Heard but not seen: an acoustic survey of the African forest elephant population at Kakum Conservation Area, Ghana

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Abstract

This study, designed to survey forest elephants (*Loxodonta africana cyclotis*) at Kakum Conservation Area, Ghana, is the first to apply acoustic methods to elephant abundance estimation and to compare results with independent survey estimates. Nine acoustic sensors gathered sound continuously for 38 days. Low-frequency calling rates have been established as useful elephant abundance indices at a Namibian watering hole and a central African forest clearing. In this study, we estimated elephant population size by applying an abundance index model and detection function developed in central Africa to data from simultaneous sampling periods on Kakum sensors. The sensor array recorded an average of 1.81 calls per 20-min sampling period from an effective detection area averaging 10.27 km^2. The resulting estimate of 294 elephants (95% CI: 259–329) falls within confidence bounds of recent dung-based surveys. An extended acoustic model, estimating the frequency with which elephants are silent when present, yields an estimate of 350 elephants (95% CI: 315–384). Acoustic survey confidence intervals are at least half as wide as those from dung-based surveys. This study demonstrates that acoustic surveying is a valuable tool for estimating elephant abundance, as well as for detecting other vocal species and anthropogenic noises that may be associated with poaching.

Key words: abundance estimation, acoustic monitoring, cue count, dung count, *Loxodonta africana cyclotis*, wildlife survey

Résumé

Cette étude, conçue pour étudier les éléphants de forêt (*Loxodonta africana cyclotis*) de l'Aire de conservation de Kakum, au Ghana, est la première qui applique des méthodes acoustiques pour l'estimation de l'abondance des éléphants et qui compare les résultats avec des estimations indépendantes. Pendant 38 jours, neuf senseurs acoustiques ont récolté les sons en continu. Le rythme des appels à basse fréquence est un indice utile de l'abondance des éléphants que l'on a pu établir à un point d'eau en Namibie et dans une clairière d'une forêt d'Afrique centrale. Ici, nous estimons la taille d'une population d'éléphants en appliquant un modèle d'indice d'abondance et une fonction de détection mis au point en Afrique centrale à des données provenant des senseurs de Kakum pour des périodes d'échantillonnage simultanées. La batterie de senseurs a enregistré une moyenne de 1.81 appel par 20 min, pour une superficie de détection réelle de 10.27 km^2 en moyenne. L'estimation qui en résulte, qui est de 294 éléphants (95% IC 259–329), tombe dans les limites de confiance de récentes études basées sur les crottes. Un modèle acoustique étendu, qui estime aussi la fréquence à laquelle les éléphants sont silencieux pendant leur présence, donne une estimation de 350 éléphants (95% IC 315–384). Les intervalles de confiance d'une étude acoustique sont au moins la moitié de ceux des études par les crottes. Cette étude montre que l'étude acoustique est un outil intéressant pour estimer l'abondance des éléphants et aussi pour détecter d'autres espèces bruyantes et les bruits d'origine anthropique qui pourraient être associés au braconnage.

Introduction

African forest elephants (*Loxodonta africana cyclotis*) (Matschie, 1900) are threatened by habitat fragmentation

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and illegal poaching (Blake & Hedges, 2004). Monitoring is called for, but an indirect approach is required because elephants living in forests cannot be surveyed using aerial census techniques (Jachmann, 1991; Caro, 1999). The current standard approach uses dung pile abundance to estimate population size (Barnes, 1993; Barnes *et al.*, 1997; Barnes & Dunn, 2002); however, lack of resources, political instability and challenges inherent in current methods prevent roughly half of the forest elephant range from being considered in range-wide population estimates (Central Africa 52%, West Africa 66%, Blanc *et al.*, 2007). In addition to increased efforts, alternative techniques for surveying forest elephants are necessary for the detection of substantial changes in overall population size (Walsh & White, 1999).

