difference in detectability between the UFA groups. The histograms shown in Fig. 4 indicate that the CL's are wide for occupancy, which is why the difference in occupancy is not significant. In contrast, the CL's for detectability are narrow for the Central, South-West and South-East UFA groups, and there is a significant different in detectability between the UFA groups. However, the CL's for detectability in the North UFA group are as large as those for occupancy. This may be due to the small sample size obtained from these sites, therefore the interpretation of data from the North UFA group should be treated with caution.

Administrative authorities and timber concession workers reported that elephants move around within the UFAs to distance themselves from the noise of exploitation (also found to be an issue by Bowles et al. 1994; Richardson et al. 1995) and villages (Buji et al. 2007; De Boer et al. 2013). However, elephants were said not to move out of the UFA's due to proximity with villages, and major roads that separate the UFA groups, particularly in the central and northern areas where sites of high predicted occupancy are much more isolated than in the more southerly regions (Figure 4).

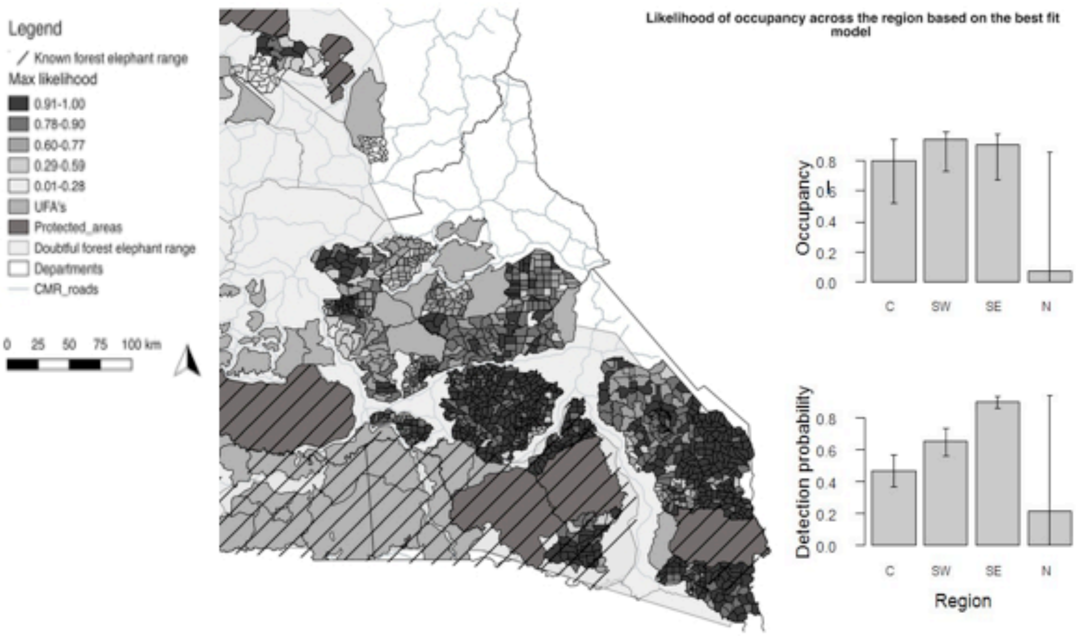


Figure 4: Likelihood of occupancy across the Eastern Region, based on the more parsimonious model shown in table 1

Discussion

While most of the detectability covariates relate to the ability of the respondent to notice and recall signs of elephant, the UFA group and year provide insights into abundance in occupied sites. The data show a decline in detectability due to a decline in detections over the course of 6 years. All sites share the same environment, activity level and level of visibility and observer variables are controlled for in the model.

While responder recall must be considered when using data over long periods of time, with the survey design and cross-checking of responses put into place, we do not believe recall to be a significant contributor to temporal changes in detectability. It is perhaps more sensible to conclude that the declining detectability over 6 years suggests a decline in abundance, supported by qualitative reports of a perceived decline in elephant abundance across the whole region, and reports of increased elephant poaching. Our estimates of occupancy and detectability from the null-model ($\Psi = 0.76 \pm 0.03$, $p = 0.59 \pm 0.01$; Table S6) are comparable with those of Martinez (2011) in neighbouring Equatorial Guinea ($\Psi = 0.44 \pm 0.03$, $p = 0.86 \pm 0.01$). The pattern of declining relative abundance is consistent with the findings of Maisels et al. (2013), and also with the latest figures released by the CITES MIKE project, showing the estimated proportion of elephants which were illegally killed in Central Africa has remained consistently above the sustainable level over the study period (CITES, 2014). It is also interesting that the only sites with a likelihood of occupancy of >0.6 in the Northern UFA group are adjacent to the Mbam & Djerem National Park (Figure 4), suggesting that elephant populations living in Mbam & Djerem may be using the north of the timber concession as a corridor for access to Deng Deng National Park (see Figure S1 for National Park locations). The same pattern of elevated likelihood of use in sites adjacent to Boumba Bek National Park can also be seen in the South West group.

This study has addressed a major knowledge gap concerning elephant distribution across a large region of previously unsurveyed timber production forest. We find that forest elephant range extends further north and east of the 2012 known elephant range (shown in figure 2), extending into areas deemed ‘unlikely’ by the IUCN. Therefore, we recommend that current IUCN known elephant range be extended and that further surveys are conducted in timber concessions where elephants have been detected. In particular, sites adjacent to protected areas are potentially of high conservation value, therefore it is important to work closely with timber concession companies to develop sustainable logging approaches and anti-poaching activities that will help to protect forest elephants in their sites.

