Received: 7 December 2021 | Revised: 23 October 2022 | Accepted: 21 November 2022

DOI: 10.1111/aje.13095

RESEARCH ARTICLE

African Journal of Ecology WILEY

Mitigating crop raiding by forest elephants and baboons at Kibale National Parkh

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Funding information
International Development Research Centre, Grant/Award Number: 108570-001

Abstract

In Africa, most protected forests are in densely human-dominated landscapes where human–wildlife conflict is intense. We documented farmer perceptions and responses to crop-raiding wildlife from Kibale National Park, Uganda. Crop raiding was mostly (95%) by baboons (*Papio anubis*) and elephants (*Loxodonta africana*). While the financial loss caused by baboons and elephants did not differ, elephants were perceived as more damaging. Guarding and trenches were perceived as the most effective deterrent strategies for baboons and elephants, respectively. Distance from the park boundary and household income were significantly associated with a greater likelihood of crop raiding. Distance from the park, household head age and the species that raided crops, influenced whether a household applied one or more deterrent strategies. Households headed by women or older adults were most vulnerable, experiencing greater losses to raiding. Patterns of human–wildlife conflict around Kibale forest are complex, but the extent of crop damage was mostly determined by distance from the park and farm socio-economic status and thus their ability to mitigate or deter raiding. Managing crop raiding requires collaboration between the park and affected farmers to ensure that mutually managed deterrent methods, such as trenching (elephants) and guarding (baboons), are effectively shared, applied and maintained.

KEYWORDS
baboons, deterrent strategies, elephants, human–wildlife conflict, trenches, tropical forest

Résumé

Dans la plupart des pays d'Afrique, les forêts protégées se trouvent dans des paysages à forte densité humaine où les conflits entre l'homme et la faune sauvage sont intenses. Nous nous sommes documentés sur les perceptions et les réactions des agriculteurs face aux animaux sauvages qui pillent les cultures dans le parc national de Kibale, en Ouganda. Les pillages de cultures étaient principalement (à 95%) le fait des babouins (Papio anubis) et des éléphants (Loxodonta africana). Si les pertes financières causées par les babouins et les éléphants ne diffèrent pas, les éléphants sont perçus comme plus dommageables. Le gardiennage et les tranchées ont été perçus comme les stratégies de dissuasion les plus efficaces pour les babouins et les éléphants, respectivement. Les facteurs suivants ont été associés de manière significative à une plus grande probabilité de pillage des cultures : la distance par rapport à la limite du parc et le revenu du ménage. La distance par rapport au parc, l'âge du chef de ménage et les espèces qui attaquent les cultures ont influencé l'application d'une ou plusieurs stratégies de dissuasion par les ménages. Les ménages dirigés par des femmes ou des adultes plus âgés étaient les plus exposés et subissaient des pertes plus importantes en raison des pillages. Les schémas de conflit homme-faune autour de la forêt de Kibale sont complexes, mais l'étendue des dommages aux cultures a été principalement déterminée par la distance du parc et le statut socio-économique des fermes et donc leur capacité à atténuer ou à dissuader les pillages. La gestion du pillage des cultures nécessite une collaboration entre le parc et les agriculteurs concernés afin de s'assurer que les méthodes de dissuasion gérées mutuellement, telles que le creusement de tranchées (éléphants) et le gardiennage (babouins), sont effectivement partagées, appliquées et maintenues.

1 | INTRODUCTION

Africa's biodiversity faces unprecedented environmental challenges. Already, 20% of Africa's land surface (6.6 million km^2), an area twice the size of India, is degraded and projections suggest that by 2100 more than half of Africa's bird and mammal species could be lost (Archer et al., 2018). In addition, Africa's human population is set to quadruple by 2100 (Gerland et al., 2014; UN, 2015). The need to feed this growing population has contributed to the fragmentation of Africa's forests, so that most forests outside the Congo Basin are now small fragments enclosed by large human populations (Chapman & Peres, 2021; Potapov et al., 2017). An inevitable consequence of a burgeoning human population is that human–wildlife conflict is increasing around the few remaining forested parks in Africa (Hartter et al., 2011; Webber et al., 2007). This contributes significantly to many parks struggling to effectively protect biodiversity (Laurance et al., 2012) and has led to retribution killings of wildlife, including endangered wildlife species (Chomba et al., 2012).

Crop raiding around protected areas is the most prevalent form of human–wildlife conflict and the damage can be substantial (Baynham-Herd et al., 2018). Forest-fringe farmers in Africa lose on average 16.7% of their crops to animals (Oerke et al., 1994), and in some cases an average victim household may lose as much as 26% of its annual total income (Tumusiime & Vedeld, 2015). Although small losses can be planned for and tolerated, crop raiding by large animals, such as elephants (*Loxodonta africana*) are so devastating that an entire season's crop may be lost in one night (Naughton-Treves, 1998; Naughton-Treves et al., 1998). Farmers confront these threats by using physical barriers, such as trenches and electric fences (MacKenzie, 2012b), and planting of thorny hedges (Tumusiime & Svarstad, 2011), deploying chemical deterrents such as burning chilli peppers or smoky fires, placing beehives along park borders (King et al., 2010), and guarding and noisy deterrents (yelling, drums, whistles) to scare animals away (Litoroh et al., 2012). However, these deterrent measures are labour-intensive and incur lost opportunity costs through reduction of income (Naughton-Treves, 1998) or keeping children from school to guard crops (Kagoro-Rugunda, 2004; Mackenzie et al., 2015; Tumusiime & Svarstad, 2011). As a result, crop raiding inhibits socio-economic development in several ways.