For vocal taxa such as songbirds, whales, and elephants, acoustic monitoring is emerging as a non-invasive technique for obtaining information on populations living in habitats where visual surveys are not practical (Baptista & Gaunt, 1997; Payne, Thompson & Kramer, 2003; George *et al.*, 2004). Acoustic surveys are particularly promising for elephants, as their low-frequency calls can travel long distances (Langbauer *et al.*, 1991; Garstang *et al.*, 2005). A model using low-frequency vocalization rates to predict forest elephant numbers has been developed, based on data from a reference population of forest elephants at the Dzanga saline, Central African Republic (Thompson *et al.*, in press). In this study, we applied that model to acoustic cue count data from Kakum Conservation Area, Ghana, a densely forested area where elephants are difficult to detect visually, but where recent dung abundance surveys and dung-DNA sampling provide population estimates for comparison.

Materials and methods

Field methods

Kakum National Park (KNP) and Assin Attandanso Forest Reserve (AAFR) comprise 366 km^2 in southwestern Ghana (5.35 N, 1.31 W) (Fig. 1). This combined area, referred to as the Kakum Conservation Area (KCA), harbours a small population of resident African forest elephants (*Loxodonta africana cyclotis*) (Matschie, 1900). This isolated population has not recently experienced poaching and is believed to have remained relatively stable throughout the 3 years in which the acoustic and dung-based data compared here were collected.

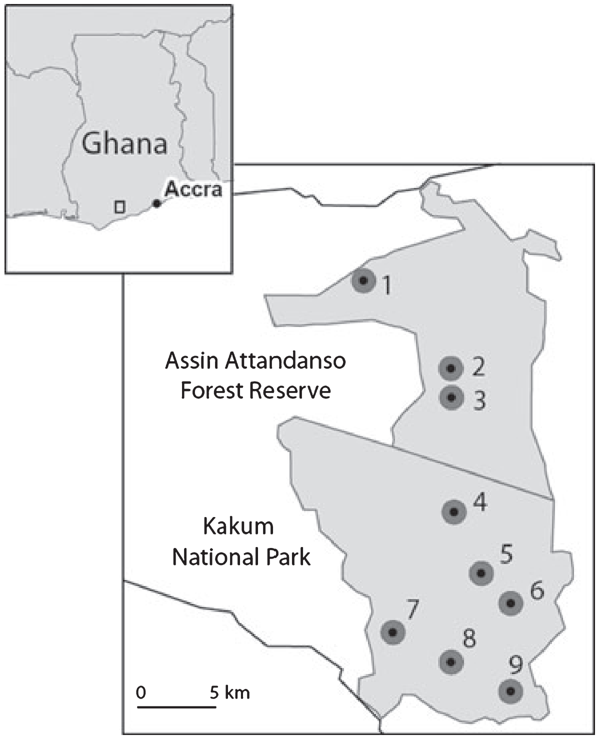

Fig 1 Map of study area with locations of acoustic recording units

We recorded low-frequency elephant vocalizations (rumbles) on nine Autonomous Recording Units (ARUs) distributed in a stratified random manner throughout the KCA. A previous survey divided Kakum into 1.84 km^2 sampling units. Three ARUs were placed at the geographical centers of randomly-selected sampling units in the 154 km^2 AAFR stratum, and six ARUs were distributed using the same randomization technique in the 212 km^2 KNP stratum (Fig. 1). ARUs were developed by Cornell University's Bioacoustics Research Program (Calupca, Fristrup & Clark, 2000). Each battery-powered unit recorded digital sound data continuously for a period ranging from 52 to 70 days during summer 2000 at a sampling rate of 1000 Hz, capturing all low-frequency elephant calls (rumbles) within listening range of the unit. During the 38 days between June 17 and July 24, the units recorded simultaneously for 24 h day^{-1}.

Sound analysis

Digital sound files were downsampled to a rate of 125 Hz for ease of low-frequency spectrographic display, then analysed with SyrinxPC software (Burt, 2000). We browsed sound data in spectrogram format for elephant rumbles using standardized settings (time resolution of 0.02 s and frequency resolution 0.49 Hz), exceeding the standards by which rumbles from the Dzanga reference population were detected. An elephant rumble was defined as a clearly visible tonal sound between 2 and 10 s in duration with a fundamental frequency between 5 and 50 Hz (Fig. 2), matching the criteria used for signals from the reference population (Thompson *et al.*, in press). Motor vehicles on nearby roads produced the only tonal sounds in the same frequency range as elephant rumbles; however, as these sounds persisted for longer than 10 s, they could be readily distinguished from elephant vocalizations. Tonal signals such as human and non-human primate vocalizations are made at fundamental frequencies well above elephant vocalizations and motor vehicle noise (e.g., human fundamental frequency 85–255 Hz, Titze, 1994). Gunshots are distinctly atonal, broadband sound bursts of varying frequency content depending on the gun type (Bell & Bell, 1994).