High levels of occupancy throughout the South East and South West UFA groups, and high likelihood of occupancy in sites adjacent to National Parks (as also suggested by Lamb et al. 2005) in the north, supports the suggestion that well-managed timber concessions can provide refuge to forest elephants in an otherwise insecure landscape (Weinbaum et al. 2007; Clark et al. 2009; Kolowski, 2010; Stokes et al. 2010). However, the emphasis on ‘well-managed’ means that additional support should be provided to concessions with a high likelihood of occupancy to improve their sustainability practices and ensure that they can continue to operate in a manner that minimizes the impact on remaining elephant populations.

Despite the high levels of occupancy in some sites, the detectability (and therefore relative abundance) is low in comparison to that observed elsewhere (Martinez, 2011), possibly indicating relatively low abundance in occupied sites, and further highlighting the importance of conservation action in these sites. For example, our findings suggest that it would be useful to carry out a more detailed survey in key concession units around protected areas in the north, which appear to be acting as de facto corridors. Such surveys could inform actions to develop more formal corridors to ensure the sustainability of these populations, which currently appear to be isolated and potentially unviable in the longer term.

The informal interviews and open-ended questions carried out highlighted some key issues, in particular the high financial value of ivory, the lack of comparable alternative livelihoods in the face of growing international demand, the lack of law enforcement and high levels of corruption, (see Supplementary Figure S4 for quotes from respondents).

Sampling in this rapid assessment was limited to sites where timber concession workers had been prospecting or exploiting, meaning that: a) the sites mostly changed each year as each site represented an area of annual exploitation, and b) the impacts of exploitation could not be explored as variation in exploitation category (pre/during/post exploitation) was not available. Applying this approach in situations where respondents' spatial frames of reference are more spatially stable would be desirable in order to support multi-season occupancy modelling (Royle & Kery 2007), potentially allowing a more sophisticated analysis of the dynamics of occupancy over time.

Occupancy estimates are generally in line with the observed detection histories and with perceived abundance. However, there are areas where the occupancy predictions do not match actual observations. Areas of underrepresentation within the detection/non-detection data may be an influencing factor. Alternatively, heterogeneity caused by incomplete overlap between home range and site may influence the probability of detecting an individual, as does the number of elephants within each plot. As a result, the relationship between the distribution of sampling effort and elephant home ranges may account for some variation between the naïve pattern and the predicted occupancy (Efford & Dawson, 2012).

Despite these potential sources of uncertainty, our study suggests that interview-based occupancy analysis is a reliable method for the rapid assessment of forest elephant occupancy at large spatiotemporal scales and in challenging forest habitat, as a complement to, or first stage in, a monitoring process (Meijaard et al. 2011). This method allowed us to gain new insights into the distribution and trends in forest elephant populations at a large scale, effectively surveying c.30,000km^2 to be surveyed in just 10 weeks on a budget of only £2000, providing extremely good value for money. It also produced contextual qualitative insights data, providing a socio-demographic context that can inform subsequent conservation planning.

This approach is best suited to surveying large, remote areas that potential informants visit on a regular basis, for poorly known but easily recognisable species (Meijaard et al. 2011). Several authors (e.g. Pan et al 2015; Nash et al 2016) have used sightings by local people to infer changes in presence or abundance of species with these characteristics. However, the addition of an occupancy modelling framework to structure and analyse observational datasets allows much more robust inferences to be drawn; specifically about detection corrected occupancy, its covariates (such as geographical factors), and, through spatio-temporal changes in detectability, trends in relative abundance. The additional requirements for using an occupancy approach are not onerous, including collecting information about potential observer effects (such as time spent in the forest), and biophysical variables, ensuring at least 4 repeat observations per sampling unit, and choosing sample units that are familiar to the respondents in order to collect spatially accurate data.

Acknowledgements

The authors thank ZSL Cameroon for their assistance during data collection, and Imperial College London for financial support. The work was supported by a NERC-CASE studentship to SB. Datasets are available on application to the first author.

Author contributions

SB and MNB collected the data. SB designed the study and conducted analysis with guidance from MR and PD. SB led the publication of the article with support and editing from EJMG, MC and input from whole team.

References

Bailey, L.L., Simons, T. R. & Pollock, K. H. (2004) Estimating Site Occupancy and Species Detection Probability Parameters for Terrestrial Salamanders. *Ecological Applications.* 14(3), 692–702.

Barnes, R.F.W., Beardsley, K., Michelmore, F., Barnes, K. L., Alers, M.P.T. & Blom A. (1997) Estimating Forest Elephant Numbers with Dung Counts and a Geographic Information System. *The Journal of Wildlife Management*. 61(4), 1384-1393.

Barnes, R., Asamoah-Boenteng, B., Naada Majam, L. & Agyei-Ohemeng, J. (1997) Rainfall and the population dynamics of elephant dung piles in the forests of southern Ghana. *African Journal of Ecology*, 35(1), 39–52.

Bikie, H., Collomb, J.G., Djomo, L., Minnemeyer, S., Ngoufo, R. & Nguiffo, S. (2000) *An Overview of Logging in Cameroon. A Global Forest Watch Cameroon Report.* World Resources Institute

Blake, S. (2002) The ecology of forest elephant distribution and its implications for conservation. A thesis submitted for the degree of PhD. University of Edinburgh.