This study evaluates the extent of crop raiding around Kibale National Park, Uganda. This forest park is managed by the Uganda Wildlife Authority (UWA) whose mandate is to manage the wildlife and protected areas of Uganda in partnership with neighbouring communities. Using a questionnaire survey of farmers surrounding Kibale National Park, this study aims to: (1) identify the wildlife species that cause the greatest damage and financial loss; (2) assess farmer perceptions and responses to crop raiding; (3) examine how raided households differ in their socioeconomic status such as age, gender structure and wealth and (4) identify the deterrent strategies used on farms and their perceived and actual efficacy. Our overall objective is to determine what ecological, physical and socioeconomic factors affect a farm's vulnerability to crop raiding and whether deterrent strategies applied by the local community or the Uganda Wildlife Authority are effective or not.

2 | METHODS

2.1 | Study area and stakeholders

This study was conducted in the communities neighbouring Kibale National Park, a 795 km^2 protected area in western Uganda (0°13′–0°41′N and 30°19′–30°32′E) near the foothills of the Rwenzori Mountains (Chapman et al., 2021; Chapman & Lambert, 2000). Kibale is dominated by mid-altitude (920–1590 m), moist-evergreen forest and receives an annual rainfall of 1655 mm (1970–2020) in two rainy seasons (Chapman, Valenta, et al., 2018).

Human population density surrounding Kibale increased 10.5-fold between 1959 and 2002 (Hartter et al., 2015). Between 2000 and 2020, the population within 1 km of the park boundary almost doubled from 123 to 229 people km^{-2} (MacKenzie, Salerno, Chapman, et al., 2017; WorldPop, 2020). Local Batoro and Bakiga people are primarily subsistence farmers growing staple foods, such as bananas, maize, beans and cassava and the average farm size is 1.4 ha (MacKenzie, Salerno, Chapman, et al., 2017; Majaliwa et al., 2015). Some farms also grow cash crops, such as tea, eucalyptus and coffee, while others find work in tea plantations, at the Makerere University Biological Field Station, in the tourism industry, with reforestation projects, as casual labourers on local farms, or commute to the nearest large town of Fort Portal to work (Mackenzie, 2012a; Sarkar et al., 2019).

Nine villages adjacent to the park (within 1400 m) that experience frequent crop-raiding events were surveyed – Kabucuukire, Kanyashohera, Kyamugarra, Kaburara, Makobyo, Ibura, Miranga, Sebitoli and Isule (Figure 1). The gap between the southern cluster of villages and Sebitoli village is filled by tea plantations. Sebitoli was included because raiding by elephants has been reported by this village and we used this village as an outlier for comparison with other villages to determine if any location-specific differences in crop-raiding trends were detected. A village was defined according to Mackenzie and Ahabyona (2012), as the spatial extent of households associated with a village name under the leadership of one village chairperson.

2.2 | Questionnaire and survey design

Within each village there were 20–104 ($\bar{x} \pm SE = 58.2 \pm 1.3$) households. Household registers were accessed through the village chairperson and there were 524 registered households. In each village, 14–49 households were randomly surveyed depending on the number of households. In total, 297 households were interviewed representing 56.7% of the registered households. Each household's location was recorded. Only household heads or their spouses were interviewed. The researcher and the Ugandan field assistant conducted all interviews in one of the local languages (Rutoro and Rukiga) or English.