Basic model for estimating elephant numbers within the listening area

We calculated call rates by aggregating the Kakum vocalization data from each site into 20-min time blocks matching the sampling period employed in the acoustic abundance index model used here to estimate elephant numbers from low-frequency call rates (Thompson *et al.*, in press). Nighttime data (1800–0600) were excluded from this analysis because the abundance index was modeled using visual counts of elephants at the Dzanga saline during daylight hours, limiting the index's ability to predict elephant numbers to those hours. In addition, the validity of the acoustic model relies on a separation of at least 4 h between the beginnings of 20-min sampling periods to avoid autocorrelation among successive elephant counts. To ensure that each 20-min period used was separated by at least 4 h from all others, we partitioned the data into 12 datasets, each consisting of sampling periods beginning 20 min later than those in the previous dataset. Thus, each of the 12 datasets contained three sampling periods per day (n = 114/dataset).

As 20-min sampling periods containing zero calls can correspond to either the absence or silent presence of elephants, such periods were excluded from the original abundance index and from the basic model analysis. For each 20-min period during which elephant calls were detected, the basic model estimated the number of elephants in the listening area of each recorder using the abundance index: $\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 \text{calls}_i$ where $\hat{\beta}_0 = 16.5558$ and $\hat{\beta}_1 = 0.6987$ (Thompson *et al.*, in press). For the periods in which no low-frequency elephant calls were detected, we assumed that no elephant was present in the listening area.

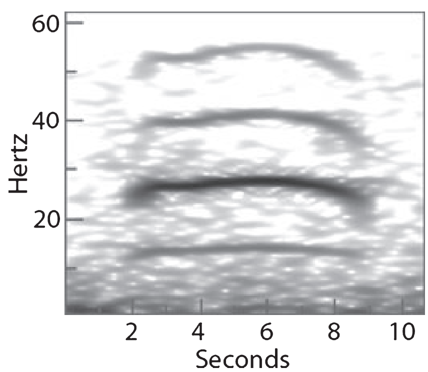

Fig 2 Spectrogram of a typical elephant call detected in acoustic recordings from Kakum Conservation Area

Extended model for estimating elephant numbers within the listening area

The basic model is expected to have a conservative bias, because sampling periods with zero calls are treated as having zero elephants present. We developed an extension of the basic method using the elephant counts and acoustic recordings from the Dzanga reference population to adjust the interpretation of zero-call sampling periods. To estimate the number of sampling periods for each sensor during which elephants are silent but present, we estimated two parameters: (i) the conditional probability (p) of observing no calling during a sampling period given that animals are present; and (ii) the proportion of sampling periods (q) in which >0 calls were detected. In the reference population, the elephants were silent during 27.1% of the sampling periods in which elephants were present, so $\hat{p} = 0.271$. Using this Dzanga-based percentage and the observed proportion of sampling periods in the acoustic survey during which calling occurred ($\hat{q}$) at a specified sensor in Kakum, we estimated the number of sampling periods during which elephants were present at this sensor as $\hat{q}/(1-\hat{p})$ (Thompson *et al.*, in press). For $\hat{q}/(1-\hat{p})$ zero-call sampling periods randomly sampled from this sensor, we estimated that there is an average-sized forest elephant family group (2.5 elephants, Turkalo & Fay, 2001) present in the listening area.

