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Systematics and Biodiversity
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t913521959

Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human-elephant conflict

MAXIMILIAN D. GRAHAM[ab]; BENEDIKT NOTTER[c]; WILLIAM M. ADAMS[b]; PHYLLIS C. LEE[d]; TOBIAS NYUMBA OCHIENG[a]
[a] Laikipia Elephant Project, Nanyuki, Kenya [b] Department of Geography, University of Cambridge, Cambridge, UK [c] Centre for Development and Environment, University of Bern, Bern, Switzerland [d] Department of Psychology, University of Stirling, Stirling, UK

Online publication date: 21 December 2010

To cite this Article GRAHAM, MAXIMILIAN D. , NOTTER, BENEDIKT , ADAMS, WILLIAM M. , LEE, PHYLLIS C. and OCHIENG, TOBIAS NYUMBA(2010) 'Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human-elephant conflict', Systematics and Biodiversity, 8: 4, 435 — 445

To link to this Article: DOI: 10.1080/14772000.2010.533716

URL: http://dx.doi.org/10.1080/14772000.2010.533716

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Systematics and Biodiversity (2010), **8(4)**: 435–445

Research Article

Patterns of crop-raiding by elephants, *Loxodonta africana,* in Laikipia, Kenya, and the management of human–elephant conflict

MAXIMILIAN D. GRAHAM[1,3], BENEDIKT NOTTER[2], WILLIAM M. ADAMS[3], PHYLLIS C. LEE[4] & TOBIAS NYUMBA OCHIENG[1]

[1]Laikipia Elephant Project, P.O. Box 174, Nanyuki, 10400, Kenya
[2]Centre for Development and Environment, University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland
[3]Department of Geography, University of Cambridge, Cambridge, CB2 3EN, UK
[4]Department of Psychology, University of Stirling, Stirling, FK9 4LA, UK

(Received 10 June 2010; revised 28 September 2010; accepted 28 September 2010)

Recorded incidence of conflict between humans and elephants, in particular crop-raiding, is increasing in rural Africa and Asia, undermining efforts to conserve biological diversity. Gaining an understanding of the underlying determinants of human–elephant conflict is important for the development of appropriate management tools. This study analysed crop-raiding by African elephants (*Loxodonta africana*) in Laikipia District, covering 9700 km^2 in north-central Kenya to identify spatial determinants of crop-raiding by elephants at different spatial extents. On average crop-raiding incidents occurred within 1.54 km of areas of natural habitat where elephants could hide by day undisturbed by human activities (‘daytime elephant refuges’). The occurrence of crop-raiding was predicted by settlement density, distance from daytime elephant refuges and percentage of cultivation. However the relationship between crop-raiding and six candidate variables varied with sampling extent, with some variables diminishing in importance at a finer spatial scale. This suggests a tiered approach to human-elephant conflict management, with different interventions to address factors important at different spatial scales. Our results show that small-scale farms are particularly vulnerable to crop-raiding at settlement densities below approximately 20 dwellings per km^2, above which crop-raiding declines. Land-use planning is therefore critical in preventing settlement patterns that leave farms vulnerable to crop-raiding by elephants. Where human–elephant conflict exists, efforts should focus on identifying and managing elephant refuges, through the use of electrified fences where resources are sufficient to construct, maintain and enforce them. This approach has been adopted for mitigating human–elephant conflict in Laikipia and with a major investment in resources and human capital it has been successful. Where such resources and human capital are not available then efforts should instead focus on the application of farm-based deterrents among vulnerable farms.

Key words: African elephant, conservation, fences, GIS, human–animal conflict, human–elephant conflict, Kenya, scale, smallholder agriculture, spatial analysis

Introduction

Large mammals may impose direct or indirect costs on the people who share their range, including threats to life and loss of productive assets such as livestock (Mishra, 1997; Thirgood *et al*., 2005). Crop-raiding by a range of wildlife species is a major cost for people in many parts of the world, in some extreme cases leading to subsistence crisis (Naughton-Treves, 1997). Such direct costs are relatively straightforward to quantify. Wildlife can also impose indirect costs, in the form of the time and money required to avoid or prevent human–wildlife conflict, such as the curfews on school children created by the presence of elephants on or near to roads leading to school (Hill, 2004). People often respond to these direct and indirect costs by actions such as injuring or killing animals, creating conflict with wildlife authorities (Woodroffe *et al.*, 2005) or management interventions to control animal movement, such as fences (Hoare, 1992). As a consequence many species of large ‘fierce’ animals are in rapid decline (Woodroffe & Ginsberg, 1998). The management of human–wildlife conflict is perhaps the greatest challenge for the future survival of many species of large mammal. This is particularly true for elephants, both African (*Loxodonta africana*) and Asian (*Elephas maximus*).

Correspondence to: Maximilian D. Graham. E-mail: mdg34@cam.ac.uk

ISSN 1477-2000 print / 1478-0933 online

DOI: 10.1080/14772000.2010.533716

Recorded incidence of human–elephant conflict (HEC), in particular crop-raiding, is increasing in rural Africa and Asia as intensification and extent of cultivation lengthens the human–elephant interface (Sukumar, 1991; Barnes *et al*., 1995; Hoare, 1999*a*; Hedges *et al*., 2005). Sustained political and media interest in the problem presents a considerable challenge to *in-situ* conservation of elephants (Lee & Graham, 2006). For these reasons it is critical to identify where and why HEC occurs (Thouless, 1994; Hoare, 1999*a*, 2000).