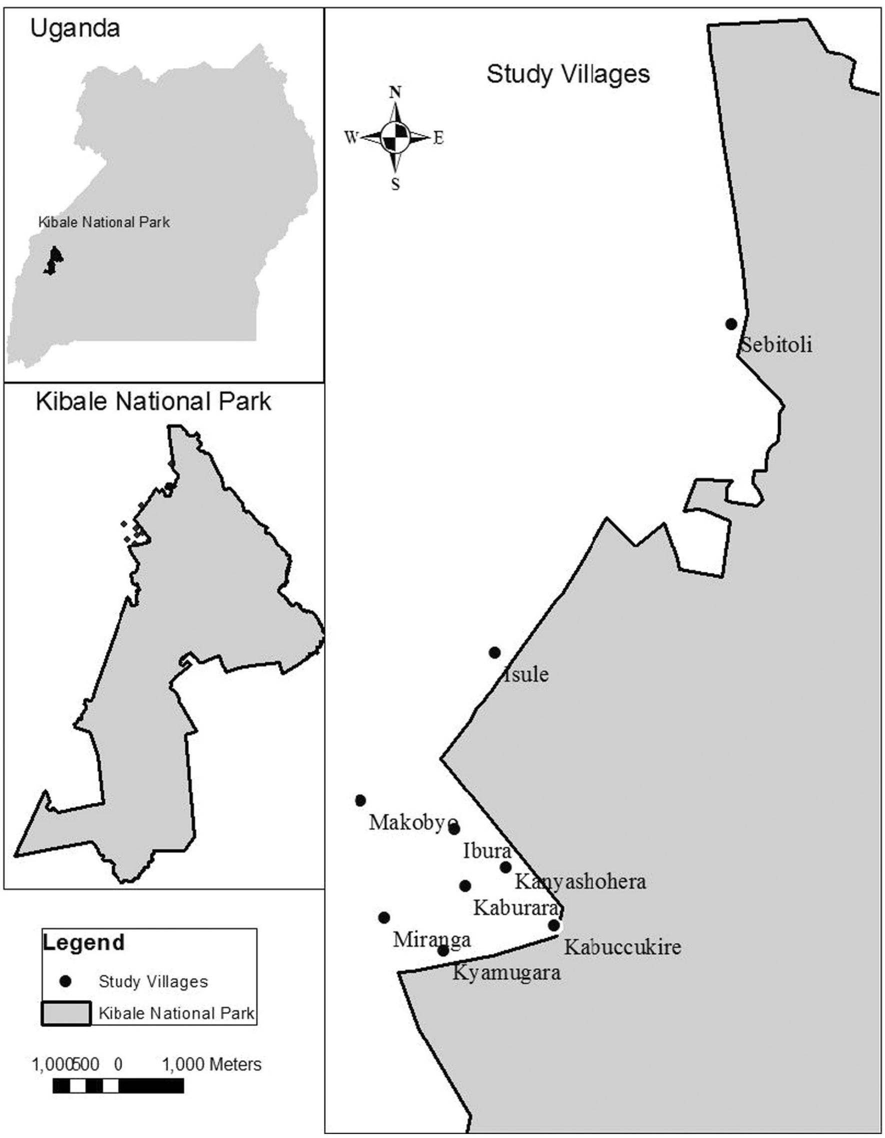

FIGURE 1 All nine villages on the north-western boundary of the park close to the Makerere University Biological Field Station at Kanyawara were visited.

The questionnaire survey of farmers' perceptions of the damage caused by crop-raiding animals was administered in June and July 2018. Respondents were asked to rate and report their experience for the last growing season only. Pre-testing of the questionnaire was conducted through focus group discussions to assess the reliability of responses and the relevance of the questions. The questionnaire comprised closed-ended questions to characterise demography, land use and education level of respondents and the people occupying a particular farm (Appendix S1). Open-ended questions were used to determine perceptions of and responses to crop raiding (following Hartter et al., 2016). To rank the wildlife perceived as most problematic on a scale of 1 (most problematic) to 4 (least problematic), farmers were asked if their household had experienced crop raiding in the previous growing season up to the present (i.e., during 2018) and what wildlife species had raided specific crops. The type of crop(s) raided, the growth stage of the raided crops, the type and extent of damage to the crops, the frequency of raids by each wildlife species, and the financial loss (farmer's estimated market value) to crop raiding were recorded from stakeholders' responses.

The types of deterrent strategy used, if any, was recorded from each household representative, who also ranked the perceived effectiveness of the strategies. In addition, each household estimated the direct financial cost of maintaining the deterrent methods throughout the season. In this way, the cost to a household of all deterrent methods except trenches was evaluated. Along some areas of the park boundary, trenches have been dug (3 m deep and 2–3 m wide) to prevent elephant crop raiding. Their construction was funded from 20% of the park entrance fees that UWA shares with the local communities for development projects, or directly from UWA, Face the Future Foundation and the International Union for Conservation of Nature (MacKenzie, 2012b; Mackenzie & Ahabyona, 2012).

To verify crop loss to wildlife estimated by farmers, from June through July 2018 a trained local assistant in each village collected quantitative data about the type and extent of crop raiding on local farms, and also verified the strategies farmers used to deter crop raiding. The size of the farm and the area of a crop type that was damaged were measured on the ground using GPS waypoints and farm-level estimates calculated using GIS. Physical and financial crop losses were verified from extrapolation of the amount of produce lost per area damaged and the corresponding value of that produce on the local market. The wildlife species causing damage to crops was verified from tracks, dung and teeth marks on food items. The distance the animals travelled from the park boundary was measured by following animal tracks back to the park boundary.

2.3 | Statistical analyses

Analyses are focused on raids caused by baboons and elephants because these species were the primary crop raiders with frequent visits and intense damage per-unit-area. Analyses of baboon and elephant raids were handled separately. The frequency of raids per crop type and the stage of growth when the crop was raided were examined using chi-square tests. Univariate analysis of variance (ANOVA) was used to determine the differences in the financial cost of crop raiding among crops. The influence of distance from the park boundary on the financial cost of crop raiding was examined using ordinary least-squares regression. The sample population of 297 households was examined for differences in socio-economic and physical variables influencing the use of deterrent strategies using multinomial logistic regression. Principal Component Analysis (PCA) reduced the set of variables to a smaller set with little or no collinearity for inclusion in the multinomial logistic regression (Field, 2013). The selected variables were further checked for collinearity using variance inflation factor analysis (VIF $<$ 5, acceptable). Only116 households reported deterring crop raiding animals and the methods used by these households were examined. For the 297 households, the socio-economic and physical correlates of the binary likelihood of raids (raid or no raid) were examined separately for baboons and elephants using generalised linear models (GLM) with a log-link function. The data were weighted by the number of households interviewed in each village and village identity was set as a fixed factor. No striking differences in the physical and socioeconomic variables were found between Sebitoli and the southern cluster of villages and Sebitoli was not included in further analyses, that is analyses focused on the southern cluster of villages. The financial loss to crop-raiding wildlife estimated by households was examined using generalised linear mixed models with raiding wildlife species, crop type and deterrent strategy as fixed factors and household identity as a random factor.

