Coexistence between People and Elephants in African Savannas

RICHARD E. HOARE* AND JOHAN T. DU TOIT†

*Tropical Resource Ecology Program, Department of Biological Sciences, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe

†Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Pretoria 0002, South Africa

Abstract: *The decline in the range and numbers of elephants as a result of expanding human activity in Africa is recognized as one of the continent's more serious conservation problems. Understanding the relationship between human settlement patterns and elephant abundance is fundamental to predicting the viability of elephant populations. The prevailing model of human-elephant interaction predicts a negative linear relationship between rising human density and declining elephant density at a coarse (national or subcontinental) scale. Using observed elephant densities and human population data, we tested this prediction in a study area of 15,000 km*^{2} *in northwestern Zimbabwe. The results did not fit a linear model. Elephant and human coexistence occurs at various levels of human density, up to a threshold of human density beyond which elephant populations disappear. This threshold seems to be related to a particular stage in the process of agriculturally transformed land becoming spatially dominant over the natural woodland that constitutes elephant habitat. Within the contexts of conservation and sustainable development in African savannas, investigating spatial relationships between elephant and human abundance should be a priority topic for future research.*

Coexistencia entre Humanos y Elefantes en Sabanas Africanas

Resumen: *La declinación del rango y número de elefantes como resultado de la expansión de actividades humanas en Africa ha sido reconocido como uno de los problemas de conservación mas serios del continente. El entendimiento de las relaciones entre los patrones de asentamientos humanos y la abundancia de elefantes es fundamental para predecir la viabilidad de poblaciones de elefantes. El modelo prevalente de interacción entre humanos y elefantes predice una relación lineal negativa entre el crecimiento de la densidad humana y la disminución de la densidad de elefantes a una escala burda (nacional o subcontinental). Evaluamos esta predicción en un área de estudio de 15,000 km*^{2} *en el norte de Zimbabwe utilizando densidades observadas de elefantes y datos de poblaciones humanas. Los resultados no se ajustan a un modelo lineal, la coexistencia de elefantes y humanos ocurre a varios niveles de densidad humana hasta un límite después del cual las poblaciones de elefantes desaparecen. Estos límites parecen estar relacionados con un particular estado en el proceso de transformación de tierras agriculturales convirtiéndose en espacialmente dominantes sobre las zonas forestales que constituyen el hábitat de los elefantes. Dentro del contexto de la conservación y desarrollo sustentable en las sabanas africanas, la investigación de relaciones espaciales entre abundancia de elefantes y humanos deberá tener prioridad en investigaciones a futuro.*

Introduction

The distribution and abundance of African elephants (*Loxodonta africana*) is inextricably linked to that of humans (Hanks 1979; Parker 1983; Parker & Graham 1989*a*,1989*b*; Barnes et al. 1991; Said et al. 1995), and anthropogenic effects on this keystone species (Owen-Smith 1988; Western 1989; Milner-Gulland & Beddington 1993) are considered a serious conservation problem in Africa (Dublin 1994; World Wildlife Fund 1997). Few attempts have been forthcoming, however, to produce a model by which the interaction between people

**email rhoare@mango.zw*

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and elephants may be interpreted in terms of the predicted viability of an elephant population.

The only prevailing model of interaction between elephants and humans (Parker & Graham 1989*a*,1989*b*) proposes that elephant distribution is the inverse of human distribution and that elephant abundance is dependent upon human abundance, based on relative densities at a national or subcontinental scale. Mathematically, this is represented by a linear regression model whereby elephant density declines linearly as a function of the natural logarithm of human density. Parker and Graham (1989*a*,1989*b*) give two examples of this inverse relationship: one from fertile soil areas of Kenya and the other from more arid, less fertile areas in Zimbabwe. The nature of this linear model implies that elephant density can be roughly predicted from the density of coexisting humans within the range of 0–20 people/km^2. The linear model has considerable support in the literature (e.g., Eltringham 1990; Newmark et al. 1994) and has even been proposed as applicable to the decline of other African large mammal species (Happold 1995).

Although we accept that the distribution of data points relating African elephant density to human density, such as that presented by Parker and Graham, suggests a negative linear relationship at a coarse (national or subcontinental) scale, we report on an investigation into the interaction between elephants and humans at a finer scale, which is more relevant to the practicalities of management planning. We also explore whether increasing human density is in itself causing elephant density to decrease or whether human density is an indicator of some other anthropogenic agent affecting elephant density.