Temporal variation in crop-raiding by elephants is widely recognized (Bell, 1984; Thouless, 1994; Hoare, 1995; Tchamba, 1996; Osborn, 1998, 2003, 2004) and increasingly understood (Chiyo *et al*., 2005; Graham *et al.*, 2009*a*). The cultivation cycles of local farmers together with predominant rainfall patterns define a 'window' of vulnerability to crop-raiding by elephants (Bell, 1984; Sukumar, 1989; Osborn, 2003; Hillman-Smith *et al.*, 1995; Tchamba, 1996; Nyhus *et al.*, 2000). Spatial patterns of HEC, however, are less well understood (Sitati *et al.*, 2003).

Sitati *et al.* (2003) suggest there are two factors that make it hard to identify spatial determinants of HEC. First, a number of authors have noted the significance of the sexual composition of the elephants involved in HEC incidents. Hoare (1999*a*) explains the lack of strong spatial correlates for HEC in the Sebungwe region of Zimbabwe, by the preponderance of 'unpredictable' male elephants in human–elephant conflict incidents. Other studies, in Zimbabwe, Kenya and India also report a preponderance of male elephants involved in HEC incidents (Sukumar & Gadgil, 1988; Osborn, 1998; Sitati *et al.*, 2003). It has been argued that male elephants adopt behavioural strategies of risk-taking to optimize nutrient intake, and to maximize reproductive success (Sukumar & Gadgil, 1988; Hoare, 1999*a*). Around Tsavo National Park in Kenya, female elephants are responsible for the majority of HEC incidents. Interestingly spatial correlates of HEC were identified here, including distance to permanent water, elevation and proximity to protected areas (Smith & Kasiki, 2000).

Second, Sitati *et al.* (2003) explore the significance of the use of administrative boundaries as sampling units in spatial analyses of HEC, for example by Hoare (1999*a*) and Smith & Kasiki (2000). While it may be convenient to analyse HEC in relation to administrative boundaries, because data collection and practical decisions in relation to conservation planning and land use are often carried out in relation to geopolitical units (Erasmus *et al.*, 1999), the use of administrative units is problematic, because non-standard spatial units make it difficult to make comparisons between studies.

Using 1 × 1 and 5 × 5 km grid cells as sampling units, Sitati *et al*. (2003) were able to predict crop-raiding by both male and female elephants. Crop-raiding by male elephants was predicted by distance from towns and area under cultivation while crop-raiding by female-led family groups was predicted by area under cultivation alone.

In 2006, we initiated a project to build capacity to alleviate human–elephant conflict in north-central Kenya with funding provided by the UK Darwin Initiative (grant no: 15/040). As part of this project, we looked to assess the determinants of crop-raiding with a view to identifying appropriate mitigation tools. The aim of this study was to apply the grid-based method developed by Sitati *et al.* (2003) to identify spatial determinants of crop-raiding in Laikipia District in northern Kenya. We discuss the implications of our results for the management of HEC.

Materials and methods

Study-area selection

The Laikipia Plateau (9700 km^2), located in north-central Kenya (36°10′–37°3′E and 0°17′S–0°45′N), encompasses rolling low hills at an elevation of 1700–2000 m above sea level, straddling the equator, northwest of Mt. Kenya (5199 m) and northeast of the Aberdare highlands (3999 m). Annual rainfall in Laikipia varies from 750 mm in the south to 300 mm in the north, and typically falls in two seasons; the long rains, between April and June, and the short rains, between October and December (Berger, 1989; Gichuki *et al*., 1998). Laikipia is unusual in that it supports high densities of large mammals (Blanc *et al.*, 2003). An aerial survey of Laikipia in 2002 recorded 3036 elephants (Omondi *et al*. 2002), which is Kenya's second largest population after Tsavo National Park. However, the area contains no formally protected wildlife areas. Instead wildlife in Laikipia exists within a mosaic of different forms of human land-use.

In the wetter, more productive parts of south and west Laikipia, land use is dominated by smallholder farms, typically ranging from 0.5 to 2 ha in size, and covering 37% of Laikipia. These were created through the sub-division of large-scale ranches after Kenyan independence in 1963 as part of government and private settlement schemes. Crops are mostly rain-fed, although some land is irrigated along permanent rivers and streams originating on Mt Kenya and the Aberdares. These areas have the highest human population densities, ranging from 200 to 300 people per km^2 (Thouless, 1994). In the more arid central and northern parts of Laikipia subdivision of ranches has been limited, and settlement is sparse: human population density is lower, at around 25–50 people per km^2. Most smallholder farms in this area have been abandoned by their owners, due to low agricultural potential. In these failed settlement schemes, pastoralists from northern and western Laikipia and a few resilient small-scale farmers occupy the land opportunistically. The remaining large-scale ranches, ranging in size from 2500 to 100 000 acres, constitute approximately 42% of Laikipia's surface area. On ranches, human population densities are lower still (1 per km^2). With very few exceptions, ranches are tolerant of wildlife, including elephants. Many ranches run wildlife-based tourism operations and

