
Elephant calling patterns as indicators of group size and composition: the basis for an acoustic monitoring system

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Abstract

The paper gives evidence that the vocal activity of elephants varies with group size, composition and reproductive status, and that elephants' calling patterns could therefore provide the basis for a remote monitoring system. We examined a 3-week set of array-based audio recordings of savanna elephants (*Loxodonta africana*), searching for diagnostic acoustic parameters. An acoustic array made it possible to locate recorded sounds and attribute the calls to particular elephants or elephant groups. Simultaneous video recordings made it possible to document visible behaviour and roughly correlate it with vocalizations. We compared several measures of call density in elephant groups containing up to 59 individuals, and found that rates of calling increased with increasing numbers of elephants. We divided all call events into three structural types (single-voice low-frequency calls, multiple-voice clustered low-frequency calls, and single-voice high frequency calls), and found that the incidence of these varies predictably with group composition. These results suggest the value of a network of listening systems in remote areas for the collection of information on elephant abundance and population structure.

Résumé

Cet article donne des preuves du fait que l'activité vocale des éléphants varie avec la taille du groupe, sa composition et le statut reproducteur, et que le schéma des appels

des éléphants pourrait donc constituer la base d'un système de contrôle continu à distance. Nous avons examiné trois semaines d'enregistrements audio d'éléphants de savane (*Loxodonta africana*) pour chercher des paramètres de diagnostic acoustique. Un arrangement acoustique permet de localiser les sons enregistrés et d'attribuer les appels à des éléphants identifiés ou à des groupes. Des enregistrements vidéo simultanés ont permis de documenter un comportement visible et de le mettre grossièrement en rapport avec les vocalisations. Nous avons comparé plusieurs mesures d'intensité d'appel dans des groupes qui comptaient jusqu'à 59 individus et nous avons constaté que le taux des appels augmentait avec le nombre d'éléphants. Nous avons classé tous les appels en trois types structuraux (appels à basse fréquence d'une voix unique, appels à basse fréquence de voix multiples, appels à haute fréquence d'une voix unique) et nous avons constaté que l'incidence de ceux-ci varie de façon prévisible selon la composition du groupe. Ces résultats incitent à croire qu'un réseau de systèmes d'écoute dans des endroits éloignés serait très utile pour la récolte d'informations sur l'abondance des éléphants et la structure de leurs populations.

Introduction

At a time when elephant habitats are shrinking, elephant-human conflicts are on the rise, and the resumption of international trade in elephant ivory is under fierce debate, a pressing need exists for information about the location, size and reproductive health of existing elephant populations. Information is particularly needed in the case of forest elephants. Most African forest elephants (*Loxodonta cyclotis*) (Roca *et al.*, 2001), Asian elephants (*Elephas maximus*), and a few populations of

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African savanna elephants (*Loxodonta africana*) spend most of their time in thick forest habitats where visual censuses are impossible. The current technique for estimating elephant numbers in environments of this sort involves counting elephant dung piles on transect paths cut through forest. Much work has gone into the development of this technologically simple procedure (Barnes, 1993; Barnes *et al.*, 1997), which is, however, extremely labour-intensive, so that simultaneous dung-based censuses are seldom obtained. It seems that acoustic monitoring could provide complementary information and should be explored.

All elephants are highly social and make powerful low-frequency vocalizations that carry over substantial distances (2–10 km for savanna elephants; Payne, Langbauer & Thomas, 1986; Langbauer *et al.*, 1991; Larom *et al.*, 1997). Acoustic arrays have proven valuable for assessing the distribution and abundance of whales that make powerful, relatively low-frequency calls (Clark *et al.*, 1996; Clark & Fristrup, 1997). To what extent might a similar approach yield information about elephants? Could the size of an elephant population be estimated on the basis of rates of calling? How much information about group and/or population structure and health can be inferred from elephants' calls and patterns of calling?

With these questions in mind we examined a set of audio and video recordings which were made in Etosha Park, Namibia, during a 3-week period in the 1986 dry season.