Study Area

The Sebungwe region of northwest Zimbabwe forms some 15,200 km^2 of the Zambezi river basin immediately to the south of Lake Kariba. The mean elevation is 700–800 m, with generally undulating topography. The climate is semiarid (mean annual rainfall 680–750 mm/year), characterized by a single wet season from November to March and a long dry season from April to October. The natural land cover is deciduous woodland savanna dominated by *Colophospermum mopane* (mopane) and *Brachystegia-Julbernadia* spp. (miombo) vegetation interspersed with abundant riparian fringes on the extensive northward drainage and with occasional small, dense thickets (Anderson et al. 1993).

Land tenure consists of protected areas for wildlife and communal lands with varying degrees of human settlement (Fig. 1). Protected areas are national parks and safari areas in which the settlement of people is prohibited; they form three large but separate blocks and are under the control of the wildlife authorities of the central government. Communal lands are areas where people and some wildlife are both resident and have to coexist. Immigration of people into the communal lands for subsistence agriculture has caused continuous loss of elephant range for 45 years (Cumming & Lynam 1997). Immigration has accelerated since eradication of the tsetse fly (*Glossina* spp.) in the mid 1980s. Communal land areas fall into the three administrative districts of Binga, Gokwe, and Kariba, which since 1990 have each had authority to manage their own wildlife. Districts are further subdivided administratively into wards, which vary from approximately 150 km^2 to 700 km^2. Some wildlife management functions of the districts are being devolved to ward level. This region thus encapsulates many of the factors acting simultaneously upon rural African people and elephants: a land-use mosaic in which human expansion has been continuous and where the full spectrum of wildlife conservation—traditional (Cumming 1981) to contemporary (Taylor 1993)—is represented.

We selected three Sebungwe districts for analysis because human and elephant census data from these districts were used by Parker and Graham (1989*a*,1989*b*) to derive their linear model. Also, we selected these areas because they (1) are distributed across the same ecosystem; (2) are together occupied by one elephant population (estimated at 11,900 animals; Department of National Parks and Wildlife Management 1996) isolated from other populations, eliminating possibilities for immigration and emigration; (3) are relatively unaffected by elephant poaching (Cunliffe 1994); and (4) are distributed across a region in which the overall elephant population size has remained relatively stable over the past 15 years (Hoare 1997).

Census Data and Methods

Before we examined the predictions of the linear model for our case study, we took into account that there are several problems with the data used by Parker and Graham (1989*a*,1989*b*) in the original development of their human-elephant density relationship for this part of Zimbabwe. They used relative densities of elephants instead of absolute (observed) densities to derive the relationship, and they defined relative densities as "observed densities relative to the potential density estimated for rainfall conditions." They estimated potential elephant densities in Zimbabwe from a relationship between rainfall and elephant population density in Kenya. Kenyan elephant populations are, however, subject to very different environmental conditions from those in Zimbabwe; many had suffered drastic pre-1989 declines (Douglas-Hamilton 1987; Ottichilo et al. 1987) and they have exhibited certain genetic distinctions from Zimbabwe populations (Georgiadis et al. 1994). Their data for the elephant-human density regression in Zimbabwe come from seven districts, three of which were never surveyed conventionally