Effective sampling area

In the Dzanga reference site, a forested environment free of vehicle noise, the average effective sampling area for a forest sensor was calculated to be 3.22 km^2 using a sample of elephant rumbles from known sources (Thompson *et al.*, in press). As background noise in the elephant vocal range can have a substantial effect on detection, the effective sampling area must be adjusted at each survey site to reflect average noise conditions. The average daytime background noise measurement during the Dzanga call sample (b_{ref}) was 156 micropascals (μPa) (95% confidence interval 138–174 μPa). In Kakum using the same recording equipment, we sampled the degree of background noise on the nine randomly distributed sensors for a 5-min period during each 20-min sampling period for which we estimated elephant numbers. A received-level measurement tool implemented in XBAT software (Figueroa, 2006) was used to calculate background noise (b) in the 5–50 Hz range, yielding an RMS pressure value in micropascals for each noise segment (Settings: Calibration = 9 dB re 20 microPa/bit, Sampling rate = 125 samples/s, FFT = 256 samples for a filter bandwidth of 0.702 Hz).

An effective sampling area estimate was then calculated for each sensor in each 20-min period using the detection function $g(r)$ developed for forest elephant calls in the Dzanga population and a set of noise-adjusted ranges (r_{new}). For the ith sensor in the jth sampling period, the effective sampling area is

$$A(S_{ij}) = 2\Pi \int_{1}^{w} r_{new}\, g(r)\, dr \qquad (1)$$

where $g(r)$ = the probability of detecting an acoustic event when such an event occurs at distance r from the sensor, w = 10,000 m, the truncation distance, $r_{new} = r/(b/b_{ref})^2$ for which r = 1–10,000 m, b_{ref} = the average noise value at the Dzanga reference site, and b = the average noise value at a sensor site during a given sampling period.

Population estimate for Kakum Conservation Area

We calculated a population estimate for each stratum, AAFR and KNP, during each 20-min period ($\hat{N}_j$). To keep notation simple, we will not introduce additional subscripts for the strata. For the jth sampling period, for a specified stratum,

$$\hat{N}_j = \frac{A(F)}{\sum_{i=1}^{m} A(S_{ij})} \sum_{i=1}^{m} \hat{y}_{ij} \qquad (2)$$

where $A(F)$ = total area of the stratum, $A(S_{ij})$ = effective sampling area of the ith sensor in this stratum during the jth sampling period, m = the number of sensors in the stratum, and $\hat{y}_{ij}$= the estimated number of elephants within the area sampled by the ith sensor during the jth sampling period (Lohr, 1999).

This resulted in an abundance estimate for the specified stratum for each 20-min sampling period. We obtained an overall estimate for the stratum ($\hat{N}$) by averaging the $\hat{N}_j$ values. This process was repeated for each of the 12 datasets, using both the basic and extended methods of estimating $\hat{y}_{ij}$. Park-wide estimates for each dataset were calculated by summing the $\hat{N}$ values from the two strata together. To obtain an overall park-wide estimate, denoted by $\tilde{N}$, we averaged the park-wide estimates from the D = 12 datasets, which we now denote as $\hat{N}^d$ for d = 1,…,12: $\tilde{N} = (1/D)\sum_{d=1}^{D} \hat{N}^d$.

We also calculated an estimate of the number of elephants within the listening area using the same process, but without the $\frac{A(F)}{\sum_{i=1}^{m} A(S_{ij})}$ expansion factor.

The estimated variance of $\hat{N}_j$ for each stratum in each sampling period j was calculated as

$$\hat{\sigma}^2_{\hat{N}_j} = \left[\frac{A(F)}{\sum_{i=1}^{m} A(S_{ij})}\right]^2 \left[\sum_{i=1}^{m} s^2_{\hat{y}_{ij}} + 2\sum_{\substack{i,i'=1\\ i<i'}}^{m} \widehat{\mathrm{cov}}(\hat{y}_{ij}, \hat{y}_{i'j})\right]$$
$$= \left[\frac{A(F)}{\sum_{i=1}^{m} A(S_{ij})}\right]^2 \left[\sum_{i=1}^{m}\left(s^2_{\hat{\beta}_0} + c^2_{ij}s^2_{\hat{\beta}_1} + 2c_{ij}s_{\hat{\beta}_0,\hat{\beta}_1}\right) \right. \qquad (3)$$
$$\left. +2\sum_{\substack{i,i'=1\\ i<i'}}^{m}\left[s^2_{\hat{\beta}_0} + c_{ij}c_{i'j}s^2_{\hat{\beta}_1} + (c_{ij} + c_{i'j})s_{\hat{\beta}_0,\hat{\beta}_1}\right]\right]$$