Blake, S. (2005) *Central African forests: final report on population surveys (2003 - 2004)*. CITES

Blake S, Strindberg S, Boudjan P, Makombo C, Bila-Isia I, et al. (2007) Forest Elephant Crisis in the Congo Basin. *PLOS Biology* 5(4)

Blake S, Deem SL, Strindberg S, Maisels F, Momont L, et al. (2008) Roadless Wilderness Area Determines Forest Elephant Movements in the Congo Basin. *PLOS ONE* 3(10)

Blake, S. & Hedges, S. (2004) Sinking the Flagship: The Case of Forest Elephants in Asia and Africa. *Conservation Biology*. 18: 1191–1202.

Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.T., Thouless, C.R., Douglas-Hamilton, I. & Hart., J.A. (2007). *African elephant status report. An update from the African elephant database.* Occasional Paper Series of the IUCN Species Survival Commission. Report number 33.

Buij, R., McShea, W.J., Campbell, P., Lee, M.E., Dallmeier, F., Guimondou, S., Mackaga, L., Guisseougou, N., Mboumba, S., Hines, J.E., Nichols, J.D. & Alonso, A. (2007) Patch-occupancy models indicate human activity as major determinant of forest elephant *Loxodonta cyclotis* seasonal distribution in an industrial corridor in Gabon. *Biological*

Conservation. 135(2), 189–201.

Burnham, K.P. & Anderson, D.R. (2002) *Model selection and multimodel inference: a practical information-theoretic approach.* Second edition. New York, New York, USA Springer-Verlag.

Clark C.J, Poulsen, J., Malonga, R. & Elkan, P. (2009) Logging Concessions Can Extend the Conservation Estate for Central African Tropical Forests. *Conservation Biology.* 23(5), 1281–1293.

CITES (2015). Monitoring the Illegal Killing of Elephants: An Update on Elephant Poaching Trends in Africa to 31 December 2015. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Monitoring the Illegal Killing of Elephants. https://cites.org/sites/default/files/eng/prog/MIKE/reports/MIKE_trend_update_2015.pdfD'Souza, E., Patankar, V., Arthur, R., Alcoverro, T. & Kelkar, N. (2013) Long-term occupancy trends in a data-poor dugong population in the Andaman and Nicobar archipelago. *PloS One*. 8(10): e76181. https://doi.org/10.1371/journal.pone.0076181

Danielsen, F., Balete D.S., Poussen, M.K., Enghoff M., Nozawka C.M. & Jensen, A.E. (2000) A simple system for monitoring biodiversity in protected areas of a developing country. *Biodiversity and Conservation.* 9(12), 1671-1705.

Danielsen, F., Burgess, N. & Balmford, A. (2005) Monitoring matters: examining the potential of locally-based approaches. *Biodiversity and Conservation*. 14(11), 2507–2542

Danielsen, F., Burgess, N.D., Jensen, P.M. & Pirhofer-Walzl, K. (2010). Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples' involvement. *Journal of Applied Ecology*. 47(6),1166–1168

De Boer, W.F., Langevelde, F.V., Prins, H.H.T., de Ruiter, P.C., Blanc, J., Vis, M.J.P., Gaston, K.J. & Douglas-Hamilton, D. (2013) Understanding spatial differences in African elephant densities and occurrence, a continent-wide analysis. *Biological Conservation*. 159, 468–476

Douglas-Hamilton, I., Krink, T. & Vollrath, F. (2005) Movements and corridors of African elephants in relation to protected areas. *Die Naturwissenschaften*. 92(4), 158–63

ESRI (2011) ArcGIS Desktop: Release 10

Fiske, I. & Chandler, R. (2011) Unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance, 1–23.

Hedges, S. (ed.) (2012) *Monitoring Elephant Populations and Assessing Threats. A manual for researchers, managers and conservationists*. Hyderabad, University Press.

IUCN 2012. *The IUCN Red List of Threatened Species. Version 2012-1*. <http://www.iucnredlist.org>.

IUCN/Species Survival Commission (2008) *Strategic planning for species conservation: A handbook.* Version 1.0

IUCN/Species Survival Commission (2013) *African Elephant Specialist Group Database*. http://www.elephantdatabase.org/

Jones, J.P.G., Andriamarovololona, M.M., Hockley, N., Gibbons, J.M. & Milner-Gulland, E.J. (2008) Testing the use of interviews as a tool for monitoring trends in the harvesting of wild species. *Journal of Applied Ecology*. 45(4), 1205–1212.

Joseph, L.N., Field, S.A., Wilcox, C. & Possingham, H.P. (2006) Presence-absence versus abundance data for monitoring threatened species. *Conservation Biology*. 20(6), 1679–87

Karanth, K.U., Nichols, J. D., Seidensticker, J., Dinerstein, E., Smith, J.L.D., McDougal, C., Johnsingh, A.J.T., Chundawat, R.S. & Thapar, V. (2003) Science deficiency in conservation practice: the monitoring of tiger populations in India. *Animal Conservation.* 6(2), 141–146.

MacKenzie, D.I. (2006) Modelling the Probability of Resource Use: The effect of, and dealing with, detecting a species imperfectly. *Journal of Wildlife Management.* 70(2), 367–374

MacKenzie, D.I. & Bailey, L.L. (2014) Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics,* 9, 300–18.

MacKenzie, D., Nichols, J., Lachman, G., Droege, S., Royle, A., & Langtimm, C. (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology,* 83(8), 2248–2255.

MacKenzie, D.I., Nichols, J.D., Hines, J.E., Knutson, M.G., & Franklin, A.D. (2003) Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. *Ecology*. 84(8), 2200–2207.