Existing information on the vocal behaviour of savanna elephants

Savanna elephants make low-frequency calls (fundamental frequency as low as 14 Hz) which range in duration from <1 to 6 s. Frequency modulation varies from nearly flat, unmodulated calls to calls whose fundamental frequencies may rise and fall by 40 Hz. Many of these calls have fundamental frequencies that are infrasonic (below 20 Hz, the lower limit of human hearing) with audible upper harmonics (Payne *et al.*, 1986; Poole *et al.*, 1988). Powerful calls of this description are audible by humans at close range (several hundred metres) and by elephants over several kilometres, as demonstrated in playback experiments (Langbauer *et al.*, 1991). Among the vocalizations peculiar to females are long sequences of powerful low-frequency calls: these are made during oestrus to

attract near and distant males (Poole *et al.*, 1988; Langbauer *et al.*, 1991). Other female calls are involved in group coordination. These include clustered or overlapping calls during reunions of family members, during and after a mating, and during group manoeuvres such as a calf rescue and the subsequent group cohesion (Fig. 1D). In times of excitement, elephants also make trumpets, roars and screams, with fundamental frequen-

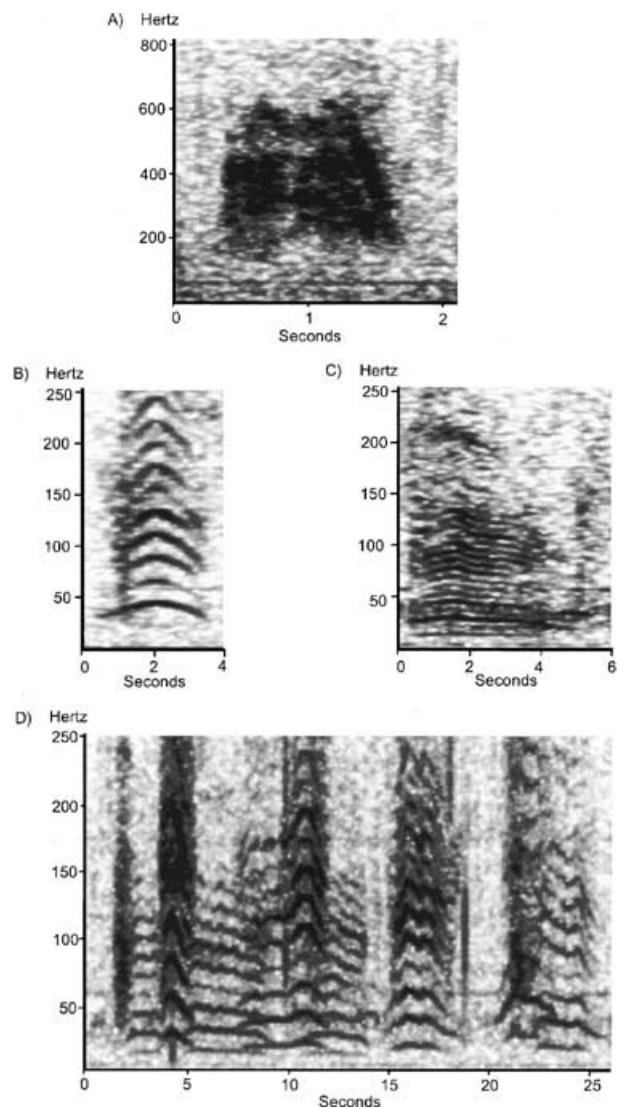


Fig 1 Spectrograms showing variation among calls used in this study. (A) A single-voice high-frequency call (note different frequency scale). (B, C) Single-voice low-frequency calls; and (D) a clustered call

cies ranging from 50 to 600 Hz. (Fig. 1A). Both low- and high-frequency calls are produced by elephants of both sexes and all ages.