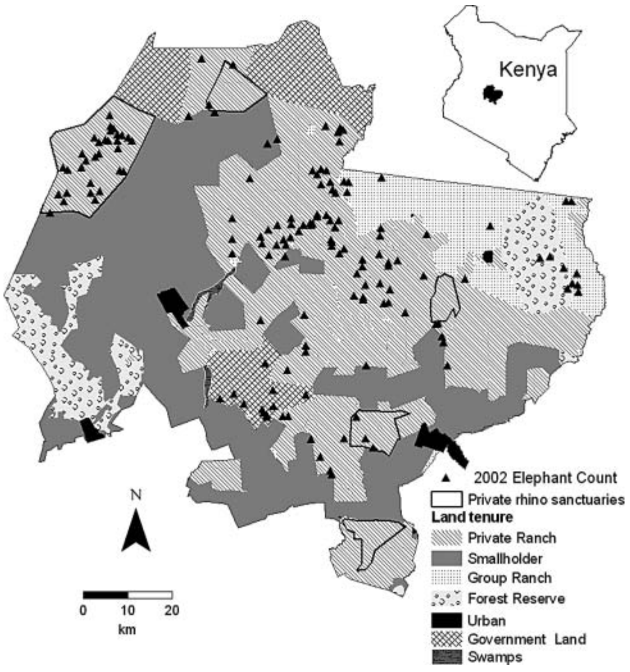

Fig. 1. Map of Laikipia District showing land-tenure and the location of elephants counted during a 2002 total aerial count.

benefit from the presence of elephants. In the northern, most arid parts of Laikipia, communally owned group-ranches under traditional livestock husbandry (and, increasingly, wildlife-based tourism) have population densities of around 10 people per km^2. Group ranches cover 11% of Laikipa. The remaining area of Laikipia consists of government forest reserves, wetlands and urban areas (Fig. 1).

Crop-raiding by elephants has been a problem in Laikipia for a very long time. In 1928, the District Commissioner (DC) under the British colonial government reported elephants shot in defence of crops on European farms surrounding the Marmanet and Ol Arabel Forests in west Laikipia (District Commissioner, Laikipa, 1928). These two forests have since been subjected to a *de facto* land subdivision process (UNEP, 2006) and in this part of the district elephants have largely disappeared. Elsewhere in Laikipia crop-raiding by elephants has intensified, associated with subdivision of large-scale cattle ranches into smallholder agricultural holdings (Omondi *et al*., 2004) and the movement of substantial populations of elephants into Laikipia from Samburu and Isiolo Districts in response to uncontrolled poaching during the 1970s and 1980s (Thouless, 1994).

Management of crop-raiding in Laikipia has taken several forms. Elephants have been shot in defence of crops since the 1920s and continue to be shot on control, legally by the wildlife authorities or killed illegally by local farmers. The current preferred solution to crop-raiding is electrified fencing (Thouless & Sakwa, 1995). In 1982 a district-wide elephant fence was proposed separating elephant-tolerant from elephant-intolerant properties (Jenkins & Hamilton, 1982). Designs for the configuration of this fencing 'solution' were proposed in 1993 (Thouless, 1993), 1998 (Wafula, 1998) and 2002 (Thouless *et al*., 2002). In 2007, funds were secured by a local NGO, the Laikipia Wildlife Forum, to construct 163 km of electric fence. The data in this paper relate to the period before the fence was constructed, and provide a baseline for the analysis of its impacts on HEC in Laikipia.

Data collection

Data on crop-raiding and other forms of human–elephant interaction in Laikipia District were collected by 10 local enumerators ('elephant scouts'), equipped with a Garmin handheld Global Positions System device and a mobile phone, and trained using an adapted version of the IUCN's *Training package for enumerators of elephant damage* (Hoare, 1999*b*). Scouts were recruited from locations identified as vulnerable to human–elephant conflict through previous research (Thouless, 1993, 1994), reports compiled in the district office and outposts of the Kenya Wildlife Service (KWS), and interviews with local people. Supervision of scouts was carried out on a weekly basis by a trained project officer with access to a motorbike. Particular care was taken to ensure that coverage was sufficient to detect all crop-raiding incidents within Laikipia over the course of the 12 months of the study. Our confidence that we recorded all crop-raiding events is based on (1) our identification of past crop-raiding locations from KWS data; (2) the depth and intensity of the project's engagement with smallholders; (3) the presence of our scouts on the ground as local residents; (4) the capacity for mobility by scouts and supervisors; (5) the care with which scouts were monitored, and reports on raids followed up; and (6) the attention paid to crop raiding by local government and the Kenya Wildlife Service.

Through public meetings and established links with schools and churches, each scout requested their respective community members to report all HEC incidents. They visited the location of any reported crop-raiding incident that occurred in their area. Once verified, the location in Universal Transverse Mercator (UTM) coordinates and incident details were recorded, including the area under cultivation, crop species damaged, time of incident and the number and sex of elephants involved, where known. The latter was estimated by examining tracks of the elephants, using standard techniques (Western *et al*., 1983) or by following up the crop-raiding group to confirm the number and sex of elephants involved directly. All data collected were thoroughly checked for errors on a monthly basis and then entered into a database.

In defining crop-raiding incidents, we used individual farms as the sampling units of measurement. From a farmer's perspective, each event has a unique causality and consequences, even if, in terms of elephant movement,

Table 1. Hypotheses and reference sources underlying the selection of candidate variables for analysing spatial patterns of crop-raiding in Laikipia District.