where $A(F)$ = the total area of stratum, $A(S_{ij})$ = the effective sampling area of the ith sensor during the jth sampling period, m = the number of sensors in stratum, $\hat{y}_{ij}$ = the estimated number of elephants within the area sampled by the ith sensor during the jth sampling period and $calls_{ij}$ = the number of calls counted on the ith sensor in the jth sampling period; $\hat{\beta}_0 = 16.5558$, $s_{\hat{\beta}_0} = 2.2561$, $\hat{\beta}_1 = 0.6987$, $s_{\hat{\beta}_1} = 0.0646$, and $s_{\hat{\beta}_0,\hat{\beta}_1} = \hat{\rho}_{\hat{\beta}_0,\hat{\beta}_1} s_{\hat{\beta}_0} s_{\hat{\beta}_1} = -0.109$ (Thompson *et al.*, in press). This resulted in an estimate of elephant count variance for each stratum in each sampling period (Lohr, 1999). We estimated the variance of $\hat{N}^d$ for each stratum in each dataset (d = 1,…,12) as

$$\hat{\sigma}^2_{\hat{N}^d} = \frac{1}{K^2}\sum_{j=1}^{K}\hat{\sigma}^2_{\hat{N}_j} \qquad (4)$$

where K = the number of sampling periods in the dataset (=114).

For each dataset, we obtained the estimated variance of the park-wide $\hat{N}^d$ by summing the estimated variance for an individual stratum given by Eq. 4, over the two strata. If the 12 park-wide $\hat{N}^d$ values are uncorrelated, we can treat them as independent estimates and calculate the overall variance by $\hat{\sigma}^2_{\hat{N}} = (1/D^2)\sum_{d=1}^{D}\hat{\sigma}^2_{\hat{N}^d}$.

For a summary of the acoustic survey technique, see Table 1.

Results

A total of 3898 calls were detected from the nine sensors during the 38-day recording session. Histograms of elephant call counts per day are displayed in Fig. 3. The unit at site 10 recorded many more calls than the other units, comprising 31% of all calls recorded (n = 1226), whereas the unit at site seven recorded only 1.5% of all calls (n = 60). Site 10 also recorded the maximum calling rate value of 61 calls/20-min period (average maximum rate across sites = 28 calls/period). From the 9-sensor array as a whole, we detected an average of 1.81 calls per 20-min period with an average effective detection area of 10.27 km^2.

Table 1 Summary of acoustic survey techniques

To obtain acoustic estimate of elephant abundance:
Survey area of interest using random distribution of long-term acoustic recorders.
Detect low-frequency elephant calls on each recorder.
Apply acoustic abundance index model to each recorder's calling rate data from sampled periods.
Sum resulting estimated number of elephants across recording sites for each sampled time period. Then average the summed estimates from individual sampling periods to yield an estimate of animals within the listening area.
Measure background noise on all recorders in the low-frequency range. To estimate area sampled, adjust detection area of recorders during each sampling period in reference to central African standard.
Use expansion factor to estimate number of elephants in the wider area of interest and calculate its estimated variance.

Overall, the noise conditions at Kakum were louder than at the Dzanga reference site. This was not surprising, as Kakum is relatively small and surrounded by roads, farms, and villages, whereas the Dzanga site is buffered from roads and villages by tens of square kilometers of protected forest. During a small percentage of sampling periods in each dataset (mean = 5.6% across datasets, range = 2–12 sampling periods), the noise conditions were especially loud, making the effective detection area <1 km^2. As a spatial sampling effort term is included in the variance equation, noisy conditions inflate the estimated variance. To avoid biasing the variance estimate through the inclusion of a small percentage of noisy sampling periods, we set a 1 km^2 effective detection area threshold. This criterion changed the elephant abundance estimate from the basic model by <1% (from 294.6 to 293.9 elephants), but reduced the variance estimate by 95% (from 71968 to 3759).

For the extended model analysis, the fraction of sampling periods during which elephant calls were detected (q) varied among sensors between 1% and 15%, and the number of zero-call sampling periods for which we estimated elephant presence ranged from 1 to 17 depending on the sensor-specific value of $\hat{q}/(1-\hat{p})$ (mean = 6 periods).

