Human-Lion conflict around Nairobi National Park: Lion (Panthera leo melanochaita, Hamilton Smith, 1842) Population Structure, Landscape Use and Diet, in a Semi-Fenced Park

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Effectiveness of LED Flashlight Technique in Reducing Livestock Depredation by Lion (*Panthera leo melanochaita*) around Nairobi National Park, Kenya

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Conflict of Interests

The authors confirmed that they have no conflict of interests.

Abstract

The global lion (*Panthera leo*) population decline is partly a result of retaliatory killing in response to livestock depredation. Nairobi National Park (NNP) is a small protected area in Kenya surrounded by a human-dominated land-

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scape. Communities around the park use flashlights to deter lions from their livestock bomas. We investigated the response by lions to the installation of LED flashlight technology during 2007-2016. We interviewed 80 owners of livestock bomas in the surroundings of NNP with flashlights (n=43) and without flashlights (n=37) and verified reported attacks on bomas against depredation data over 10 years. The frequency of attacks on bomas equipped with flashlights was significantly lower compared to bomas without flashlights. We also found that after flashlights were installed on livestock bomas, lion attacks took place further away from the park edge, towards areas where the bomas had no flashlights. Furthermore, with increased numbers of flashlight installations at bomas in recent years, we noticed a shift from nocturnal to more diurnal depredation incidences. Our study shows that LED flashlight technology is effective in reducing nocturnal livestock depredation at bomas by lions. Long-term studies on the effects and expansion of this technique into other communities around NNP are recommended.

6.1 Introduction

The global decline in lion (*Panthera leo*) populations has largely been attributed to habitat fragmentation, diminished large prey populations in some areas and retaliatory killing over livestock losses (Bauer & Van der Merwe 2004; Tumenta et al. 2010; Riggio et al. 2013). Retaliatory killing of lions has serious repercussions in terms of both declining population densities and disturbed social structures (Bertola et al. 2011; Tumenta et al. 2013). Especially in areas where natural habitat is encroached on by expanding settlements and land-use practices, retaliatory killing ranks amongst the greatest threats for lions. Several studies in Kenya as well as in e.g. Namibia and Botswana have reported retaliatory killing of lions by local farmers after livestock attacks due to economic losses (Linnell et al. 2001; Patterson et al. 2004). In West and Central Africa, lion mortality due to retaliatory killing is a major concern as the few remaining lion populations have reached critically low densities (De Iongh et al. 2009; Bauer et al. 2010; Sogbohossou et al. 2011; Tumenta et al. 2013). For conservationists working in these areas, conflict retaliation has therefore, become a main priority (Patterson et al. 2004; Bauer et al. 2010; Tumenta et al. 2013; Henschel et al. 2014).

We explored a novel method for reducing human–lion conflict in Kenya. Kenya is a stronghold for lions, with an estimated population of 2,000 individuals in 2008 (Musyoki et al. 2012). With an estimated population of 35, including cubs, lions in Kenya's Nairobi National Park (NNP) are surviving despite their relative confinement inside the park and being surrounded by a densely populated urban area. Although the park is largely fenced (Steinhart 1994), an unfenced connection between the southern border of the park and the Athi-Kapiti Plains (Ogutu et al. 2013) provides a wildlife migratory corridor and a possibility for lions to roam into surrounding communities. The intensified human demand for space around Nairobi City in recent decades has led to a spillover of human activities around NNP and the surrounding buffer zone, which has affected the availability of natural prey for lions (Rudnai 1974; Gichohi 2003; Owino et al. 2011). At the same time, livestock pressure has intensified, which has led to more livestock incursions into the park and significantly higher portions of livestock in the lions' diet (Patterson et al. 2004; Bauer et al. 2008, 2010; Tumenta et al. 2013). In 2011, six lions were killed in retaliation by the community south of NNP after livestock was lost to lions (KWS depredation records). Between 2012 and 2016, more frequent attacks by lions on livestock in bomas were reported and three more lions known to reside inside the park were killed in 2016 in the community land (KWS Predation Records).