MacKenzie, D.I. & Nichols, J.D. (2004) Occupancy as a surrogate for abundance estimation. *Animal Biodiversity and Conservation*. 1(27),461–467.

MacKenzie, D.I. & Royle, J.A. (2005) Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology*. 42(6),1105–1114

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L., Hines, J. E. (2006). Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence. Academic Press, Burlington, MA, USA.

MacKenzie, D. I., Nichols, J. D., Seamans, M. E., Gutiérrez, R. J. (2009). Modeling species occurrence dynamics with multiple states and imperfect detection. *Ecology*, 90(3), 823–35.

Maisels F, Strindberg S, Blake S, Wittemyer G, Hart J, et al. (2013) Devastating Decline of Forest Elephants in Central Africa. *PLOS ONE* 8(3): e59469.https://doi.org/10.1371/journal.pone.0059469

Martinez Marti, C. (2011). *The leopard (Panthera pardus) and the golden cat (Caracal aurata) in Equatorial Guinea: A national assessment of status, distribution and threat.* Annual Report April 2010 to March 2011. Conservation International.

Meijaard E, Mengersen K, Buchori D, Nurcahyo A, Ancrenaz M, et al. (2011) Why Don't We Ask? A Complementary Method for Assessing the Status of Great Apes. *PLOS ONE* 6(3): e18008. https://doi.org/10.1371/journal.pone.0018008

Newing, H., Eagle, C.M., Puri, R.K. & Watson, C.W. (2011) *Constructing research in conservation: A Social Science Perspective.* Oxon, Routledge.

Pillay, R., Johnsingh, A.J.T., Raghunath, R. & Madhusudan, M.D. (2011) Patterns of spatiotemporal change in large mammal distribution and abundance in the southern Western Ghats, India. *Biological Conservation*. 144(5), 1567–1576.

Puri, M., Srivathsa, A., Karanth, K. K., Kumar, N. S., & Karanth, K. U. (2015). Multiscale distribution models for conserving widespread species: The case of sloth bear *Melursus* *ursinus* in India. *Diversity and Distributions*, *21*(9), 1087–1100. https://doi.org/10.1111/ddi.12335

Richardson, W.J., Greene Jr, C.R., Malme, C.I. & Thomson, D.H. (1995). *Marine Mammals and Noise*. San Diego, CA, USA. Academic Press.

Royle, J.A., & Nichols, J. (2003) Estimating abundance from repeated presence-absence. *Ecology,* 84(3), 777–790.

Royle, J. A. & M. Kéry, M. (2007). A Bayesian state-space formulation of dynamic occupancy models. *Ecology*, 88, 1813-1823.

Sapsford, R & Jupp, V. (eds) (1996) *Data Collection and Analysis*. London: Sage.

Schuttler, S.G., Blake, S. & Eggert, L.S. (2012) Movement Patterns and Spatial Relationships Among African Forest Elephants. *Biotropica*, 44(4), 445–448

Service, C.N., Adams, M.S., Artelle, K.A., Paquet, P. & Grant, L.V. (2014) Indigenous Knowledge and Science Unite to Reveal Spatial and Temporal Dimensions of Distributional Shift in Wildlife of Conservation Concern. *PLoS ONE.* 9(7): e101595.

Sethi, G., Costello, C., Fisher, A., Hanemann, M. & Karp, L. (2005) Fishery management under multiple uncertainty. *Journal of Environmental Economics and Management*. 50(20), 300–318.

Social Research Association (2003). *Ethical Guidelines, 2003.* www.the-sra.org.uk

Stokes, E.J., Strindberg, S., Bakabana, P.C., Elkan, P.W. & Iyenguet, F.C. (2010) Monitoring great ape and elephant abundance at large spatial scales: measuring effectiveness of a conservation landscape. *PLoS One.* 5(4): e10294. https://doi.org/10.1371/journal.pone.0010294

Sutherland, W.J., Pullin, A.S., Dolman, P.M. & Knight, T.M. (2004) The need for evidence-based conversation. *Trends in Ecology and Evolution*. 19(6), 305–308.

Sutherland, W.J. (2006) *Ecological Census Techniques: A Handbook*. 2nd ed. Cambridge, University Press Cambridge

Turvey, S.T., Barrett, L.A., Yuliang, H, Lei, Z., Xinqiao, Z., Xianyan, W., Yadong, H., Kaiya, Z., Hart, T. & Ding, W. (2010) Rapidly Shifting Baselines in Yangtze Fishing Communities and Local Memory of Extinct Species. *Conservation Biology*. 24(3), 778–787

Turvey, S.T., Risley, C.L., Moore, J.E., Barrett, L.A., Yujiang, H., Xiujiang, Z. & Ding, W. (2013) Can local ecological knowledge be used to assess status and extinction drivers in a threatened freshwater cetacean? *Biological Conservation*. 157, 352–360.

Turvey, S.T., Trung, C.T., Quyet, V.D., Nhu, H.V, Thoai, D.V, Tuan, V.C.A. & Wilkinson, N.M. (2015) Interview-based sighting histories can inform regional conservation prioritization for highly threatened cryptic species. *The Journal of Applied Ecology*. 52(2),422–433.

Walsh, P.D., Thibault, M., Mihindou, Y., Idiata, D., Mbina, C. & White, L.J.T. (2000) A Statistical Framework for Monitoring Forest Elephants. *Natural Resource Modelling.* 13(10), 89-134.

Wintle, B.A., Walshe, T.V., Parris, K.M. & McCarthy, M.A. (2012) Designing occupancy surveys and interpreting non-detection when observations are imperfect. *Diversity and Distributions*, 18(4),417–424.