We entered the present study intending to test the following hypotheses, which, if validated, might prove useful in an acoustic monitoring programme:

- That family groups have generally higher rates of calling than do male groups;
- That a larger percentage of calls in family groups are in clustered group calls than is the case in male groups;
- That a larger percentage of calls in family groups are high-frequency than is the case in male groups;
- That multifamily groups have higher rates of calling, and higher percentages of clustered calls than do single-family groups; and
- That certain easily recognizable calls are indicative of reproductive activity.

Methods

Data acquisition

Recordings of the calls and behaviour of savanna elephants were made in Etosha Park, Namibia, during the daylight hours of 30 August to 18 September 1986. Video tapes were recorded on an observation tower overlooking a waterhole that was frequently visited by several elephant herds. Four microphones surrounded the waterhole in a roughly square array, approximately 140 m on each side, with each microphone protected by a large rock pile. Sounds received at the microphones were transmitted via radio frequency links and recorded on four-track audio tapes at the tower.

Localization of recorded calls

We used an enhanced version of the CANARY sound analysis program (Charif, Mitchell & Clark, 1995) to acquire four-channel digital sound files from the tapes and to estimate the locations of calling elephants. Locations relative to the array were estimated by analysis of time-of-arrival differences for calls recorded on three or four microphones. For each location, the program also estimated the likely error in position. In this way we verified that the calls in our sample were made by the same elephants we were counting and observing. Success in localizing group calls varied with the number of overlapping voices,

the degree of overlap, and the distances between calling individuals.

Relating elephant numbers to calling rates

Field notes and video recordings enabled us to divide 53 h of recording into visually defined sessions. We defined a *session* as a period that started when all members of an elephant group were within 100 m of at least one microphone in the array, and ended when two or more animals left or joined that group. The calls recorded in the same physical area and time period were counted. Thus each session represented the calling behaviour of a particular elephant group. We examined 43 sessions with average duration of 51 min (range 14–202 min). Numbers of elephants/session ranged from 1 to 59.

We explored several methods of assessing calling rates. Each had advantages and drawbacks, which we will present here along with an explanation of the role each played in the development of a model for acoustic monitoring.

1. Calling rate based on direct counts of calls visible in spectrograms

Using the CANARY acoustic analysis program, we examined our recordings as continuous spectrograms and counted the elephant calls by visual inspection. This was a labour-intensive process which contained some error, as distant and/or soft calls which occurred at the same instant as closer or louder calls could not be counted. Figure 1D illustrates a group vocalization in which individual calls were fairly easy to separate visually, but in other situations group calls included up to 30 overlapping calls. Figure 2 portrays the temporal distribution of calls in a few sessions with different numbers of elephants.

2. Calling rate based on counts of call events

We defined a *call event* as any vocalization (regardless of the number of contributing calls) flanked by at least 2 s without vocalization: each diamond in Fig. 2 corresponds to one call event. In order to eliminate the inaccuracy associated with trying to count all the calls in complex vocalizations, we experimented with counts of call events instead of calls. We found greater intra-observer