3 | RESULTS

3.1 | Crop-raiding wildlife

Ninety-one percent of respondents ($n = 290$ households) considered crop raiding the worst problem facing farming in the region. Of the respondents, 56% ($n = 166$) had experienced crop raiding in the previous season. Crops were raided throughout the year regardless of the growth stage of the crop. In addition, baboons took chickens and young goats.

We verified 132 incidents of crop damage to 69 farm gardens, representing 41.5% of the farms that reported crop damage by wildlife. The physical assessment of the actual crop damage indicated that most (95% by frequency and 91.6% by mean area of damage) of the crop raiding was caused by baboons (*Papio anubis*) and elephants (*Loxodonta africana*) (Table 1). Accordingly, we focus on these two species. Very little damage was done by bushbuck (*Tragelaphus scriptus*), chimpanzees (*Pan troglodytes*) and red-tailed monkeys (*Cercopithecus ascanius*) (Table 1).

3.2 | Farmer perceptions and responses to crop-raiding baboons and elephants

The crop area lost to wildlife per raid ranged from only a few square metres to over a hectare (Table 1). Most gardens had one to three crops that were inter-cropped. Twelve crop types were damaged

TABLE 1 The area of crop damage and the estimated financial loss to crop-raiding animals from Kibale National Park, Uganda

	Damage validation					Household survey		
		Garden area damaged (m^2)		Financial loss ($US)		Damaged	Financial loss ($US)	
Raiding species	%	Mean	Max	Mean	Max	%	Mean	Max
Baboons	64	448	3600	$25.60	$209.90	35	$62.70	$279.90
Bushbuck	1	15	15	$2.80	$2.80	No record		
Chimpanzee	1	13	12.7	$1.70	$1.70	0.5	$232.30	$232.30
Elephant	31	895	12,175	$35.80	$209.90	48	$87.30	$285.50
Redtails	3	96	325	$4.70	$8.40	7	$50.00	$279.90
Vervet	No record					9	$30.80	$70.00

Note: A total of 132 incidences of crop raiding were verified by physical examination at the crop-raiding site and 205 reports of crop raiding were described during household surveys.

by wildlife: bananas, beans, cassava, cabbage, cowpeas, eggplants, ground-nuts, potatoes, maize, millet, papaya and sugarcane. Baboons and elephants differed in their crop type preferences. Incidents of elephant raids were 39.4% for maize and 30.3% for bananas. By contrast, 29.3% of raids by baboons were for potatoes, 14% for maize and 9% for beans. For a particular crop, 83.3% of the raids on bananas were by elephants and 16.7% by baboons, while 27.7% of raids on maize were by elephants and 72.3% were by baboons. On average, a single crop covered 1783 m^2 or 0.18 ha (range 10 m^2 to 2 ha). There was no overall difference between baboons and elephants in the financial loss they caused ($F_{11, 104} = 0.92$, $p = 0.53$), although on average elephants caused more financial loss ($2.45 per m^2) per unit area of a garden than baboons ($0.56 per m^2) and per crop-raiding event (Table 1).

Only baboons and elephants were considered to cause important financial loss. Other species that damaged crops were not considered important crop raiders; however, it is noteworthy that the one incidence where chimpanzee raided a crop, the damage was substantial. Elephants travelled longer distances than baboons to raid crops causing greater financial loss to farms further from the boundary. Elephants targeted mature crops, while baboons raided crops at all stages, but most frequently raided crops during the flowering stage ($\chi^2 = 24.5$, df = 6, $p < 0.0001$).

TABLE 2 Generalised logistic regression model of the socio-economic variables associated with crop raiding by baboons in Kibale National Park, Uganda

Variable	Coeff. (B)	Wald	df	Chi. pr.
Age	−0.019	1.238	1	0.266
Income	0	0	1	0.997
Household size	−0.118	0.771	1	0.38
Distance to forest	0.002	0.362	1	0.548
Village				
Ibura	20.97	0	8	0.997
Isule	−0.328	0.159		0.69
Kabuccukire	−0.781	1.032		0.31
Kaburara	0.758	0.394		0.53
Kanyashohera	1.733	4.523		0.033
Kyamugarra	20.396	0		0.999
Makobyo	19.927	0		0.997
Miranga	20.028	0		0.997
Gender-Female	−0.273	0.171	1	0.679

Note: Age = age of primary respondent; Income = income of household; Gender = gender of household head. Variable selection was based on PCA analysis.

3.3 | Socioeconomic and physical factors implicated in crop raiding

3.3.1 | Baboons

The bi-plots and component scores from PCA indicated that the age of the respondent, gender of the respondent, income level, household size, distance from the forest and the location of a village were relatively independent variables characterising farms raided by wildlife. Nevertheless, logistic regression of crop raiding by baboons revealed no influential variables except that the Kanyanshohera village was raided significantly more than expected by baboons (Table 2). Otherwise, there was no statistical difference in the likelihood of raiding by baboons among the villages ($F_{8, 153} = 170$, $p = 0.103$). Households further from the forest edge were less likely to be raided (Figure 2). However, wealthier households with potentially better managed and bigger farms were raided by baboons slightly more frequently than poorer households (Wald statistic with χ^2 distribution: $W = 3.79$, $p = 0.053$).