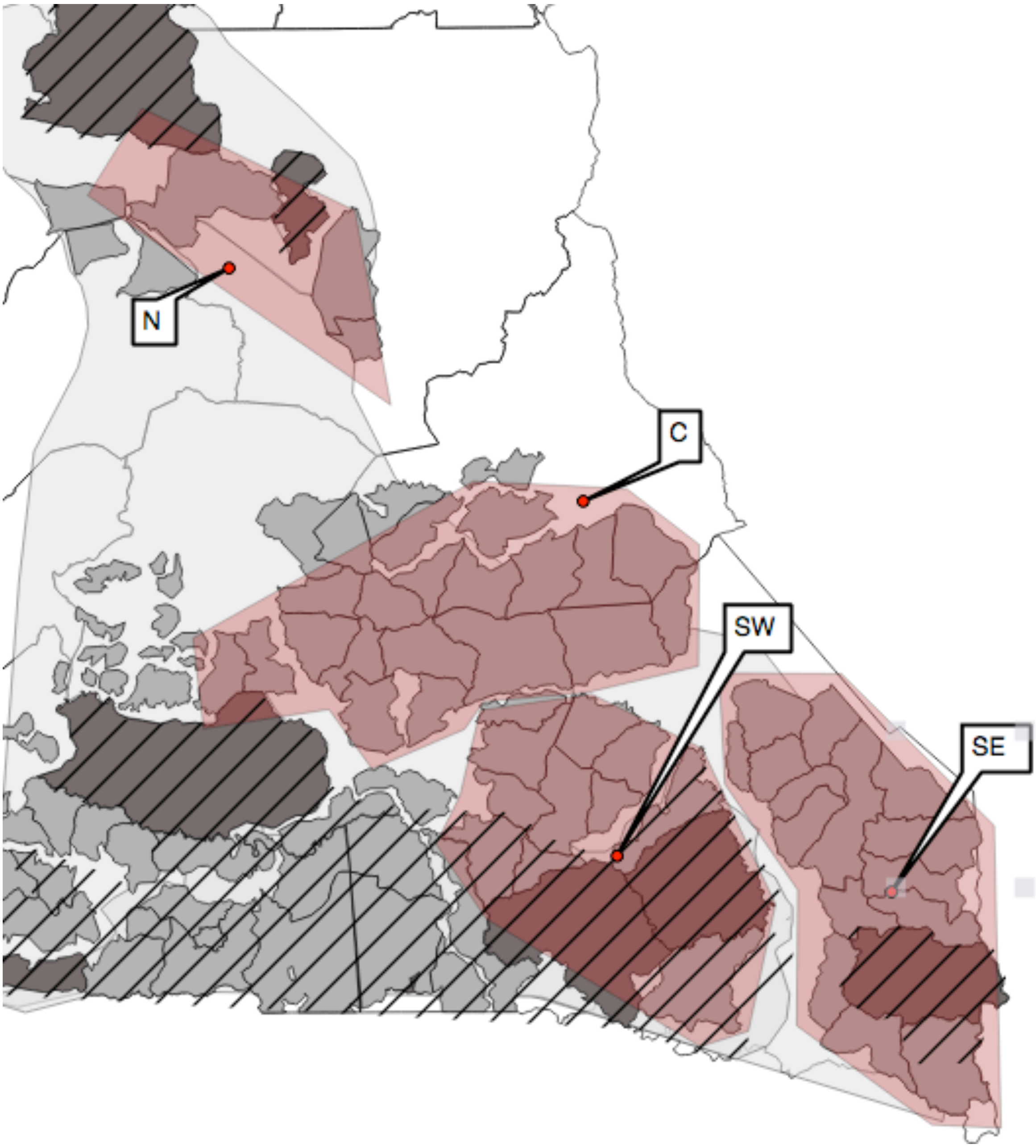
Yackulic, C.B., Strindberg, S., Maisels, F. & Blake, S. (2011) The spatial structure of hunter access determines the local abundance of forest elephants (*Loxodonta africana cyclotis*). Ecological Applications 21(4), 1296–1307.