Variable	Hypotheses	Source of hypotheses
Distance to roads	Human–elephant conflict is negatively correlated with distance from roads	Sitati *et al.*, 2003
Distance to daytime elephant refuges	Human–elephant conflict increases with decreasing distance from daytime elephant refuges	Bell, 1984; Hoare & Du Toit 1999; Naughton-Treves, 1997; Newmark *et al.*, 1994; Smith & Kasiki, 2000
Slope/elevation	Human–elephant conflict decreases with increasing slope	Smith & Kasiki, 2000; Wall *et al.*, 2006
Area under cultivation	Human–elephant conflict increases with increasing area under cultivation	Sitati *et al.*, 2003
Dwelling density	Human–elephant conflict varies in relation to human population density	Barnes *et al.*, 1995; Hoare, 1999*a*; Sitati *et al.*, 2003; Smith & Kasiki 2000; Sukumar, 1991

sequential events are statistically dependent because a single night's foray by an elephant group may have involved more than one crop-raiding incident. We recognize this problem, but the sample size of raids was sufficiently large at 2420 events to ensure that both power (95%) and effect sizes (0.1) would be unlikely to suffer from dependence (G*Power3; Faul *et al.*, 2007).

Five candidate variables for explaining the spatial distribution of HEC were selected from previous studies (Table 1). Road vector files and a 25 m resolution digital elevation model (all derived from 1:50 000 topographic sheets) were made available through the Centre for Training and Research in Arid and Semi-Arid Lands Development (CETRAD). A 30 m resolution land-cover raster image for Laikipia and the surrounding areas, derived from a supervised classification of two 2002 Landsat ETM scenes, was made available by Mpala Research Centre (MRC). This classified image includes 14 categories, eight vegetation types, five abiotic (urban, smoke, water, ice and bare rock), and one residual category ('unknown'). Digital settlement density data for 2003 (number of dwellings/km^2), based on a high-resolution aerial survey (described in detail by Georgiadis *et al.*, 2007), was made available by the Government of Kenya Department of Resource Surveys and Remote Sensing (DRSRS).

Georgiadis *et al.* (2004) found a strong relationship between settlement data derived from a 2001 aerial sample count and known numbers of people derived from a national population census ($R^2 = 0.47$, $P < 0.001$) with the reciprocal of the slope of their regression model suggesting a mean of 4.71 people per dwelling. Bell (1984) suggested that at higher human densities, HEC occurs where nearby elephant refuges exist. There is no standard definition of what constitutes a daytime elephant refuge in the literature. However in Laikipia, elephants that raid areas of smallholder crops spend preceding days on large-scale elephant-tolerant ranches and forest reserves bordering the smallholder farming land (Graham *et al.*, 2009*a*). These provide large contiguous areas of natural vegetation where elephants can spend daylight hours with minimum human disturbance and the associated risk of injury or mortality. We identified 'daytime elephant refuges' from a map of land tenure/use (Kohler, 1987) which were subsequently verified with aerial count data (Omondi *et al.*, 2002), GPS tracking data collected by Save the Elephants (Graham *et al.*, 2009*a*), interviews with landowners and local people and local knowledge of trained enumerators on the ground.

While previous spatial analyses of HEC have included elephant density as a candidate variable (Hoare, 1999*a*; Smith & Kasiki, 2000), there is considerable movement of elephants among large-scale private ranches and forest reserves in Laikipia (Thouless, 1995, 1996; Graham *et al.*, 2009*a*). Elephant density values for individual sampling units, based on an aerial survey carried out over a single day could therefore be misleading, and so we did not include elephant density as a candidate variable in the analysis.

Data analysis

Spatial analysis of crop-raiding data was carried out following methods adapted from Sitati *et al.* (2003). As the main objective of our Darwin Initiative funded project was local capacity building our strategy here was to undertake analyses that were comparable with a range of studies, and could easily be replicated by collaborators and stakeholders over time. As such, we have not used either complex multivariate GLMM statistics or complex methods to statistically assess any effects of spatial autocorrelation (e.g. Dormann *et al.*, 2007). All crop-raiding incident data and candidate variables were imported into a GIS and superimposed onto a 5 × 5 km grid. We used a 5 × 5 km grid here because in the study carried out by Sitati *et al.* (2003) crop-raiding values at the 5 × 5 km grid cell level were spatially independent, whereas they found that crop-raiding values at higher resolution sampling units (1 × 1 km grid cells) were found to be significantly autocorrelated. We calculated the Euclidian distance from the centre of each 5 × 5 km grid cell to the nearest daytime elephant refuge and road using ArcInfo (ESRI, 2004). Settlement densities at 2.5 km resolutions were resampled to the 5 × 5 km grid using the

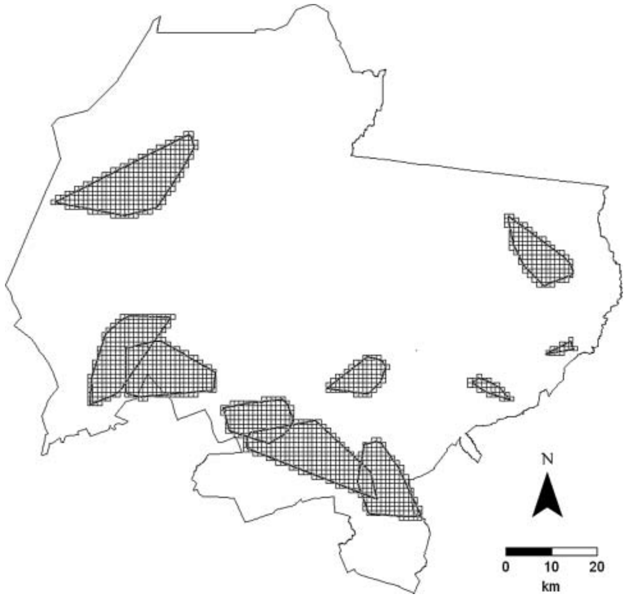

Fig. 2. Minimum convex polygons (MCPs) comprising the total area in which all crop-raiding events were recorded by each enumerator.

bilinear algorithm in ArcInfo. Percentage of crop cover in each 5 × 5 km grid cell was calculated by resampling the available land cover layer to a 100 m resolution, using the nearest neighbour algorithm, and then computing the count of individual 100 m cells classified as cultivated in each 5 × 5 grid cell.