The basic acoustic model and the extended model were applied to each dataset separately, yielding estimates for the number of elephants within the listening area and the number of elephants in Kakum, and the variance for each estimate (Table 2). The estimates were similar across datasets, varying for the basic modeling approach by three elephants within the listening area. As these estimates show non-significant autocorrelation among adjacent values (Durbin–Watson statistic d = 2.18 basic model, d = 2.50 extended model), it is conservative to estimate the overall variance by averaging the values across the datasets and then dividing by 12. Using these methods, the average number of elephants within the listening area of the acoustic units is 7.4, and the overall estimate for Kakum using the basic acoustic model is 294 elephants (95% CI: 259–329). Using the extended model that incorporates elephant estimates during periods when there was no calling, we estimated that the population of elephants in Kakum is 350 elephants (95% CI: 315–384).

Discussion

The results reported above represent the first estimates of elephant abundance using acoustic survey techniques.

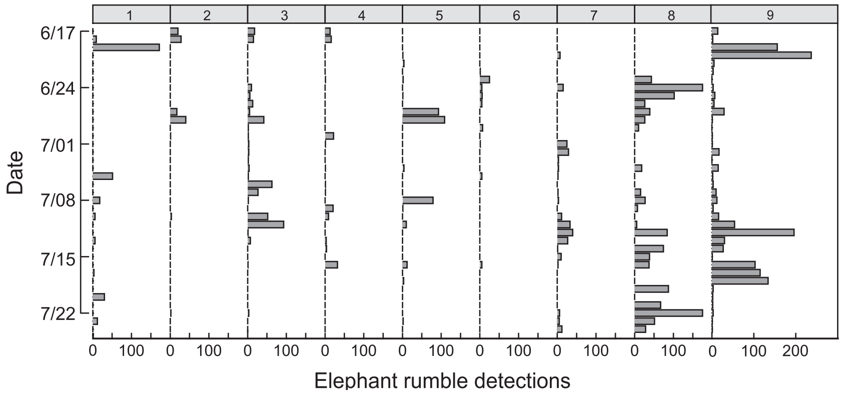

Fig 3 Calls detected during 24-h periods on each of the nine recording units during the 38-day recording session. Site 1: n = 367, Site 2: n = 111, Site 3: n = 376, Site 4: n = 126, Site 5: n = 321, Site 6: n = 60, Site 7: n = 237, Site 8: n = 1134, Site 9: n = 1226

Table 2 Estimates of forest elephant numbers for the basic and extended models within each listening area, Kakum and associated variances

Basic acoustic model				Extended acoustic model		
Data set	Elephants in listening area	Population size	Population variance	Elephants in listening area	Population size	Populationvariance
1	8.2	263.9	3316.3	9.4	314.0	3301.5
2	8.9	343.3	3140.1	10.1	398.2	3120.3
3	8.1	277.2	3105.3	9.3	330.5	3086.0
4	8.3	298.3	3659.0	9.4	342.3	3648.1
5	8.4	347.1	3192.3	9.6	395.2	3180.9
6	7.0	306.4	3411.7	8.2	362.9	3389.8
7	6.7	243.2	3812.3	7.9	309.0	3787.5
8	6.1	271.7	4623.6	7.3	340.2	4598.9
9	6.3	263.1	4801.5	7.5	331.9	4776.1
10	6.8	306.0	4148.5	8.0	366.6	4128.0
11	6.1	250.0	3581.7	7.3	300.0	3569.8
12	7.7	356.8	4309.3	8.9	414.9	4291.5
Overall estimate	7.4	293.9	3758.5/12 = 313.2	8.6	350.5	3739.9/12 = 311.7