BIOGRAPHICAL SKETCHES

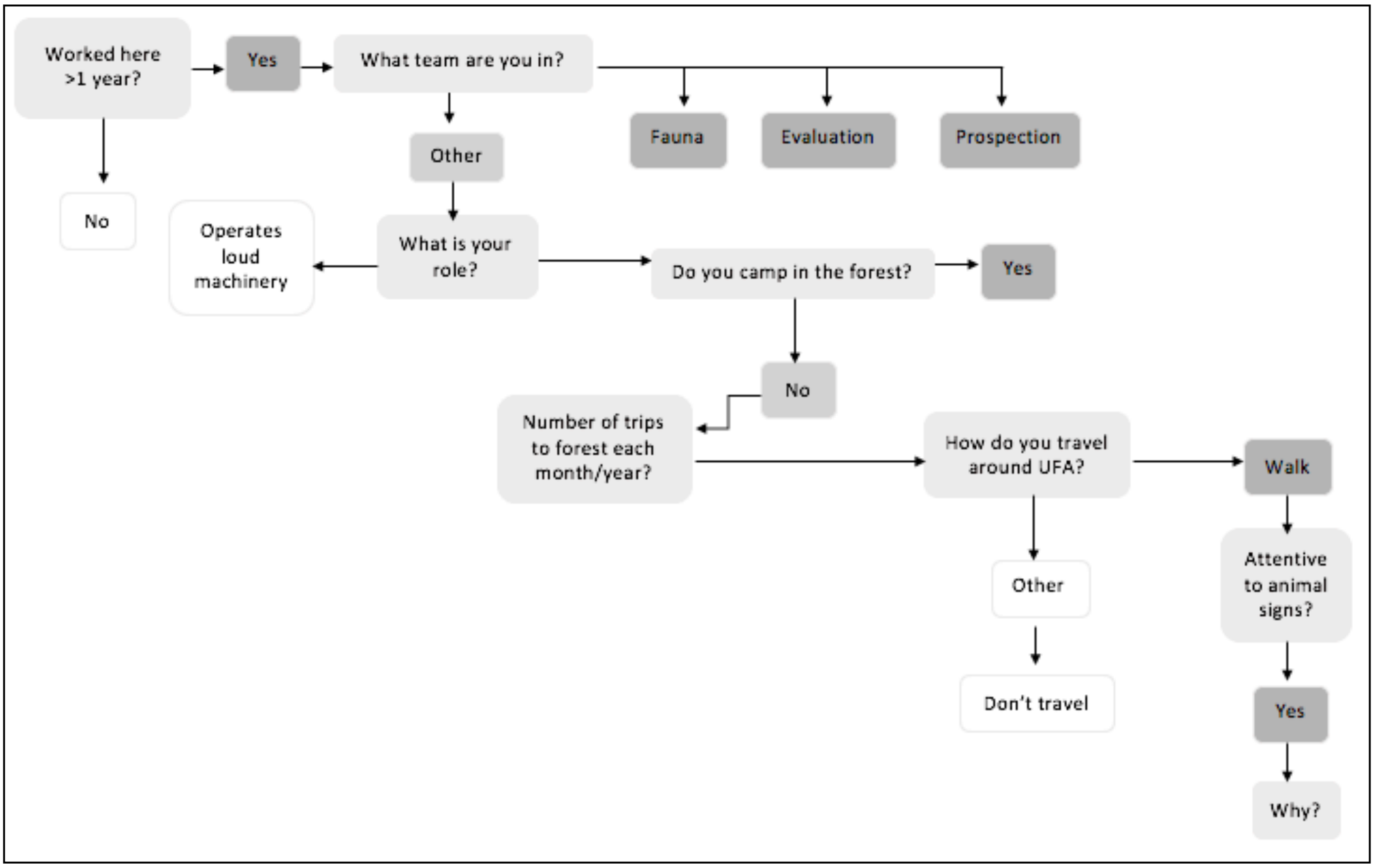
Stephanie Brittain's research interests lie in the use of local knowledge for wildlife population monitoring. Madeleine Ngo Bata monitors threatened species in timber forest concessions in Cameroon. Paul DeOrnellas focusses on the illegal wildlife trade, and improvement of monitoring within reserve across Africa. Professor E.J. Milner-Gulland has a broad range of interests in interdisciplinary conservation science; her website is at www.iccs.org.uk. Dr Marcus Rowcliffe is a conservation scientist interested in improving methods for the monitoring of elusive and threatened species.

SUPPLEMENTARY MATERIAL

Supplementary Figure S1 Map displaying UFA's visited and UFA groups (North (N), Central (C), South West (SW), South East (SE)



Supplementary Figure S2: Responder selection process flow chart



Supplementary Figure S3: semi structured interview

Basic information

Age: 16-26 ☐ 27-37☐ 38-48 ☐ 49-59☐ 60+ ☐

Gender: Male☐ Female☐

Where were you born? Urban ☐ rural ☐
Team :

Job position:

What tasks does that involve? (Chainsaw operator/truck driver etc.)

Detectability

How long have you worked here? < 1year ☐ 1-5 years ☐ 6-10 years ☐ >11 years ☐

How many trips do you make into the forest?

4 trips/week☐ 2 4 trips a week☐ 1-2 trips a week☐ 1 2 trips a month☐

1 2 trips a year☐ 0 trips☐

Do you camp in the forest? Yes ☐ No ☐

How many nights do you spend in the forest when working?

0 ☐ 1-7 ☐ 8-14 ☐ 15+ ☐

Are you attentive to animal signs when you see them? Always ☐ Sometimes☐ Rarely ☐

Occupancy

Have you ever seen an elephant or sign of an elephant? Yes ☐ No ☐

What sign(s) did you see? Describe it to me.

Foot prints ☐ dung ☐ actual sighting ☐ heard one ☐

carcass ☐ reports from others☐ other (please state)

In what AAC did you see it in?

What year was this in?

What time of year did you see this (Wet/Dry season)

Was the AAC; active ☐ being prepared ☐ post evaluation ☐

Supplementary Figure S4: Key quotes from informal and semi structured interviews

Poaching forest elephants for their ivory can be very financially rewarding, and therefore worth the risk:

"Elephant poaching has become harder, but they do it anyway. You have to be secretive or get arrested. All of the elephant is worth money, the meat, the skin, and the tusk" (Anon, Timber concession worker)

"Alternatives how? People look to get rich quick. Even 30 days of work doesn't match the price of ivory…alternatives don't work" ((Anon, Authority)

There is a perceived lack of alternatives in the face of the high value of ivory:

"I like my work… I have 13 kids; this allows them all to go to school. XXX offered me work but for how much? I prefer poaching" (Poacher)

"People like elephants because their tusks are worth something. There is no emotional attachment to elephants. If there are no more elephants, people will be sad because there is no more ivory" (Anon, Authority)