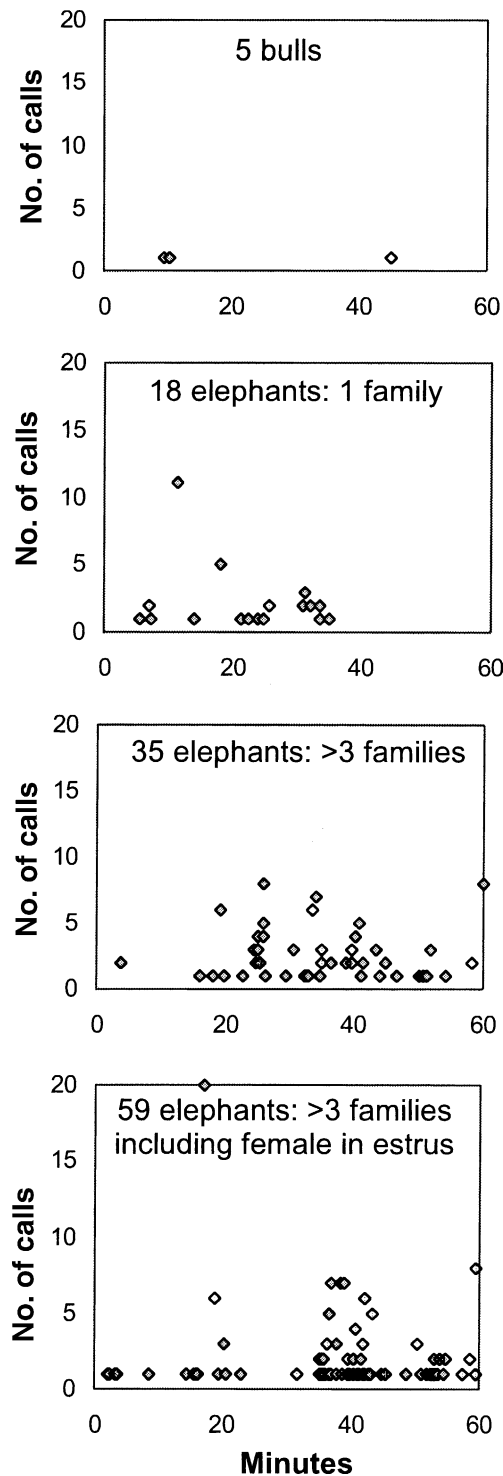


Fig 2 Four timelines showing patterns of calling in groups of different sizes. Each data point represents a call event. Numbers of calls in the call events are represented on the *y*-axis

consistency when call events rather than calls were used as the basis for call rate calculations.

A further step was needed in order to use a measure of calling rate in situations where a visual confirmation of the presence of elephants, and therefore of the duration of sessions, was not possible. The following method for calculating calling rates seemed to meet this visual-free criterion.

3. Calling rates in densest period/session

We defined the *densest period* as the segment of a sampling period which contained its highest call event rate. In order to test the value of densest calling periods as an indicator of elephant numbers, we used our pre-established sessions as our sampling periods. We explored two segment lengths: 30 min and 10 min. Obviously other lengths are also possible, but these two sufficed as a sample for the purpose of establishing whether comparisons of short periods would yield the same sorts of relationships we had found through comparison of session-long samples.

This method has two advantages over the previous methods. (i) Only short segments of the data required intense attention from the data analyst; and (ii) calling rates could be calculated without reference to session length. Anything – including silence – flanking the densest periods did not count. In future monitoring efforts this will enable us to analyse recordings made in areas where visual confirmation of the presence or absence of elephants is impossible.

Relating calling rate to group composition

Classifying group composition

Elephant group composition was categorized in relation to demographic structure and to the presence or absence of oestrus and musth. *Oestrus* was identified circumstantially, by the presence of an adult female separated from her family and being pursued, mounted and/or guarded by one or more adult and subadult males (Moss, 1988). *Musth* was identified by discharges from the temporal glands and penis and by a head-high posture, often coupled with aggressive and/or mate-searching behaviours, as first described by Poole & Moss (1981).

The following types of elephant group were identified: (A) single family group, possibly accompanied by one or

more adult males; (B) bulls (one alone or two or more travelling together, not in musth); (C) a composite group containing multiple families, or one or more families with one or more bulls. Two B groups and one C group contained one or more musth male, and three C groups

contained both musth and oestrus—these are labelled in Fig. 3.

The sample analysed for this paper consisted of 19 bull group sessions (total recording time 17.2 h); 12 single-family sessions (total recording time 8.1 h); 9 composite