Recognizing the potential problems of scale in obfuscating the relationship between dependent and independent variables (Turner *et al*., 1989), we carried out an analysis of crop-raiding by elephants at two different spatial extents. The first of these was the entire district, while the second was the 'HEC zone' specifically (Fig. 2), delineated by combining minimum convex polygons (MCPs) created for each individual enumerator. Each MCP was calculated using the spatial locations of crop-raiding incidents recorded by each enumerator with the Animal Movement extension for ArcView v.3.2 (Hooge & Eichenlaub, 1997). MCPs overlapped in some cases because scouts occasionally supported each other during times of intense crop-raiding. MCPs varied in size, due to differences in local patterns in crop-raiding and do not represent the total area monitored by each scout but rather the total area in which crop-raiding occurred, based on the incidents recorded.

After pre-processing in the GIS environment, data were analysed in SPSS v.12. (SPSS, 2002). Spearman's rank correlations were used to test the significance of relationships between crop-raiding intensity and individual candidate variables. For multivariate analysis, crop-raiding data in each cell were binary coded into presence/absence to build logistic regression models. The entry and exit of potential predictor variables was determined by the Wald statistic using P values of 0.05 and 0.1, respectively. The relative significance of each variable included within logistic regression models was evaluated using the Wald statistic.

Where spatial autocorrelation among data exists, statistical analyses can exaggerate degrees of freedom, increasing the risk of committing type I errors (Haining, 2003). The Moran's I statistic provides a measure for quantifying spatial dependence among data (Cliff & Ord, 1981). In this study we tested for spatial autocorrelation in the dependent variable. An auto covariate term was generated to improve the fit of logistic regression models and remove spurious variables from the analysis (Augustin *et al*., 1996; Sitati *et al*., 2003). The term used in this study was an inverse Euclidean distance weighted mean of conflict intensity in the eight surrounding cells of each cell in the sample, after Sitati *et al.* (2003).

For logistic regression analyses carried out at the spatial extent of the entire district, a random set of approximately 50% of grid cells was used to train models (34 presences, 138 absences) with the remaining 50% of cells used to test models (49 presences, 164 absences). Within the HEC zone there were 104 grid cells available for analyses. Of these, crop-raiding was present in 85. To build and test multivariate logistic models a random set of 94 training cells and 10 testing cells (7 presences and 3 absences) was generated. Because of the small sample of absences, we carried out this analysis five separate times, so that model performance was tested on 50 difference cells in total. Model performance for testing sets was assessed by calculating the area under the curve of receiver operating characteristics, ROC (Hanley & McNeil, 1982). ROC values range from between 0.5 to 1 with values above 0.7 indicating a good model fit (Sitati *et al.*, 2003).

Results

Crop raiding characteristics

Between November 2003 and November 2004 a total of 2420 crop-raiding incidents were recorded by trained enumerators, an encounter rate of approximately 10 per day. A total of 25 different species of crop were damaged in crop-raiding incidents. Maize *Zea mays* L. was the species most frequently damaged (63% of cases), followed by beans *Phaseolus vulgaris* L. (40%), potato *Solanum tuberosum* L. (37%), sweet potato *Ipomoea batatas* L. (20%), onion *Allium cepa*, L. (17%) and sorghum *Sorghum vulgare* L. (15%). In 50% of cases, 6% or less of the total cultivated area was damaged (median = 5.7, interquartile range (IQR) = 14) and cases in which farms were severely damaged (>50% of the planted area) were relatively rare, comprising just 8% of all cases. There were 66 cases (3% of the

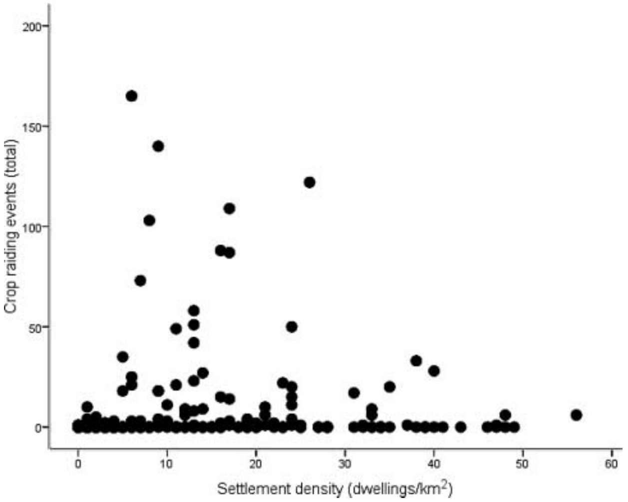

Fig. 3. The relationship between crop-raiding intensity and settlement density among 25 km^2 grid cells at the spatial extent of the entire Laikipia District.

total number of crop-raiding incidents reported) in which 100% of the crop on a single farm was damaged.