"I like elephants, but we can't kill them anymore. People have stopped killing them only because it is illegal…If elephants disappear, people will be a bit sad But, as elephant meat is illegal I don't see why people will regret the loss of the species," (Anon, Timber concession worker)

"We need to protect elephants for our forests. Elephants are important for other animals too… and move seeds around the forest… Without them our forests wouldn't be the same" (Anon, Timber concession worker)

"… When we go to the CDP, he says no to culling. People are frustrated… opinions of elephants have gone down because of this" (Anon, Timber concession worker)

International markets and growing demand is perceived to be having a growing impact on forest elephant poaching in Cameroon:

"… opening up of Africa to the Asian market, the price of Ivory has gone up and led to an increase in poaching. They say they are doing research for mineral exploitation, or they are here for pangolin scales… they hide behind that to illegally trade Ivory" (Anon, Authority)

"…I remember in 2008/2010 a kilo of ivory cost 40,000…But in 2011-2013 it rose to 120-140,000 the kilo… At first, it was people within the Cameroonian administration…Since then it's the Asians who lead it, who say, 'we are in need of ivory, import as much as you can'… (Anon, Authority)

Lack of law enforcement and high levels of corruption mean that much of the poaching is perceived to be driven by government officials, or permitted to happen:

"Gendarmes are involved, the CDP is implicated, everyone is implicated " (Anon, Authority)

"It's always the generals, the ministers, the CDP that are behind it and involved. It's them that are behind the poaching. There are road blocks and yet no one gets stopped. There is a lot of money to be made from it…" (Anon, TCW 10-030)

"…the authorities use local people, Baka's especially, to go and find them elephants and poach them… What can I say…people capitalize on their positions of power to their advantage. On top of their salary, they can make a lot more by poaching elephants (Anon, Authority)"

The price of ivory and the level of poverty in the region mean that alternatives to poaching are perceived to be lacking and a lack of desire to protect elephants further reflects the sentiment. Although some stat that they didn't want to lose the species for future generations, overall the feeling was that elephants are of financial worth, and are a fast source of large sums of money.

"People like elephants because their tusks are worth something. There is no emotional attachment to elephants. If there are no more elephants, people will be sad because there is no more ivory"

The influence of international markets was regularly cited by authorities as a key force behind poaching across the region:

"… opening up of Africa to the Asian market, the price of Ivory has gone up and led to an increase in poaching. They say they are doing research for mineral exploitation, or they are here for pangolin scales… they hide behind that to illegally trade Ivory"

"…I remember in 2008/2010 a kilo of ivory costs 40,000 CFA…But in 2011-2013 it rose to 120-140,000 CFA the kilo… At first, it was people within the Cameroonian administration…Since then it's the Asians who lead it, who say, 'we are in need of ivory, import as much as you can'

Supplementary Table S1: Spearman's correlation coefficient results

The closer the R value is to +1 or -1, the stronger the likely correlation. The R values of 0.976 and 0.909 suggest a strong positive relationship, denoted by ***. Results show a strong positive correlation between the detectability variables Age and Number of Trips (P=0.976) and Years and Number of Trips (P=0.909) and were therefore eliminated from analysis. (Sample size=154)

	Age	**Years worked**	**Nights camped**	**Number of trips**
Age	NA	0.002	0.180	0.976 ***
Years worked	NA	NA	0.356	0.909 ***
Nights camped	NA	NA	NA	0.002
Number of trips	NA	NA	NA	NA

Supplementary Table S2: Analysis of occupancy variable relationships using Pearson's correlation coefficient (for parametric data).

The absolute value of r: 0.40-0.59 (weak *), 0.60-0.79 (moderate **), 0.80-1.0 (strong ***). No R values displayed either a moderate or strong correlation, therefore none were removed from analysis (Sample size= 342)

	Distance from towns (km)	**Distance from road (km)**	**Elevation (m)**	**Slope (gradient)**	**Distance from villages (km)**	**Distance from river (km)**
Distance from towns (km)	NA	-0.016	-0.411 *	-0.041	0.347	-0.138
Distance from road (km)	-0.012	NA	0.083	0.161	-0.116	0.103
Elevation (m)	-0.410 *	0.083	NA	0.153	-0.288	0.175
Slope (gradient)	-0.041	0.161	0.153	NA	0.132	0.074
Distance from villages (km)	0.347 *	-0.116	-0.288	0.132	NA	-0.160
Distance from river (km)	-0.138	-0.042	0.175	0.074	-0.160	NA

Supplementary Table S3: Environmental and observer variables considered for use in the modelling process

Detectability covariates (measurement unit)	**Justification**	**Expected direction of effort**	**References**
Age (years) 16-37 years/ 38-48 years/ 49+ years	Loss of perspective about past ecological conditions caused by lack of communication between generations may create "shifting baseline syndrome," in which younger generations are less aware of local species diversity or abundance in the recent past (Turvey et al (2010).	The older the respondent, the better they will be at detecting signs of forest elephant.	Turvey et al. (2010)
Gender (male/female)	While all timber concession workers were male, there were some females from the villages in the pilot.	None. Gender does not have an effect on the reliability or ability of the respondent to detect the species.	NA
Where born (local/urban)	Patterns of awareness and experience may be influenced by variation	People growing up in rural areas or locally will have been more	Turvey et al. (2014)

	both in species status, ecology and distribution and in socio-cultural factors, People from different backgrounds living in the same landscapes may have different levels of awareness and experience	exposed to nature and biodiversity. They will, therefore, have a greater level of Local Ecological Knowledge (LEK)	
Years worked (<10 years / >=10 years)		The longer a respondent has worked in that role, the more forest experience they will have and the more experienced they will be at detecting signs of forest elephants	
Nights camped (nights) (1-7 nights / >8 nights)		The longer the informants spend in the forest at a time, the more likely they are to detect signs of forest elephants	NA
Number of trips **>**1- 5 trips a week/		Similarly to the nights camped variable, the	NA