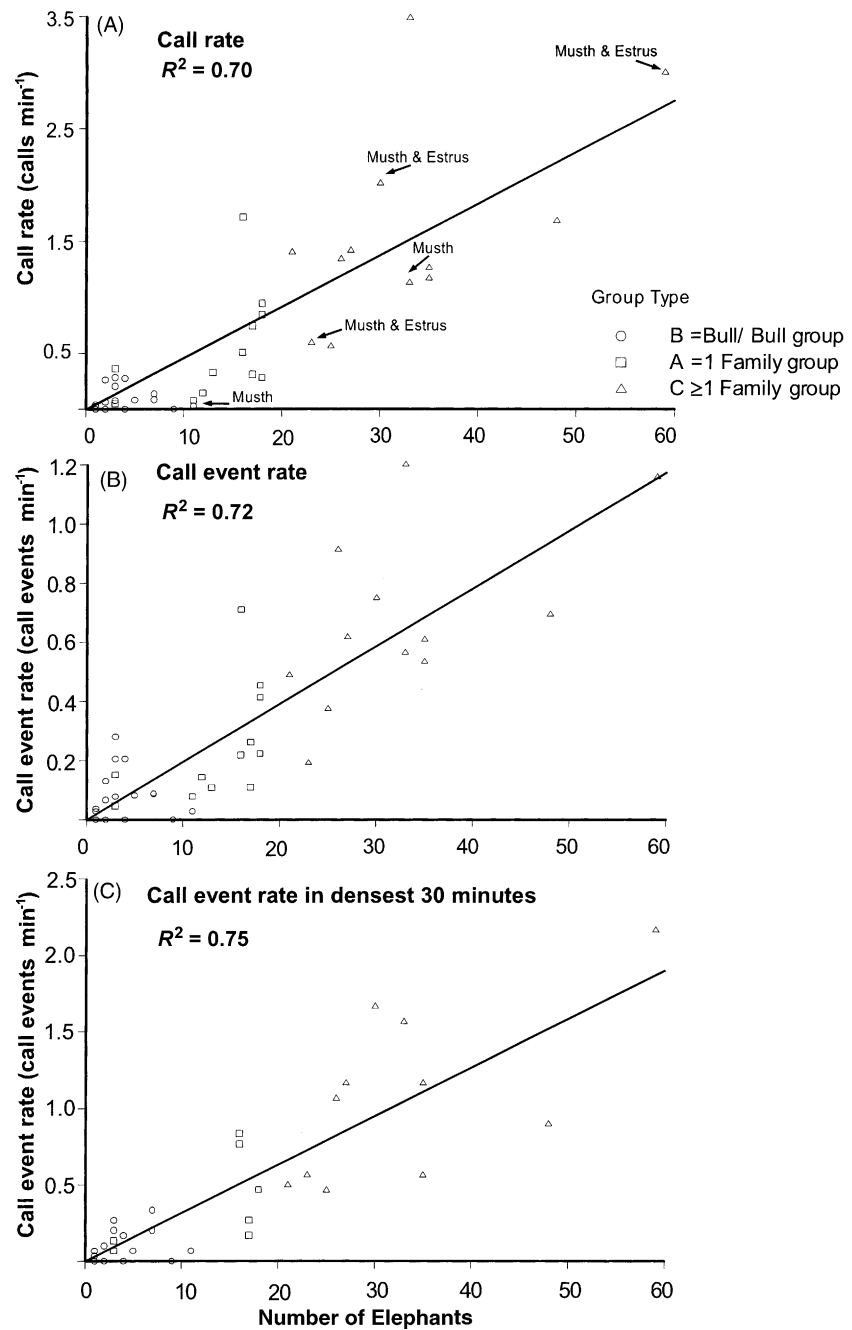


Fig 3 (A) Linear regression analysis of call rate versus number of elephants present ($P > 0.0001$). Sessions containing musth and/or oestrus are labelled. (B) Linear regression analysis of call event rate vs. number of elephants ($P > 0.0001$). (C) Linear regression analysis of call events in the densest 30 min of each session vs. number of elephants ($P > 0.0001$)

group sessions (total recording time 8.9 h); and 3 composite group sessions with musth and oestrus (total recording time 7.6 h).