Several factors are known to influence the frequency of lion attacks on bomas, including prey densities, season, distance to the park, time of day, livestock herd size, type of livestock and energy cost (Bauer & De Iongh 2005; Van Bommel et al. 2007; Woodroffe et al. 2007; Kissui 2008; Sogbohossou et al. 2011). Due to their large body size, lions need large prey to compensate for energy lost during hunting and handling (Carbone et al. 2007). To maximize the gain, they seek to take advantage of landscape and habitat elements with high prey catchability (Grant et al. 2005). In the Amboseli Ecosystem in Kenya, where severe climate conditions have changed and habitats are fragmented, there is evidence that large carnivores are increasingly ranging into communal land, resulting in more frequent reports of human–carnivore conflicts (Tuqa 2015). In other protected areas, e.g. Waza National Park, northern Cameroon (Van Bommel et al. 2007), Serengeti National Park, Tanzania (Holmerna et al. 2007), Pendjari Biosphere Reserve in north-west Benin (Sogbohossou et al. 2011), the distance of a community to the protected area boundary was found to be a determinant of depredation by lions. In Laikipia, Kenya, daytime depredation was lowest for small livestock herds with human herders in open fields, while depredation at night was lowest when livestock herds were held inside decently built enclosures (Ogada et al. 2003; Woodroffe et al. 2007). Studies conducted in India, Nepal and South Africa (Khorozyan et al. 2015) and in Laikipia, Northern Kenya (Ogada et al. 2003) further showed that depredation rates could depend on biomass of the domestic prey or on mitigation technique and type of predator and wild prey density, respectively.

Bomas around NNP generally consist of a nighttime livestock enclosure fenced with a ring of thorn bushes, wood, posts and chain-links and/or live vegetation. They are usually owned by one family or related family members with a single herd of cattle and a flock of shoats, herded together during the day. Some bomas keep shoats and cattle together in one large enclosure, separated by a small fence but sharing one flashlights unit.

In this study, we investigated if and how nocturnal attacks by lions on bomas around NNP could be controlled by using the so-called LED flashlight technique. This novel method was initially proposed by an 11-year old school pupil named Richard Turere as a measure to prevent nocturnal livestock depredation at his family's boma near NNP (see http://edition.cnn.com/2013/02/26/tech/richard-turere-lion-lights/). This technique has received international attention following its publication online as a TED talk (see www.youtube.com/watch?v=DdH6L5u2eMM).

In 2012-2013, the first 19 flashlights were installed in accordance with this technique at livestock bomas along the southern border of the park by Non-Governmental Organization (NGOs), including The Wildlife Foundation and FoNNaP. As soon as their effectiveness became apparent for some households, neighbouring livestock owners started to use the LED flashlight technique for their bomas. With approximately 30 additional bomas equipped with flashlights by NGOs, such as Friends of Nairobi National Park and KWS, the technique slowly became a standard practice for many pastoralists in the surroundings of NNP. As a result, a spatial gradient has become apparent; the closer a boma is located to the park's edge, the more likely it is to have flashlights installed. To date, the installation of flashlights in the study area has not been systematic and is not part of any official protection scheme.

Although similar techniques have been used in other areas to deter carnivores and birds, either from livestock, crops or other properties (see www.niteguard.com; http://predatorguard.com; www.foxlights.com), the application of lion deterrence lights is the first in Africa to our knowledge. The system uses a solar panel to power a series of LED flashlight bulbs connected by cable wire (Fig. 6.1). Depending on the size of the boma, a car battery supplies energy to between four and six bulbs mounted on several outward facing poles along the boma perimeter. The flashlights are set to continuously flicker at a rate that mimics a livestock guardian holding a flashlight and walking on foot around the boma. An investment of approximately $250 is required to equip one livestock boma with flashlights (Nickson Parmisa personal comm.).