Crop-raiding occurred exclusively at night. Groups of male elephants were implicated in 53% of all crop-raiding incidents. Lone males were involved in 13% of crop-raiding incidents. The number of elephants involved in crop-raiding incidents varied between 1 and 45 (median = 3, n = 2418). On average, crop-raiding incidents occurred within 1.54 km of identified daytime elephant refuges (IQR 0.38–1.64, n = 2420).

Spatial pattern of crop-raiding

Crop-raiding incidents among 25 km^2 grid cells at the spatial extent of the entire district were significantly autocorrelated (Moran's I statistic = 0.21, $P < 0.01$). At this spatial extent crop-raiding intensity was most strongly correlated with settlement density followed by distance from daytime elephant refuge (negative) and area under cultivation (positive). The relationship between crop-raiding intensity and settlement density was non-linear (Fig. 3) with crop-raiding intensity values non-existent to low in cells with very low settlement density, increasing sharply at intermediate values of settlement (5–15 dwellings per km^2) and then decreasing beyond a density 'threshold' of around 20 dwellings per km^2.

At the more refined sampling extent of the HEC zone crop raiding incidents among 25 km^2 were not significantly autocorrelated (Moran's I statistic = 0.004, $P > 0.1$). Crop-raiding intensity was significantly correlated with distance from daytime elephant refuges (Fig. 4) followed by settlement density and slope (Table 2).

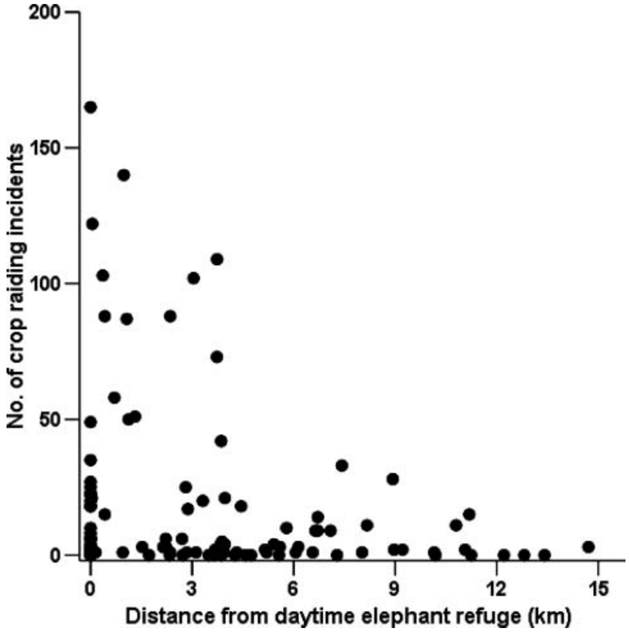

Fig. 4. Relationship between crop-raiding intensity and distance from elephant refuge among 25 km^2 grid cells at the HEC zone scale.

At the spatial extent of the entire district, significant logistic models were generated for predicting the occurrence of crop-raiding among 25 km^2 grid cells (ROC = 0.82). Crop-raiding among 25 km^2 grid cells was predicted by settlement density and distance from elephant refuge (Wald statistic = 16.3 and 13.1, respectively). The auto-covariate term was not a significant predictor of crop-raiding among 25 km^2 grid cells at the district scale. Models for predicting the occurrence of crop-raiding among 25 km^2 grid cells within the HEC zone were weaker, but still significant (ROC IQR: = 0.7–0.66). Distance from daytime elephant refuge was the only predictor of crop-raiding occurrence at this spatial extent.

Discussion

This study applied the spatial analysis procedure developed by Sitati *et al.* (2003) to a larger, heterogeneous land-use

Table 2. Spearman's rank correlations (r_s) for associations between six independent variables and crop-raiding among 25 km^2 spatial units at two different scales, $^*P < 0.05$, $^{**}P < 0.01$. Because of significant spatial autocorrelation at the district level, significance levels are not stated (Balmford *et al.*, 2001).

Variable	District	HEC zone
Auto covariate term	−0.048	0.097
Distance from refuge	−0.352	−0.260**
Area of cultivation	0.259	0.013
Slope	0.08	−0.179*
Settlement density	0.395	0.181*
Distance from roads	−0.175	−0.003

region with high elephant density. Our results also show that determinants of crop-raiding by elephants can be identified through a simple GIS grid based analysis. Hoare (1999*a*) did not identify significant spatial determinants of crop-raiding in Zimbabwe. He argued that this was because the majority of crop-raiding incidents involved male elephants which are unpredictable. However the majority of crop-raiding incidents we recorded in Laikipia also involved male elephants and so we believe his results are possibly a consequence of methodology rather than elephant ecology. When comparing the results of this study to previous spatial analyses of crop-raiding by elephants there are several issues that emerge that merit discussion.

Firstly our results suggest that the relationship between crop-raiding and independent variables varies with the spatial extent of analysis. It appears to be easier to identify predictors of HEC at broader spatial extents. Therefore, if resources are limited, then the use of districts or known elephant ranges to define the spatial extent to be used in the analysis of HEC, as undertaken by Sitati *et al*. (2003), Smith & Kasiki (2000) and Hoare (1999*a*) is adequate for identifying broad priorities for management intervention. The effect is illustrated by Sitati *et al.* (2003) who found that the main predictor of the occurrence of crop-raiding at 1000 km^2 was area under cultivation. Here, area under cultivation also had some explanatory power for the occurrence of crop-raiding at the extent of the entire Laikipia District. At this broad spatial extent, effective management intervention requires an understanding of where HEC might occur, and therefore knowledge of the location of cultivation zones in relation to elephant refuges. This could help, for example, with planning appropriate locations for establishing wildlife authority outposts.