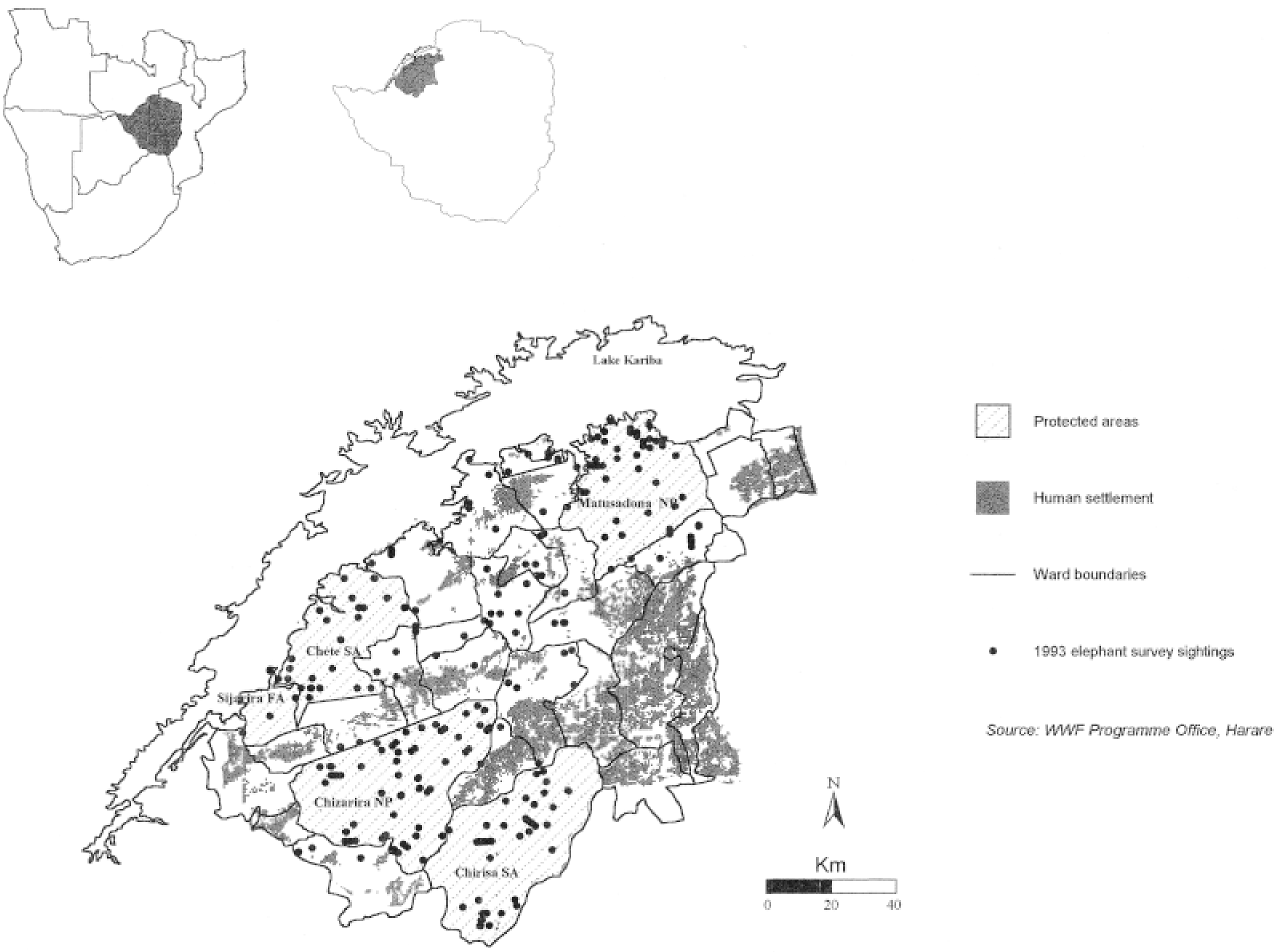

Figure 1. The relative distribution of human settlement and elephants in the Sebungwe region, Zimbabwe, 1993 (reproduced from Cumming & Lynam [1997] with permission from World Wide Fund for Nature, Programme Office, Harare).

(two of them because they exhibited only occasional and restricted elephant occupancy), and one of which was a national park with zero human density. Their three remaining data points are districts in the Sebungwe region, which also comprise our study area. In Sebungwe, crude estimates of elephant density have been obtained by aerial census with standard methodology (Norton-Griffiths 1978; Mbugua 1996) for nearly 20 consecutive years (Department of National Parks and Wildlife Management 1996).

Our study area consisted of 25 census units (communal land wards) in the unprotected range of the Sebungwe region's elephant population (Fig. 1). At this scale, where rainfall and environmental conditions are similar across all census units, the potential elephant density (Parker & Graham 1989*a*) can be regarded as effectively constant. Thus, with one discrete elephant population distributed across these census units, the effect of human density on absolute elephant density can be detected and interpreted more reliably than with Parker and Graham's index of relative elephant density.