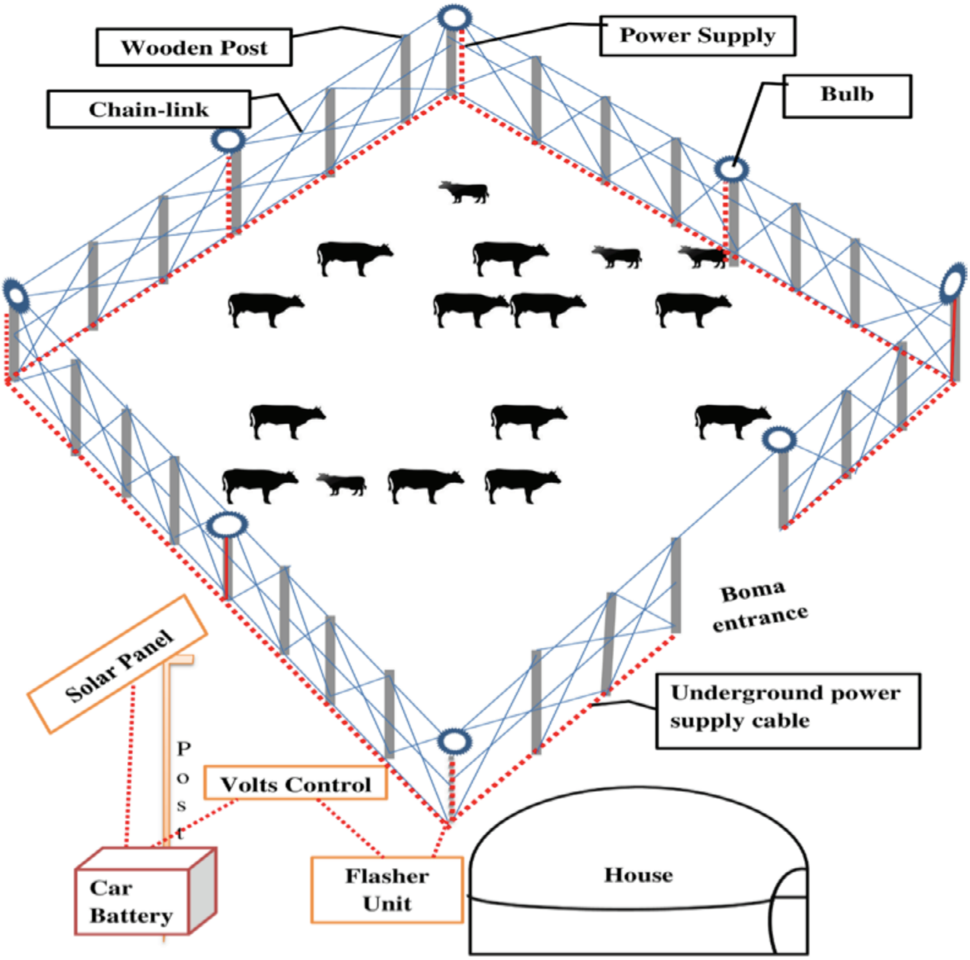

Figure 6.1
Diagram of a livestock boma with flashlights installed. The car battery is powered by a solar panel. The bulbs at the fence perimeter are connected by a wire from the flasher unit to flicker at night.

We hypothesize that the presence of flashlights would reduce the frequency of lion attacks on livestock bomas during the night and could lead to behavioural changes in livestock raiding lions. Such behavioural changes could include avoidance strategies, in which lions would move greater distances from the park boundary in search for bomas that are not equipped with flashlights, or a certain level of habituation to the flashlights. An attack is defined as a livestock depredation incident leading to either death or injury to one or more heads of livestock (cattle, donkeys, or shoats). A boma is a Kiswahili term for a livestock or household compound enclosing structure (Manoa &

Mwaura 2016) used for overnight livestock protection against predators constructed with tree branches, wood, poles and/or chain-link material. In this chapter, we use the term "shoats" to refer to a mixed flock of sheep and goats.

6.2 Materials and methods

6.2.1 Study area

Our study was conducted in the Kitengela triangle in Kenya, adjacent to the southern part of NNP. The study area is situated between latitudes S013.9054° to S01.15162° and longitudes E036.8251° to E036.9681° at an altitude ranging from 1495 m to 1684 m above sea level (see Fig. 6.2). The eastern part of the study area is defined by the Athi River export industries processing zone and the Kitengela River. The western part is characterized by two high density human settlement areas: Rongai and Twala.