3.3.2 | Elephants

Like baboons, elephants visited Kanyanshohera more than expected ($W = 4.37$, $p = 0.035$), nevertheless there was no statistical difference in the likelihood of raids among villages ($F_{8, 155} = 170$,

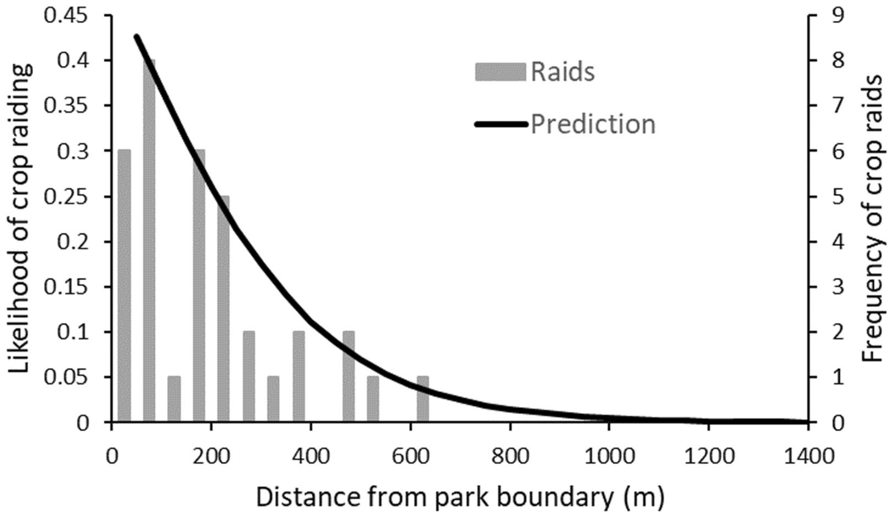

FIGURE 2 Predicted likelihood of crop raiding by baboons as a function of the distance from the forest boundary. Actual number of raids during the study is shown as bars.

$p = 0.348$). Of the other socioeconomic factors, only distance from the park boundary and the income level of a household significantly influenced the likelihood of elephants raiding a village (see Table 3 for variables identified by PCA). The probability that a farm was raided by elephants was 0.22. Household income was positively correlated with farm size ($r_{sp\,(296)} = 0.226$, $p < 0.001$). Thus, like baboon raids, the larger wealthier farms closer to the park boundary were most prone to crop raids by elephants (Figure 3).

3.4 | Deterrent strategies: Perceived and actual efficacy

Only 56% (n = 116) of households reported crop raiding by wildlife and all of these used one or more deterrents. Farmers often used more that than one strategy to deter crop raiders (Table 4). To deter crop raiders, farmers adopted one or more of the following strategies:

1. Watching over, or guarding, the fields by a member of the household or someone hired for this purpose;
2. Dogs were used to alert farmers to the presence of crop-raiding animals. Dogs effectively scared baboons away but not elephants.
3. Loud noises were used, such as shouting or hitting jerry cans or drums, to chase the animal away.
4. Flashlights – at night, elephants were chased with the help of flashlights and by drumming.
5. Lighting fires at night was also believed to deter elephants.
6. Burning chilli was regarded as the least effective strategy to deter elephants.

The effectiveness of these deterrents was based on anecdotal evidence from the farmers. There was a significant difference in the frequency with which deterrent strategies were deployed by farmers (χ^2 = 411.99, df = 7, $p < 0.001$). Guarding was the most commonly used strategy and was perceived as the most effective pre-emptive means of deterring crop raiding. Twenty farmers hired people to guard their crops for the whole season and on average this cost $25.5 US (± $3.1) for the season. However, guards were usually hired when the crops were about to be harvested.

The number of deterrent strategies used increased with the size of the garden ($F_{3,\,112} = 2.71$, $p = 0.05$), although this was not a linear relationship with the largest gardens using more strategies than either small or medium-sized gardens. Different deterrent strategies were used depending on the size of gardens ($F_{5,\,110} = 2.26$, $p = 0.05$) with fire and dogs used on smaller gardens and noise and torches used in addition on the larger gardens. The mean financial loss of crop raiding was $0.67 US per m^2 per event regardless of the number of strategies used ($F_{3,\,112} = 0.04$, $p = 0.99$). Dogs were the most effective active deterrent and scare-shooting by UWA the least effective deterrent of crop raiders. Scare-shooting could only be implemented after or during raids and by then significant damage had been incurred.

Trenches were dug along the park boundary by UWA in areas where crops were frequently raided by elephants. Of the

TABLE 3 Generalised logistic model of socioeconomic variables influencing the likelihood of villages being raided by elephants in Kibale National Park, Uganda

Variable	Coeff. (B)	Wald	df	Chi. pr.
Age	0.003	0.024	1	0.878
Distance	−0.0045	10.447	1	0.001
Dwelling	−0.0045	0.044	2	0.978
Education	−3.695	0.994	3	0.803
Gen	0.096	0.016	1	0.9
GenHH	−0.867	1.616	1	0.204
HHSize	−0.016	0.012	1	0.913
Income	2.2E-06	4.945	1	0.026
Occupation	3.1625	1.586	8	0.991

Note: Dwelling = household dwelling type; Education = education level; Gen = gender of household representative during questionnaire; GenHH = gender of household head; HHSize = number of occupants of household; occupation = occupation type. Variable selection was based on PCA analysis.