However, within this study the relationship between crop-raiding and cultivation disappeared at the smaller spatial extent encompassed by the HEC zone. This may be because within the HEC zone cultivation is likely to be more evenly accessible overall. While models for predicting the occurrence of crop-raiding were weaker within the HEC zone, our results indicate that from an elephant's perspective, distance during a sortie into crop lands might be more important indicators of risk and therefore willingness to raid than is simply cultivated area (see also Graham *et al.*, 2009*a*). This suggests that within human–elephant conflict zones, intervention should instead focus on elephant refuges and vulnerable farms, such as those to be supported for simple farm-based deterrents, as described by Osborn & Parker (2003), and Graham & Ochieng (2008), or for the appropriate location for an electrified fence. Given our results we suggest that future spatial analysis of HEC assesses the strength of predictor variables at different spatial extents in order to distinguish factors that are important at the regional level from factors that operate within the specific HEC areas vulnerable to crop-raiding. Such an approach could facilitate the development of a tiered management approach to HEC.

Secondly, the relationship between crop-raiding by elephants and settlement density found in this study illustrates the role of landscape structure (Forman & Godron, 1986) in defining levels of vulnerability to crop-raiding among small-scale farmers and has not been identified in previous spatial analyses. If, as suggested by our results, elephant crop-raiding declines after a density of around 20 settlements per km^2, or 94 people per km^2, then managing farm vulnerability is essential. In Laikipia relatively low and unpredictable annual rainfall has constrained the expansion of smallholder settlement, so that settlement densities are often below this threshold. The resulting settlement pattern for much of Africa's arid and semi-arid lands where human dwellings and associated cultivation patches are clustered, typically close to permanent water, within larger areas of rangeland, leaves individual households acutely vulnerable to crop-raiding by elephants. Under such conditions the importance of land-use planning as a HEC management tool is critical.

Thirdly, in contrast to previous spatial analyses of crop-raiding by elephants (Smith & Kasiki, 2000; Sitati *et al.*, 2003), distance from daytime elephant refuges emerged as a significant spatial predictor of crop-raiding in this study. This may be due to the way in which elephant refuges were defined and delineated in previous studies. For example Smith & Kasiki (2000) did not identify existing elephant refuges other than protected areas (Tsavo East and Tsavo West National Parks). However elephants also use and occupy large-scale ranches within the Tsavo ecosystem (e.g. Taita and Rukinga Ranches; M.D. Graham pers. obs. 1999/2000). Sitati *et al*. (2003) used forest boundaries as a measure of daytime elephant refuges, but they didn't have access to elephant distribution data, and thus these boundaries may not adequately represent daytime elephant refuges. The majority of crop-raiding incidents recorded in this study occurred within 2 km of daytime elephant refuges, but there were also incidents at locations some 10 km from the closest identified daytime elephant refuge. In those cases, it is possible that there were other elephant refuges, such as areas of uncultivated thicket or bush that provided individual or small numbers of crop-raiding elephants with adequate cover to hide during the day. More detailed field surveys to identify less obvious daytime elephant refuges could help explain variance in crop-raiding intensity in both Laikipia and other study sites, and should be a priority for future research. The identification of elephant refuges would also greatly facilitate the management of human–elephant conflict in land-use mosaics.

Our data and results, particularly with regards to the role of daytime elephant refuges in determining crop-raiding occurrence and density, support the logic behind the proposal by the Laikipia Wildlife Forum to construct