Classifying call structure

Spectrograms were made for every sound file. Each sound was then visually assigned to one of three *call structural types*:

- *Single-voice high-frequency calls* (fundamental frequency above 50 Hz: trumpets, screams, bellows); Fig. 1A.
- *Single-voice low-frequency calls* (fundamental frequency below 50 Hz: rumbles, growls, grunts) separated from adjacent calls by at least two seconds: for a few examples see Fig. 1B, C.
- *Clustered low-frequency calls* in which several (2–30) vocalizations were overlapping or separated by less than 2 s: for an example see Fig. 1D.

We then calculated call rates based on these structural categories, yielding a single-voice, clustered and high frequency call rate for each session.

Relating call structure to group type

To discover whether or not these call rates were diagnostic of group type, we used S-PLUS 2000 statistical software to perform a binary recursive partitioning analysis on these data (Clark & Pregibon, 1992), yielding the classification tree in Fig. 5. High frequency calls were not included in this analysis.

Results

Temporal relationships between call events

Figure 2 illustrates the temporal relationship between calls in four representative sequences from elephant groups of different size and composition. These time lines were made from direct counts, and include an assessment of number of voices/call (represented on the *y*-axis). The irregular timing of the calls, and the tendency of females to make clustered calls, reflect the fact that calling is often a response to a social interaction.

Calling rates (assessed by direct count) as indicators of elephant numbers

Figure 3A shows a linear regression analysis correlating the number of elephants with the rate of calling/session based on direct call counts. Despite unavoidable errors (see Methods), a significant positive correlation of $r^2 = 0.70$ indicated that, when assessed in this way, calling rates offer a crude means of predicting elephant numbers ($P < 0.0001$).

Call event rates as indicators of elephant numbers

Figure 3B shows a linear regression analysis correlating the number of elephants with the rate of calling events/session. A significant positive correlation of $r^2 = 0.72$ resulted ($P < 0.0001$).

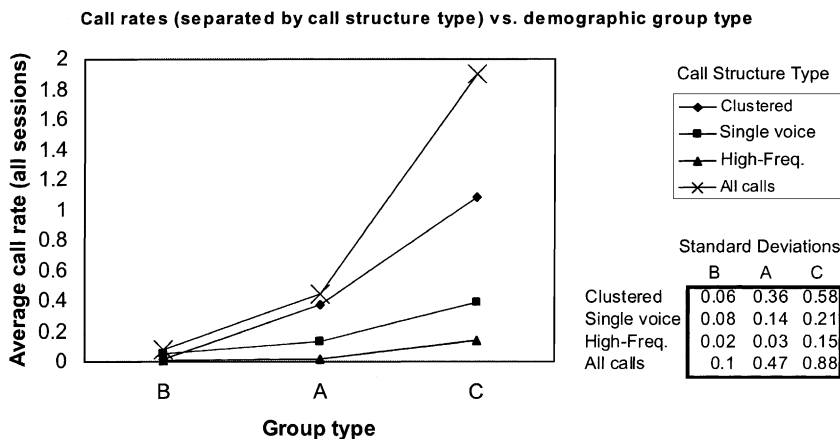


Fig 4 Average call rates (calls min^{-1}) of three call structure types, displayed by group type. Each call structure type increased in average call rate as social complexity increased

Call event rates in 30-min periods of highest call density as indicators of elephant numbers

Figure 3C shows a linear regression analysis correlating numbers of elephants with rate of calling events/densest 30 min period/session. A significant positive correlation of $r^2 = 0.75$ indicated a strong correlation ($P < 0.0001$).

Call event rates in 10-min periods of highest call density as indicators of elephant numbers

The same kind of linear regression analysis was used to correlate the number of elephants with the rate of calling events/densest 10-min period/session. A significant positive correlation of $r^2 = 0.65$ indicated a strong correlation ($P < 0.0001$).

Overall calling rates as evidence of group composition

Group composition co-varied with elephant numbers in the sample that we analysed. As shown in Fig. 3, no matter how we measured calling rate, it progressed from bull groups (B) to single family groups (A) to composite groups (C). High rates of calling coincided with high levels of social activity, and low rates coincided with low levels. The highest calling rate occurred during a 35 min session, when juvenile elephants were chasing one another and trumpeting in the midst of a large group. The lowest rate (0 calls min^{-1}) occurred in seven sessions which consisted of 1–9 bulls arriving at the water point, drinking and leaving without vocalization. The average duration of these silent sessions was 44 min.