Other recent surveys of elephant abundance in Kakum provide independent estimates for comparison. A dung count survey conducted at Kakum in February–March and October 2000 conducted by Richard Barnes and the Elephant Biology and Management Team produced a merged estimate of 233 elephants (CI: 160–347) from a model incorporating the amount of rainfall during the previous 2 weeks (Barnes & Dunn, 2002; Eggert, Eggert & Woodruff, 2003). A genetic survey from 1997 conducted by Lori Eggert, using DNA extracted from dung piles, produced an estimate of 225 (CI: 173–308) using a mark-recapture model (Eggert *et al.*, 2003). The confidence intervals for these previous surveys are not directly comparable with those reported here for the acoustic method because earlier variance estimates have not included a term reflecting the proportion of total area directly sampled by the survey (R. Barnes, L. Eggert, pers. comm.). Incorporating such a term would widen the confidence intervals for the dung-based methods substantially. Although the spatial error component is sometimes overlooked in wildlife surveys, it is important in assessing the true precision of estimates, especially in cases where only a small fraction of the area of interest can be surveyed (Skalski, 1994; Yoccoz, Nichols & Boulinier, 2001). Even with a spatial error term incorporated in the variance estimate of the acoustic survey, confidence intervals are at least half as wide as those of the dung-based surveys, demonstrating that the use of acoustic surveys can result in increased precision of forest elephant population estimates.

We are encouraged by the finding that acoustic, dung count and DNA-based estimates for the Kakum population converge on the same broad conclusion about the number of elephants in the park. This general coincidence among estimates suggests that the calling rate model developed in the Dzanga saline, a central African forest clearing, may serve as an appropriate index of forest elephant abundance in entirely forested habitats. The three methods are all indirect, each with a different set of assumptions and uncertainties; thus, the coincidence of their results provides an overall validation of them all.

Consideration of the assumptions and biases in the various models provides further insight. For example, we expect the basic acoustic model to underestimate elephant numbers because it omits sampling periods when elephants are present but not calling. However, comparing acoustic model estimates with those from other methods, we find that the basic model estimates are greater than the estimates from the dung-based methods, suggesting either that the abundance index based on calling behaviour at the Dzanga saline is skewed towards forest clearing conditions or that dung-based methods have a conservative bias. Potential sources of conservative bias in dung-based methods include under-detection of calves because of more cryptic dung boli (R. Barnes pers. comm.), under-detection of animals because of variable defecation rates, and possible under-detection of animals with small home ranges (Eggert *et al.*, 2003). To determine the extent to which the acoustic extended model is accurate for habitats without forest clearings, we recommend that additional acoustic surveys be conducted at sites where high-quality dung-based surveys have recently been completed and can be used for comparison.

Abundance estimates based on calling rates are sensitive to habitat-specific differences in background noise and calling behaviour. Here, the detection function of a random sample of elephant calls from an acoustic array in the Dzanga reference population was used to estimate the effective detection area in Kakum after correcting for differing levels of background noise (Thompson *et al.*, in press). Bias in the acoustic estimate is possible if Kakum elephants make, on average, softer or louder calls than those in the reference population. Acoustic surveys would benefit from further quantification of (i) the source levels of elephant calls in a variety of habitats and (ii) the detection probabilities in any new sampling area and calibration of these against the reference population detection function.

As elephants are highly vocal and acoustic recorder technology can be used over relatively long periods and wide areas, acoustic surveys produce a detailed spatial and temporal record of habitat use, not available through other survey methods. From this survey, we learned that the two southern-most sites were highly attractive to elephants (Fig. 3). By identifying such hotspots on a detailed time scale, acoustic surveys can provide useful guidance to wildlife managers and researchers. As acoustic surveys can be used in remote forested areas and in wetland habitats where dung-based surveys are difficult, this technique represents an important methodological advance in wildlife abundance estimation. Acoustic surveys are also minimally invasive, gathering data simultaneously on all recorders and requiring human presence only on the beginning and ending days of months-long surveys.

In addition, recordings from remote sensors capture the acoustic signatures of many other species. For example, the recordings gathered for this survey contained many primate vocalizations (including *Cercopithecus campbelli* and *Cercopithecus petaurista*); thus, the same acoustic survey equipment could be used simultaneously to monitor elephants and primate species as well as other vocal species. Acoustic surveys also provide useful information on the occurrence of anthropogenic disturbances such as gunshots, chainsaws and vehicle noises. In the Kakum environment, test shots from a 0.270 caliber rifle and a shotgun were detected on nearby recorders at distances of up to 2000 and 500 m respectively. Although the study reported here focused on estimating the abundance of elephants, the technique holds promise for any vocal species whose acoustic patterns can be demonstrated as a robust abundance index and whose acoustic signals can be detected over areas large enough to make monitoring practical.

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