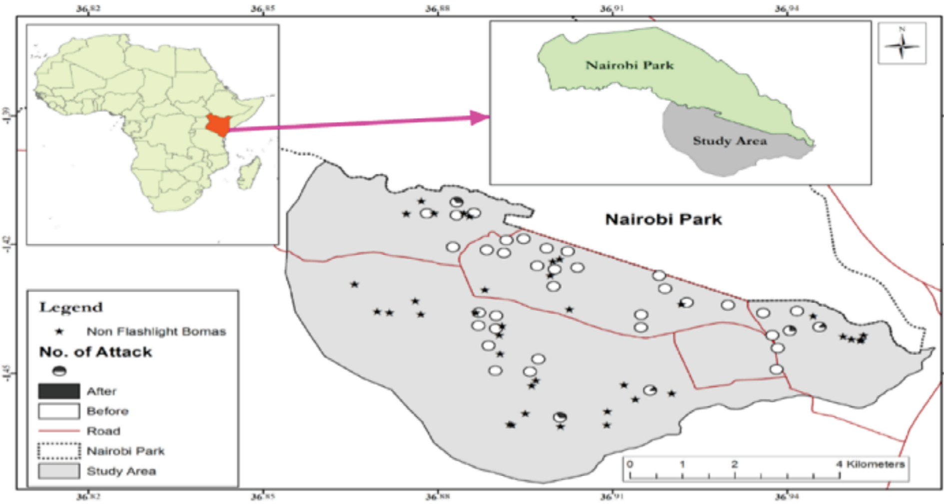

Figure 6.2
Map of the study area showing the proportion of boma attacks prior to and after installation of the flashlight technique. Empty circles (○) represent bomas where attacks had been reported before installation and none after installation. The partly filled circles (◔) represent bomas where attacks took place after flashlight installation. The stars ( ) represent bomas of interview participants without flashlights.

The study area is rich in soil nutrients and receives a mean annual precipitation of 780mm (Rudnai 1974). The riverine vegetation is dominated by *Acacia xanthophloea* and *Acacia mellifera*, while plains are dominated by *Balanites* tree species and *Themeda* savanna grassland (Rudnai 1974; Gichohi 1996). The Mbagathi and Kiserian rivers are tributaries of the Athi River and both provide a permanent water source. The study area is a wildlife dispersal zone and is part of the Athi-Kaputiei plains. It covers a surface area of 2,200 km^2 (Matiko 2014). The Kitengela triangle, which consists of 390 km^2 of open grassland, is the first stop-over for annual migration of the blue wildebeest (*Connochaetus taurinus*), Burchell's zebra (*Equus burchelli*) and other ungulates such as common eland (*Tragelaphus oryx*), coke's hartebeest (*Alcephalus buselaphus*), Grant gazelle (*Gazella granti*) and giraffe (*Giraffa camelopardalis*) in the wet season (Gichohi 1996).

The local communities in the study area are mainly represented by traditional transhumance pastoralists, mostly of Maasai origin. Unlike the exclusive pastoralists in the Maasai Mara, described by Kolowski & Holekamp et al. (2006), the communities in our study area are sedentary; families or households stay in one location for an extended period of time. During the day, cattle and shoats from different households share communal grazing fields but do not share a boma at night. Each boma owner has a separate enclosure for shoats and cattle. Guided by a few male household members, they migrate to neighbouring counties in search of pastures and water. During this time, only a few shoats or cows are kept in bomas for milk.

6.2.2 Ethics statement

This research did not involve any invasive or intrusive methods. There was no financial inducement for information, personal data and no involvement of vulnerable groups (children, mentally disabled) from the society. Interviews were conducted in a transparent manner, voluntarily and with the participant's consent. The ethical conduct of the interviewers was verified and confirmed by the PhD supervisors during field visits. The research has been approved by the Graduate School of Leiden University, the Faculty of Science and the Directory Board of the Institute of Environmental Sciences in Leiden (Ref HDI/634/2014).

6.2.3 Data collection

Data were collected from 43 bomas where flashlights had been installed at the initiative of individual livestock owners or by NGOs such as Friends of NNP during 2012-2016 (Fig. 6.2). During the time of our research, the number of bomas with functional flashlights varied to some extent, as additional flashlights were installed while some flashlights broke down. We therefore only included bomas in our analyses that had functional flashlights during the entire period of our research.