FIGURE 3 Predicted likelihood of crop raiding by elephants as a function of the distance from the forest boundary. Actual number of raids during the study is shown as bars.

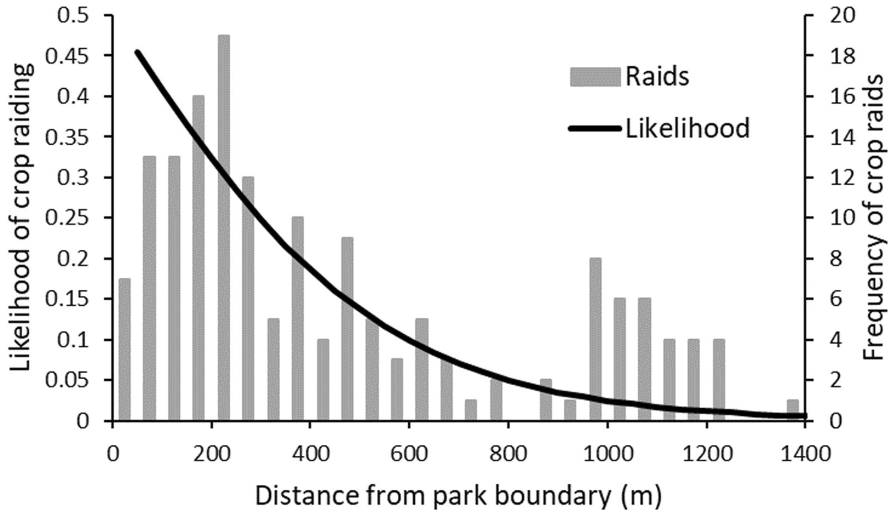

TABLE 4 Perceived effectiveness of different strategies to deter crop raiding used by 116 households neighbouring Kibale National Park, Uganda

Deterrent mechanism	% Households using deterrent	Weighted mean rank value
Human guarding	55	2.9
Dogs	1	2.5
Trench	2	2.2
Torch	29	1.9
Scare-crow	3	1.9
Noisemaking	35	1.8
Fire	16	1.5
Burning chilli	2	1.3

Note: Strategies were ranked by farmers on a scale of 1 to 4, with 4 being most effective.

TABLE 5 Multinomial logistic regression model examining what factors influence whether one or more strategies were used by farmers neighbouring Kibale National Park, Uganda to deter crop raiding by the park's animals

Variable	Coefficient value (B)	Wald	Sig.
Intercept	−0.473	0.755	0.385
Distance	**0.002**	**10.736**	**0.001**
Age	**−0.020**	**3.320**	**0.068**
Income	0.000	0.130	0.718
[Gender = female]	**1.385**	**14.388**	**0.000**
[animal = Baboons]	**−2.666**	**16.806**	**0.000**
[animal = Elephants]	**−1.108**	**9.088**	**0.003**

Note: Gender indicates whether being a female head of household had an influence. Rows in bold text indicate influential variables ($p < 0.1$).

38 elephant crop-raiding events, 25 took place at points without trenches, such as rocky and swampy areas where trenches could not be dug, eight occurred at farms that did not maintain their trenches, and five occurred at points with maintained trenches but the elephants filled the trench to cross into the garden. The latter results suggest that trenches are a very effective deterrent of crop-raiding elephants.

3.5 | Factors influencing the use and choice of deterrent mechanisms

Bi-plots and component scores from PCA indicated that the distance from park boundary, age of farmer, income of the household, gender of the household head, whether the farm had previously experienced raids and the identity of the crop-raiding animal were the most influential independent variables determining the use of a deterrent method. Multinomial logistic regression revealed that the distance from the park boundary, age of the household head and the animal that raided crops, most influenced whether a household applied one or more deterrent strategies (Table 5). Farmers closer to the park tended to apply deterrent mechanisms more rigorously than farmers farther away from the park boundary (see above).

The multinomial logistic regression of socioeconomic factors associated with each deterrent strategy confirms the findings of the general logistic model, in that the distance from the park boundary is the main determinant of the choice of deterrent strategy (Table 6). Farms closer to the park boundary used a variety of deterrents. Passive deterrent strategies such as fire and scarecrows were more likely to be deployed on large farms. Compared to male-headed households, households headed by women were less likely to deploy deterrent strategies.

4 | DISCUSSION

Crop raiding is perceived by farmers as a serious problem and just over half of farmers experienced a crop-raiding event in the previous growing season. Farmers asserted that elephants and baboons were

TABLE 6 Multinomial logistic regression of the socioeconomic factors associated with each strategy used to deter crop raiding