Among C groups, calling rate did not turn out to be a predictable indicator of pre-reproductive activity. Figure 3A identifies one B group and one C group which contained one or more musth males without an oestrus female, and three C groups which contained a musth male together with a female in oestrus. No mating was witnessed during these sessions, and the calling rate was highly variable.

Calling rates of different structural types (group, single-voice, and high-frequency calls) as evidence of group composition

Figure 4 shows a progressive increase in each of three structural call types (single-voice, clustered and high-frequency) with increasing complexity of the social group

(bulls (B), single family (A), multifamily (C)). Calling rates were based on direct counts.

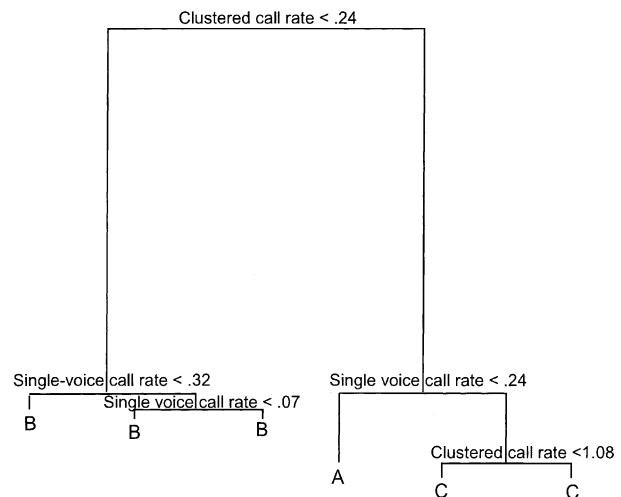
An analysis of variance (ANOVA) reveals significant differences in call rate ($F_{8,120} = 29.35$, $P < 0.0001$) among three types of call structure (Table 1). Significant differences in call rate were also found among the three elephant group types. The interaction term is also significant, indicating that call rate varies nonlinearly as a function of both elephant group type and call structural type.

The dendrogram in Fig. 5 separates demographic group types on the basis of single-voice and group call rates with 80% accuracy. The misclassified calls were all from A groups.

These comparisons offer a systematic way to differentiate between bull groups and multiple-family groups on the basis of their acoustic behaviour, and a somewhat less reliable way of identifying single-family groups.

Application: a guide to using the relationships presented above to estimate the size and composition of savanna elephant groups

- Digital acoustic data are examined either by human inspection of spectrograms or by the use of an



Misclassification rate: 0.2093 = 9 / 43

Fig 5 In this binary recursive partitioning analysis, group types can be predicted by clustered and single-voice call rates with 80% accuracy. The data set included 467 single-voice call events in 35 sessions and 1347 clustered call events in 24 sessions. Of the total 43 sessions, seven had no calls and one had only high-frequency calls

Table 1 ANOVA analysis of call rate, elephant group type and call structure type

Model	d.f.	Sum of squares	F-value	P-value
Call structural type	2	4.1386	39.317	<0.0001
Group type	2	5.7923	55.028	<0.0001
Interaction	4	3.51109	16.678	<0.0001
Error	120	6.3157		

automatic detector programmed to recognize call events in digitized sound files.

- Periods of highest call event density are selected from equal-length segments of the continuous recording.
- Call event rates from these periods are compared to the regression model shown in Fig. 3C to yield minimum estimates of elephant numbers.
- Call event rates from these periods are compared to the classification tree shown in Fig. 5, to yield probable diagnoses of group composition.