Elephant densities for census units were obtained from the region's annual aerial census (Department of National Parks and Wildlife Management 1996). An arithmetic mean of crude elephant density for 3 consecutive years of census (1993,1994,1995) was assigned to each survey stratum. Census unit (ward) boundaries (Fig. 1) were overlaid onto aerial census strata by means of a geographic information system (GIS; Atlas Draw, version 2.1; Strategic Mapping Inc.). The GIS converted elephant densities in the survey strata to elephant densities in the wards. Human densities for wards were extracted from the most recent national census (Government of Zimbabwe 1992).

Human settlement distribution in each ward was obtained from an aerial photography series (1:25,000 scale) taken in 1993. Human settlement was defined as transformed land cover indicating fields or villages and was scored visually on the photographs by means of a grid overlay with a resolution of 0.25 km^2. These data were digitized into the same GIS (Fig. 1), which then provided us with the total area transformed by settlement in each ward. This was expressed as a percentage of the total ward area and was called "settlement coverage" of each ward. Settlement coverage was then regressed against human density within wards. The area transformed by settlement in each ward was also subtracted from the total area of the ward to give the untransformed area of each ward (i.e., the area available as elephant habitat). We used these area figures to convert crude estimates of elephant density derived from the elephant census data to ecological densities in each ward. Ecological density is the number of elephants estimated to occur in each ward divided by the area of untransformed habitat actually available to elephants in each ward.

Results

Although crude densities of elephants and humans in the Sebungwe region were inversely related in broad terms (Fig. 2), the scatter of data points for elephant density and the natural logarithm of human density did not meaningfully fit a linear model. A statistically significant regression line ($p < 0.001$) can be drawn through the data, but the equation accounts for less than half of the variation ($r^2 = 0.41$) that was accounted for by Parker and Graham's regression ($r^2 = 0.98$) for the same variables in the same region but measured at a coarser scale. The pattern we found shows that elephant density is unrelated to human density until a threshold of human density is reached about 15.6 persons/km^2 ($\log_e 15.6 = 2.75$; Figs. 2 & 3). After this threshold, resident elephants effectively disappear. In Kariba, elephant densities were near the mean for the Sebungwe's protected areas (1.15 elephants/km^2) and human densities were all below the threshold level. In Binga, elephant densities were lower and human densities were distributed across the threshold. In Gokwe, elephant densities were low or absent (with one exception, on the boundary with Kariba) and human densities were at or above the threshold. Agricultural transformation of land cover over the last 15 years has correspondingly been relatively restricted in Kariba, moderate in Binga, and widespread in Gokwe (Cumming & Lynam 1997).

The dominant feature of the Sebungwe data set is two markedly different states of elephant density separated by a threshold of human density. This is a significant departure from what the linear model predicts, although there are two features of Parker and Graham's (1989*a*,1989*b*) results that do conform with ours (Fig. 2). First, the ranking of the three districts (Kariba, Binga, and Gokwe) by elephant density was the same in both data sets. Second, the threshold of human density associated with the disappearance of elephants in the Sebungwe region (15.6 persons/km^2) is not much different from the extinction point predicted by the linear model (18.9 persons/km^2).

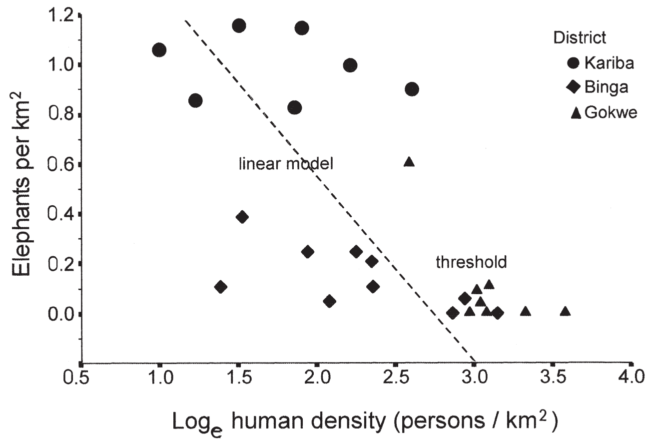

*Figure 2. The relationship between observed (crude) elephant density and human density for 25 wildlife wards in the Sebungwe region, Zimbabwe. The "linear model" (*y *= − 0.268x + 0.727;* r *= − 0.99; Parker & Graham 1989*a*) is superimposed.*