Strategy	Parameter	Coeff. (B)	Wald	Sig.	Exp (B)
Guarding	Intercept	−0.087	0.009	0.923	
	Distance to park	**−0.002**	**4.252**	**0.039**	**0.998**
	Age	0.016	1.102	0.294	1.016
	House hold size	0.167	2.561	0.110	1.182
	Income	0.000	2.469	0.116	1.000
	Land size	0.425	2.124	0.145	1.529
	Loss	**0.000**	**3.058**	**0.080**	**1.000**
	Gender	**−0.840**	**3.276**	**0.070**	**0.432**
Noise	Intercept	−0.061	0.004	0.950	
	Distance to park	**−0.002**	**3.347**	**0.067**	**0.998**
	Age	0.010	0.396	0.529	1.010
	House hold size	0.182	2.758	0.097	1.200
	Income	0.000	2.290	0.130	1.000
	Land size	0.198	0.394	0.530	1.220
	Loss	0.000	2.386	0.122	1.000
	Gender	−0.612	1.576	0.209	0.542
Flashlight	Intercept	−0.289	0.089	0.766	
	Distance to park	**−0.002**	**3.122**	**0.077**	**0.998**
	Age	0.019	1.340	0.247	1.019
	House hold size	0.093	0.697	0.404	1.097
	Income	0.000	1.254	0.263	1.000
	Land size	0.418	1.742	0.187	1.519
	Loss	0.000	2.047	0.152	1.000
	Gender	**−1.431**	**7.211**	**0.007**	**0.239**
Fire	Intercept	−1.496	1.832	0.176	
	Distance to park	**−0.003**	**4.824**	**0.028**	**0.997**
	Age	0.022	1.447	0.229	1.022
	House hold size	0.193	2.747	0.097	1.213
	Income	0.000	1.003	0.317	1.000
	Land size	0.433	1.502	0.220	1.542
	Loss	**0.000**	**6.055**	**0.014**	**1.000**
	Gender	**−1.707**	**7.200**	**0.007**	**0.181**
Chilli burning	Intercept	−4.367	3.042	0.081	
	Distance to park	−0.002	0.655	0.418	0.998
	Age	0.021	0.323	0.570	1.022
	House hold size	0.070	0.079	0.778	1.073
	Income	0.000	0.881	0.348	1.000
	Land size	**1.173**	**3.443**	**0.064**	**3.231**
	Loss	**0.000**	**5.390**	**0.020**	**1.000**
	Gender	−2.343	2.521	0.112	0.096
Dog	Intercept	−27.029	0.000	0.999	
	Distance to park	−0.032	0.000	0.999	0.968
	Age	3.136	0.000	0.992	23.010
	House hold size	11.033	0.000	0.997	61863.308
	Income	−0.001	0.000	0.995	0.999
	Land size	12.159	0.000	0.999	190794.554
	Loss	−0.002	0.000	0.992	0.998
	Gender	−158.478			1.492 E-69

TABLE 6 (Continued)

Strategy	Parameter	Coeff. (B)	Wald	Sig.	Exp (B)
Dogs	Intercept	−78.308	0.000	0.986	
	Distance to park	0.052	0.000	0.992	1.054
	Age	2.494	0.000	0.983	12.115
	House hold size	13.652	0.001	0.981	849372.298
	Income	0.000	0.001	0.980	1.000
	Land size	−15.211	0.000	0.989	2.478E-7
	Loss	−0.003	0.001	0.978	0.997
	Gender	−108.275	0.000	0.990	9.476E-48
Trenches	Intercept	−0.792	0.074	0.786	
	Distance to park	**−0.036**	**2.763**	**0.096**	**0.965**
	Age	0.036	0.207	0.649	1.037
	House hold size	−0.054	0.028	0.868	0.947
	Income	0.000	1.011	0.315	1.000
	Land size	−0.482	0.127	0.721	0.618
	Loss	0.000	0.419	0.517	1.000
	Gender	−22.385	0.000	0.997	1.899E-10

Note: Gender indicates the importance of a female head of household in the choice of strategy. Rows in bold text indicate influential variables ($p < 0.1$).

the most significant crop raiders, which was supported by the physical verification of crop-raiding events and previous assessments in the Kibale region (Naughton-Treves, 1997, 1998, 1999; Rode et al., 2006) and elsewhere in Africa (Naughton-Treves & Treves, 2005; Tiller et al., 2021). Despite baboons raiding more frequently, elephants were perceived as most problematic because, unlike baboons, they cause overwhelmingly severe damage in a single raid.

Farmers favoured guarding combined with noise and throwing objects at raiding animals as the most effective pre-emptive method for deterring crop-raiding animals (see also Mackenzie & Ahabyona, 2012). However, guarding requires consistency, is labour-intensive, and many farmers hire guards, which incurs financial cost regardless of whether a farm is raided or not (MacKenzie, Moffatt, Ogwang, et al., 2017; Musyoki, 2014). Wildlife take advantage of any lapses in guarding or slow response, as is indicated by our finding that noise methods were not effective for baboons because in many instances the crop raid was well underway and the crops damaged by the time the farmer intervened. Despite farmer's perception that guarding was most effective, financial losses did not differ among deterrent strategies, with the exception that losses were generally less when dogs were used and less than having no strategy. Dogs alert farmers to the presence of baboons before they reach the garden, allowing farmers to chase them away. Farmer perceptions of guarding did not align with financial losses because guarding is an essential and necessary activity for all farmers regardless of the extent of financial losses to raiding. Furthermore, as guarding was combined with other strategies that were applied on an ad hoc basis, their cost could not be easily separated from guarding, either statistically or by the farmers, except in the case of strategies that pre-empted damage to crops by wildlife such as guard dogs.

For elephants, fire and noise were associated with lower financial losses compared to having no strategy, but the use of flashlights was ineffective. Scare-shooting by UWA rangers was ineffective at deterring elephants. By the time the rangers arrived at the farm, the elephants had already caused significant damage. Trenches were very effective and 87% of the elephant crop-raiding events occurred in areas without trenches or where they were not maintained. Similarly, Mackenzie and Ahabyona (2012) found that well-maintained trenches were 65% effective against elephants, 100% effective against bushpig, but did not deter primates.