>1 a month- 2 trips a year		more time the informants spend in the forest, the more likely they are to detect signs of forest elephants	
Source of/reason for LEK **(**Job safety/directions learnt from childhood)	To understanding how and why respondents are suitable and reliable and if the purpose or source of their LEK has an influence on this	Those observant of signs due to safety and from their childhood will be more reliable than those using them for their job generally.	Turvey et al. (2010) Turvey et al.(2014) Daniensen
Year (factor levels for each year 2008-2013)	To understanding any changes in occupancy or detectability over time	Elephant occupancy/detectability decreases with year	Maisels et al. (2013)
Slope (gradient)	To see if the degree of slope influences the occupancy of forest elephants	Elephant occupancy decreases with increasing slope	
Elevation (metres)	Areas located at higher elevation differ in soil type, vegetation, plant biomass, rainfall, and temperature, affecting the distribution of elephants	Elephant occupancy decreases with elevation	Ngene et al. (2009) De Boer et al. (2013)

	(Ngene et al., 2009)		
Distance from river (km)	Riverine habitats are preferable for elephants (Walsh et al 2000). However, rivers also provide an access point for humans (Barnes et al, 1991) therefore in areas of high hunting pressure, elephants may actively avoid rivers.	Elephant occupancy decreases with distance from river	Barnes et al. (1991) Walsh et al. (2000)
Distance from road (km)	To see if roads influence the occupancy of forest elephants	Elephant occupancy increases with distance from road to avoid sound and human disturbance	Blake et al. (2008) Stokes et al. (2010)
Distance from town (km)	To see if distance from town influences the occupancy of forest elephants	Elephant occupancy increases with distance from town to avoid sound and human disturbance	Buij et al. (2007) de Boer et al. (2013) Maisels et al. (2013)
Distance from village (km)	To see if distance from villages influences the occupancy of forest elephants	Elephant occupancy increases with distance from village to avoid sound and human	Buij et al. (2007) de Boer et al. (2013) Maisels et al. (2013) Blake (2002)

		disturbance	Douglas-Hamilton et al. (2005) Clark et al. (2009) Yackulic et al. (2011)
UFA group (North/South east/ South West/ Central)	Interesting to see if groups of UFA's are supporting different independent elephant populations across the eastern region and if so, what their statuses are.	UFA groups furthest from major roads and large villages will have the highest forest elephant occupancy	NA

Supplementary Table S4: Top models showing the best fit models that account for detectability only (Burnham & Anderson, 2002)

Model	Covariates	AIC	ΔAIC
8	(P(C+YW) Ψ (·))	1727.91	0.00
7	P(A+C+YW)Ψ (·)	1729.46	1.55
3	p (C) Ψ (·)	1731.91	4
4	p (A+C) Ψ (·)	1734.74	6.83
2	p(A) Ψ (·)	1931.06	203.15
6	P(A+YW) Ψ (·)	1932.94	205.03
5	p (YW) Ψ (·)	1933.62	205.71

Supplementary Table S5: Top 10 best fit models. The best fit models have a ΔAIC of <4.

MODEL	AIC	ΔAIC	WI	Ψ SE	P SE
p(C+YW+G+Y) Ψ (V+Ri+Ro+E+G)	1349.16	0.00	24%	0.73	0.42
p(C+YW+G+Y) Ψ(V+Ri+Ro+E+S+G)	1349.57	0.41	20%	0.7	0.4
p(C+YW+G+Y) Ψ(V+Ri+Ro+E+S)	1350.16	1.00	15%	0.29	0.35
p(C+YW+G+Y) Ψ (V+Ri+Ro+E)	1350.24	1.08	14%	0.28	0.36
p(C+YW+G+Y) Ψ(V+Ri+Ro+S)	1350.29	1.14	14%	0.3	0.35
p(C+YW+G+Y) Ψ(T+V+Ri+Ro+S)	1350.34	1.19	13%	0.3	0.35
p(C+YW+G+Y) Ψ (V+Ri+Ro+E+G+Y)	1353 83	4.67			
p(C+YW+G+Y) Ψ (V+Ri+Ro+E+Y)	1354 64	5.48			
p(C+YW+G+Y) Ψ (V+Ri+Ro+E+S+G+Y)	1354 66	5.50			
p(C+YW+G+Y) Ψ (Vi+Ri+Ro+S+Y)	1355 21	6.05			

KEY OF SYMBOLS

AIC: Akaike Information Criterion

ΔAIC: Akaike difference

Ψ: probability of occupancy, p: probability of detection

C: Nights Camped, YW: Years Worked, G: UFA Group, Y: Year T: Distance from Towns, V: Distance from Village, Ri: Distance from River, Ro: Distance from Road, E: Elevation, S:

Slope

Wi: Akaike model weight

(Grey boxes indicate subsequent best-fit models with an ΔAIC of >4)

Supplementary Table S6: Summary of the back transformed (psi) occupancy and detectability estimates from the fixed model

	Estimate	SE	Z	P(>IzI)	Confidence interval	
P	0.58	0.01	5.64	1.66	022	0.46
Ψ	0.76	0.03	7.18	6.78	0.84	1.47