The conversion of estimates of crude elephant density into ecological density does not alter the shape of the elephant-human density plot (Fig. 3), although, as expected, the mean ecological density (0.68 elephants/km^2) is significantly higher than the mean crude density (0.46 elephants/km^2) (Wilcoxon matched-pairs signed-rank test: $T = 3.82$; $p = 0.001$). Of particular interest is the finding that as soon as the overall (crude) density of humans in a ward exceeds the threshold, the ecological

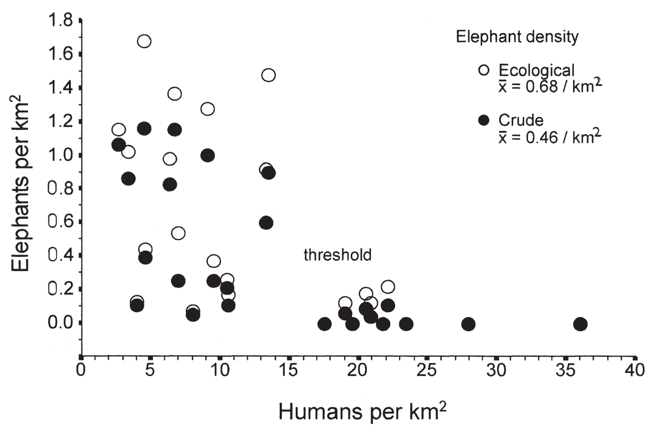

Figure 3. The observed relative abundance of elephants and humans in 25 communal land wards of the Sebungwe region, Zimbabwe. Vertical pairs of points for each ward are crude density for the total ward area derived from aerial census (solid circles) and ecological density calculated by excluding the area of human settlement (open circles).

density of elephants drops. This means that elephants disappear even from the remaining patches of untransformed habitat and do not become compressed within them once the areas of these patches is reduced to below a critical level.

In the Sebungwe region of Zimbabwe, therefore, the extinction point for elephants appears to relate to a human density of around 15–20 persons/km^2, which implies a level of land-cover transformation at the ward scale of 40–50% (Figs. 3 & 4), or the loss of about half the available habitat and fragmentation of the remainder.

Discussion

The distribution of elephants in the Sebungwe region (at the district scale) was mutually exclusive of the distribution of humans, which conforms with the findings of Parker and Graham's investigation at a broader (national) scale. At this finer scale these distributions did, however, interdigitate much more closely than is implied by Parker and Graham's model, based on the relative configurations of agriculturally transformed land cover around human settlements and untransformed natural woodland available to elephants.

Where our findings differ significantly from the predictions of the generally accepted linear model of elephant-human interaction is in the way in which local elephant densities decline in the face of increasing human pressure. Our analysis of the Sebungwe human-elephant interaction suggests the existence of a threshold phenomenon when census data are examined at the district-level scale, which is the scale at which conservation and management plans are implemented. Elephant density (whether measured in crude or ecological terms) does not decline consistently across a gradient of increasing human density and should not be modeled by any linear function, even though the two variables may be correlated over a broad spatial scale. We argue that it is more meaningful to examine the response surface described by the outermost data points in the scatterplot of human and elephant densities than it is to examine a regression line through the cloud of data points. Where human density is low, elephant density may vary widely (Fig. 2) depending on natural habitat conditions, and it is meaningless to try to account for this variation in terms of human effects. Where human density is high and elephant habitat loss is consequently significant, variation in elephant density is low because only low densities are possible.

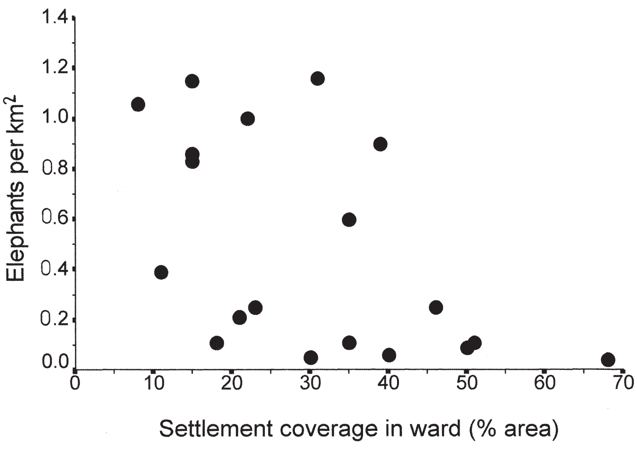

Figure 4. The relationship between the area transformed by human settlement in each Sebungwe wildlife ward and crude elephant density in the ward.