Consistent with other studies, raids were most frequent closest to the park boundary (Chiyo et al., 2005; Hill, 2017; Hsiao et al., 2013; MacKenzie, Moffatt, Ogwang, et al., 2017; Regmi et al., 2013). Such findings have led for calls to establish buffer zones outside of parks to protect resources within the park's core, provide resource benefits to local people who can extract resources from this buffer, and to protect the crops of the farmers that neighbour the park, thus reducing the burden on the park (Dudley, 2008; Naughton-Treves et al., 2005; Reid & Miller, 1989). Minimum buffer widths that would deter crop raiding are species and site specific (Wallace & Hill, 2012). However, Kibale elephants are known to travel over 450 m out from the park to raid crops and routinely travel 200 m (Chapman unpublished data). Given that the park is almost 800 km^2, that human population density just outside of the park is 229 people/km^2 (MacKenzie, Salerno, Chapman, et al., 2017; WorldPop, 2020), and that all of the land outside the park is owned by local people (Naughton et al., 2011), applying a buffer zone conservation model in this area is not tenable.

As in other crop-raiding studies, distance to the park boundary played an important role in the choice and application of deterrent mechanisms (Davies et al., 2011; Hill & Wallace, 2012; Hoare, 2015; Naughton-Treves, 1997). Farmers farther from the park used fewer deterrents and sometimes no deterrent strategies. This is because gardens closer to the park buffer those further away from immediate damage. By the time the gardens far from the park were raided, the farmers closer to the park had already detected and alerted distant farms to the danger.

Farmers who had previously experienced raids applied deterrent strategies more rigorously than farmers who had not (see also Karanth et al., 2012). Male-headed households were more likely to use deterrent strategies than the female-headed households. This could be due to lack of financial resources in households led by women. Furthermore, since women generally tend to farm during the day, they may be unable to guard against elephants at night, and guarding at night is considered risky, thus cultural norms may prevent women from guarding at night. Older respondents were less likely to use deterrent strategies and experienced higher financial losses due to crop raiding. Similar trends were documented with smallholder farmers in south-western Ethiopia that were raided by baboons (*Papio anubis*) and bush pigs (*Potamochoerus larvatus*) (Ango et al., 2017). Here, households headed by women or older people were the most vulnerable as they had fewer members to guard or deter crop-raiding animals. These households are least able to cope with crop loss and mitigate the crisis (Fairet et al., 2014).

Patterns of human–wildlife conflict around Kibale are complex with crop damage being a function of physical factors and the socio-economic status of the farmer. As the animal populations, including baboons and elephants, in Kibale are increasing (Chapman et al., 2021; Chapman, Omeja, et al., 2018; Omeja et al., 2016) and the density of people farming near the border of the park is increasing (MacKenzie, Salerno, Hartter, et al., 2017), human–wildlife conflict is inevitable. This will lead to dissatisfaction among local people and will create an increasingly difficult situation for UWA to manage. There have already been retribution killings of both elephants and baboon by farmers who justify these given the crop damage the animals cause. Our research indicates that UWA's efforts to dig trenches has been effective, but trenches have already been established in most areas where it is possible to dig them. Scare-shooting by UWA rangers is ineffective as the rangers arrive after significant damage has been done. We suggest that the management of crop raiding should respond to the social realities and provide additional support to households led by older community members and women. However, UWA's responses are limited by logistics. As it is currently impractical (i.e., funds are not available) to support compensation to farmers experiencing crop damage, we suggest that UWA and affiliated NGOs work to help the community with other aspects of their daily life, such as education (Kasenene & Ross, 2008) and health care (Chapman et al., 2015; Kirumira et al., 2019). This suggestion is based on the assumption that where local communities derive benefits and assistance from the park they will be more inclined to work with the park to manage crop raiding. This assumption is currently being tested. The management complexities posed by crop-raiding can be partly addressed with the co-operation of farmers and through proactive provision of services that balance the cost of crop-raiding to farmers on the park boundary, although these should not be seen as a panacea.

ACKNOWLEDGEMENTS

Financial support for this study was generously provided by the International Development Research Centre (IDRC) grant 'Climate change and increasing human-wildlife conflict' (108570-001) and CAC was supported by the Wilson Center while writing this paper. We thank Colleen Downs and Pellegrine Sebulime for helpful insights into research design and analysis. We are grateful to the staff of Makerere Biological Field Station (MUBFS) and Dorothy Kirumira and Wilson Kagoro of UWA for their support during the field research. Finally, we express our gratitude to the communities who so willingly shared information. Data collection was aided by John Okwiro Akiki, Miriano Amooti, Clovice Amooti and Mbabazi Edith Abwooli.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are available on request from the correspondence author and in Supporting Information-Rawdata.

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How to cite this article: Kyokuhaire, A. M., Chapman, C. A., Omeja, P. A., Tumusiime, D. M., Abwoli, B. Y., & Lawes, M. J. (2022). Mitigating crop raiding by forest elephants and baboons at Kibale National Parkh. *African Journal of Ecology*, *00*, 1–12. https://doi.org/10.1111/aje.13095