Discussion

Biological and conservation significance of these findings

The biological relationships documented in this study – the relationships between elephant numbers and calling rates, and between vocal and social complexity – came as no surprise. In this sample, in which all large social groups contained females and young, it would be surprising if rates of vocalization did *not* increase with increasing numbers. Interactions within family groups are compounded by interactions between and among groups; rising excitement levels attend these interactions and lead to further interactive behaviour. Among these are play and aggression, both of which often result in the separation of family members. These separations often lead to bouts of calling as young search for family members and as families rejoin. Add to this the fact that oestrus females are most often found in large aggregations, that musth males spend more time in large than in small mixed groups (Poole & Moss, 1989), and that several specialized vocalizations accompany and announce reproductive activities. With these additions it becomes clear that elephants' calling rates simultaneously mirror group

size and reflect the complexity of behaviour and of group structure.

Even in complex situations, however, social events are sporadic, which probably explains the variability in calling patterns between sessions that have roughly the same group structure and number of elephants.

All of this has long been obvious to elephant observers. What was not known before these analyses is that the relationships between calling behaviours, elephant numbers and group structure would be so robust and measurable, and thus potentially useful in monitoring programmes. From a practical point of view, perhaps our most important discovery is that short, dense periods of calling yield a reliable estimate of group size.

Additional measurements expected to be relevant to monitoring

This paper introduces some relationships that may be useful in monitoring elephants acoustically. Other measurements are likely to be relevant to finer-tuned assessments of population health. We believe, for instance, that a number of call types which announce reproductive activity and other aspects of an elephant population's health will prove distinctive enough to be recognized by call-sorting programs and automatic acoustic detectors, as soon as robust versions of these have been developed.

Conservation-orientated acoustic monitoring

The model presented is based on the acoustic behaviour of African savanna elephants (*Loxodonta africana*). The elephants most likely to benefit from acoustic monitoring are African forest elephants (*Loxodonta cyclotis*) or Asian elephants (*Elephas maximus*), both of which live in dense forests where visual monitoring is often impossible and monitoring via dung counts is difficult and imprecise (Walsh & White, 1999). Inasmuch as the social behaviour of all elephants is quite similar, the acoustic indicators identified in this study will inform the early stages of monitoring programmes for other elephant populations and environments.

Technical feasibility of large-scale acoustic monitoring

Acoustic monitoring seemed an impractical conservation alternative as recently as a decade ago, because of

the difficulties of collecting, storing and processing huge data sets. Several recent technical achievements have now dramatically changed the picture. Autonomous recording devices which can collect and digitally store months of continuous, or flexibly sampled and scheduled, acoustic data have been developed by the Bioacoustics Research Programme of the Cornell Laboratory of Ornithology. They can be used as single-element probes or in time-synchronized arrays with the potential for localizing sources of sound. Many of the processes associated with acoustic analysis have also been greatly simplified. Automatic detecting programs, automatic call sorting programs, and automatic localization programs now exist, in at least preliminary forms, each with the potential for further custom design. In a project that incorporates all of these time-saving devices, quantitative relationships that earlier would have been prohibitively difficult to address can now potentially be addressed in a matter of weeks. The new methodology is improving rapidly, and its current versions are being used for the assessment of biological activity in environments that were hitherto inaccessible.

Acknowledgements

The field work reported here was done with William R. Langbauer Jr., Holly Payne and Elizabeth Marshall Thomas, in a project sponsored by the National Geographic Society and the World Wildlife Fund. Members of Namibia's Department of Wildlife Conservation and Tourism made us welcome in Etosha Park; they and others, particularly Clem and Peggy Haagner, and Des and Jen Bartlett, helped our field work in innumerable ways. The data were analysed at the Cornell Laboratory of Ornithology by the authors, with partial support in the form of a World Wildlife Fund Species Action grant to K. Payne. Vanessa Baxter, Jack Bradbury, Bernard Brennan, Russ Charif, Chris Clark, Kathy Dunsmore, Melissa Fowler, Adam Frankel, Kurt Fristrup, Melissa Groo, Steve Gulick and Sandra Vehrencamp helped in many aspects of the data analysis; Naomi Altmann helped in the development of our statistical procedures. Many thanks to all.

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(Manuscript accepted 5 June 2002)