Our hypothesis is that the transition between these two states occurs when a threshold of human density is reached. This threshold is associated with a critical balance between the spatial extent of agriculturally transformed land cover and of natural elephant habitat remaining on the landscape. The nature of the sharp decline in elephant density once the human density threshold has been exceeded suggests that the decline is caused by elephants moving away to less disturbed habitats, as opposed to dying in situ. The threshold effect is self-reinforcing by virtue of the differences in elephant density between those census units from which elephants are leaving and those into which they are compressing. Our data, derived from 25 census units distributed across three districts, include all stages in the encroachment of agriculture on elephant habitats and the responses of elephants to this encroachment 15 years after tsetse flies were eradicated in the Sebungwe region.

Human effects on woodland habitat in African savannas can be measured by the areas transformed by agriculture and settlement, data which were available in our study. Crude densities of elephants did not, however, correlate closely with proportions of area transformed as measured across census units (Fig. 4). This is not unexpected because our data show that the relationship between human and elephant densities is nonlinear and that human impacts on habitats covary with human density (Hoare 1997). Furthermore, the spatial arrangement of human settlement and cultivation relative to untransformed elephant habitat is probably more relevant to the ability of elephants to coexist with humans than are the gross areas of transformed and untransformed land within any census unit. In Gokwe district, for example, overall human density approached the threshold, yet one ward in that district had elephant densities as high as 0.9 elephants/km^2. Elephant populations should persist in areas where human settlement occurs within a matrix of untransformed elephant habitat, but when the total area of transformed land exceeds a critical point, the system flips into a new state in which patches of elephant habitat now occur within a matrix of human settlement. The size and connectivity of the remaining patches of elephant habitat are then the determinants of whether or not elephants remain as residents or move away. Investigating spatial relationships between elephant and human abundance should be a priority for future research.

We agree with the widely held perception that Africa's elephant distribution will always be vulnerable to expanding agriculture. But the abundance levels of humans and elephants are dictated in different ecosystems by different environmental conditions (Parker 1983) and different temporal stages of coexistence. We thus postulate that the response surfaces on human-elephant density plots for different African savanna ecosystems will be characterized by different values for the maximum elephant density (y-axis) and for the human density threshold (x-axis), but that overall they will display the same form. The linear model can probably be expected to prevail for analyses over a coarse (e.g., subcontinental or national) spatial scale that encompasses many different ecosystems, each of which may be at a different stage in the human-elephant interaction. Although we propose our threshold hypothesis for the savanna component of the African elephant's range (inhabited by *Loxodonta africana africana*), we are cautious about extrapolating it to the forest component where the ecological requirements of the forest elephant (*Loxodonta africana cyclotis*) and the patterns of human land use are different.

The development of the linear model was justifiable from the data available at the time, and it succeeded in illustrating that habitat loss constituted a more serious long-term threat to the African elephant than did the much-debated trade in ivory. But researchers have made inappropriate use of the linear model. For example, Happold (1995) proposed that elephants are a sensitive "barometer" for measuring human-mammal interactions and states that if equivalent density data were available for other mammal species, these would also exhibit a negative linear trend. There is no basis for making such an extrapolation given the deficiencies we have demonstrated upon reexamination of the relative abundance of humans and elephants in our study area. Literature supporting the linear model (Eltringham 1990; Newmark et al. 1994; Happold 1995) is thus confounded by the issue of spatial scale, which needs to be clearly defined.

Our threshold hypothesis about human-elephant interaction implies that land clearing by a burgeoning rural human population could result in a more precipitous and less reversible local decline in elephant density than may have been assumed previously from the linear model. If our hypothesis is supported by data from other regions, then the crucial issue for development and conservation planning in unprotected areas within the range of the African elephant is the identification of the human density level that represents the threshold of human-elephant coexistence. This could be determined for any particular ecosystem by the analysis (retrospectively for some areas) of district-level human and elephant census data in regions where elephants still (or did) coexist with humans. With this information it should then be possible to predict when the threshold will be reached in areas where human settlement is expanding (areas from which tsetse flies are being eradicated). Rural planners, community institutions, and conservation agencies would then have a clear guideline to assist them in assessing the sustainability of community-based natural resource management projects that incorporate the utilization of elephant populations.

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