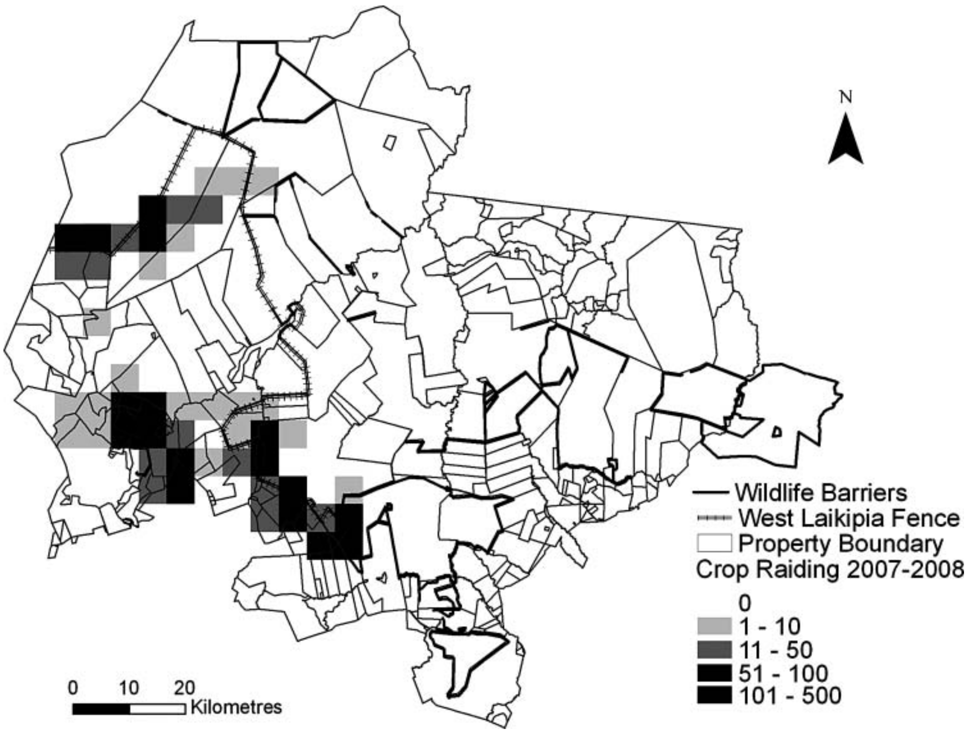

Fig. 5. Crop-raiding between 2007 and 2008, existing wildlife barriers and the newly constructed West Laikipia Fence.

the 163 km contiguous electrified fence in West Laikipia (Fig. 5) to separate properties where elephants are tolerated (large-scale ranches and communal areas) from properties where elephants are not tolerated (small-scale arable farms). This proposal was successful, with the majority of funding secured through the Royal Netherlands Embassy, and the remainder secured from the Government of Kenya, through the Kenya Wildlife Service. In Laikipia the effective management of human–elephant conflict will depend on the measures taken to ensure this electrified fence is effective. This is no easy task. Many electrified fences have been built across Africa with the aim of mitigating human–elephant conflict. However, elephants adapt to and break new fence features, creating an expensive 'arms race' between managers and elephants (Thouless & Sakwa, 1995).

This was the challenge confronting The Laikipia Elephant Project (LEP), implemented by Cambridge University with support from the UK Darwin Initiative in collaboration with local partners between 2006 and 2009. In 2007 the Laikipia Wildlife Forum and the Kenya Wildlife Service began constructing the West Laikipia Fence, after securing the funds to do so, against expectations. However, as soon as this fence was constructed elephants and people broke it. All the stakeholders involved in LEP had to respond to this challenge or the project risked becoming irrelevant to local partners. This was achieved through three key activities undertaken with support from the Darwin Initiative.

Firstly, an assessment of the factors contributing to fence performance was undertaken through a study of the Ol Pejeta Conservancy (Graham *et al*., 2009*b*), a 100 000 acre wildlife property committed to wildlife conservation, owned by a not-for-profit entity, that is located in southern Laikipia. This identified factors that are critical in ensuring electrified fences are effective barriers to elephant movement (voltage, design, maintenance and enforcement). The package of tools identified as critical to fence performance was subsequently rolled out under the supervision of LEP along the West Laikipia Fence. Secondly, a trial was undertaken of the use of mobile phone communication to enable different groups of stakeholders to report and respond to fence-breaking incidents to ensure that fences were properly monitored and so that the severity of associated crop-raiding incidents was minimized (Graham *et al.*, 2009*c*). Subsequently an adapted mobile phone-based monitoring and reporting system was also rolled out among those working to manage the West Laikipia Fence. Thirdly, trials were undertaken on the use of community drama in mobilizing community groups to take responsibility for the management of HEC (Graham *et al.*, 2009*d*). Community drama subsequently became an important tool applied to address the problem of poor performance along some sections of the West Laikipia Fence as a result of vandalism by members of the neighbouring communities.

The overall outcome of the sustained implementation of the activities described above, after funding from the

Darwin Initiative ended in 2009, by local organizations, has been a significant decline in fence breaking and an associated decline in crop-raiding among the small-scale farms neighbouring the West Laikipia Fence, on the basis of the data recorded by trained enumerators. This has been very difficult to achieve, both in terms of resources and the considerable human capital and expertise that were required. Where such resources are not available, investments in simpler communal farm-based defence systems may be more appropriate (Osborn & Parker, 2003; Sitati & Walpole, 2006; Graham & Ochieng, 2008; Hedges & Gunaryadi, 2009). However the decline in crop-raiding recorded in Laikipia demonstrates the significance of the spatial analysis and associated results described in this paper for the management of human–elephant conflict.

We demonstrate that a small investment in a local scout-based monitoring system, combined with a relatively simple 5 × 5 km grid-based analysis of the associated data at the landscape scale, using off-the-shelf GIS and statistical software, is extremely useful for understanding and managing the conflict between people and large mammals. We believe the application of this approach would be useful to the study and management of human–wildlife conflict in other sites across the world, though particularly in the developing world, where small and judicious investments in local employment and training will reap the greatest returns for conservation.

Acknowledgements

We thank the funders of this research, the UK Government's Darwin Initiative for the Survival of Species (grant no. 15/040), The Royal Netherlands Embassy in Kenya, the UK Economic and Social Research and Natural Environment Research Councils, the Swiss Agency for Development and Cooperation's Eastern and Southern African Partnership Programme, the US Fish and Wildlife Service and Save the Elephants. This research was undertaken with the kind permission of the President of the Republic of Kenya. The Centre for Training and Research in Arid and Semi-Arid Lands Development, Nanyuki, the Laikipia Wildlife Forum and the Kenya Wildlife Service provided institutional support. We are grateful to Boniface Kiteme, Nigel Leader-Williams, Iain Douglas-Hamilton and Robert Haining for their advice. We especially thank The Laikipia Wildlife Forum, in particular Anthony King, for their commitment to the mitigation of HEC in Laikipia.

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