Since no official records are kept on the number of bomas with flashlights installed in the study area, this information was collected during a survey by car and on foot, which we conducted prior to the start of the interviews. We used Arc GIS v.10.2.2 (ESRI, Redlands, USA) to plot the GPS locations of all bomas with or without flashlights in the study area. Households were then selected semi-randomly from this group, ensuring that the entire buffer zone was covered equally. The interviews covered 12% of livestock owners in the Kitengela corridor, who kept livestock in a boma within a distance of 5 km from the park boundary (Fig. 6.2). We interviewed only one person in case different families shared one boma protected by flashlights to avoid bias.

During April 2014, we interviewed a total of 80 boma owner's south of NNP, including the 43 bomas with flashlights. All households interviewed in 2014 were interviewed again in 2016, though sometimes with different respondents. The questions were specifically aimed at techniques and measures used to deter predators or otherwise protect livestock from large carnivore attacks. We used a known dataset of lion depredation cases that had been reported around NNP between 2007 and 2016 to KWS, FoNNaP and TWF, as part of the Wildlife Conservation and Management Act (2013), and the Wildlife Lease Conservation (2000-2012) and Consolation (2008-2012) program, respectively, to verify the results of our questionnaires.

Each interview consisted of a pre-structured questionnaire for which the questions had been translated from English to Maasai and Swahili language (S1 File) and which were posed by two native research assistants. The 2014 questionnaires were enhanced in 2016 with a few additional variables (S1 File). The number of livestock per boma, fence materials used (thorn branches, wood, chain-link, plant material and mix), fence height (0-1.5 m, above 1.5 m), transparency of the fence (visibility of livestock) (see Woodroffe et al. 2007) were only addressed in the questionnaires of 2016 (S1 File). We only interviewed owners of single livestock bomas (with and without flashlights). Bomas included in the depredation data that were not mentioned during the interviews were excluded from the analyses. The unit of analysis was "boma owner".

6.2.4 Data analysis and statistics

In order to isolate the effect of flashlights on the probability of a boma attack by a lion, we first identified confounding variables, possibly explaining the probability of a boma attack. These confounding variables were defined as:

(i) bomas with flashlights and without flashlights; (ii) distance of boma to the park boundary; (iii) timing of the lion attack (i.e. during the day or night); (iv) mean yearly rainfall; (v) fencing materials used; (vi) numbers of livestock in a boma; and (vii) year of flashlights installation. In all cases, our response variable was "the probability of attack per year", expressed as the number of bomas attacked in a year, divided by the number of all bomas present within a 5 km zone from the park boundary in that year. We made a distinction between boma with flashlights and boma without flashlights.

All data were tested for normal distribution with a Shapiro-Wilk test for normality. For bomas with flashlights installed, we calculated the mean number of attacks prior to and after flashlight installation by dividing the number of attacks by the number of years with and without flashlight. A Wilcox rank and paired test was used to test the significance. We tested the intensity of attacks between bomas with flashlights and those without flashlights using a Chi-square test.

To determine other factors that could affect the probability of an attack, we developed a case-specific general linear mixed model (GLMM). The dependent variable in this model was a binary variable indicating whether the boma was attacked at night during a certain year or not. Independent variables were defined as "presence of a flashlight", "year" (as a scale variable), "mean rainfall" and "distance to the park boundary". "Year" (as a factor) and "Boma code" were used as random factors. The model-family was binomial using a logit link. For testing the significance of the different stable factors, we applied a likelihood-ratio test (LRT). For fitting the model, we used glmer from the lme4-package (Bates and Maechler, 2010) in R (R Development Core Team 2017).

The distance of a boma to the park boundary was determined from coordinates obtained with a global positioning system (Garmin eTrex 20) and Arc View v.10.2.2 (ESRI, Redlands, USA). The bomas were classified into four distance categories: (i) near (at 0-1 km); (ii) intermediate (at 1-2 km); (iii) far (at 2-3 km); and (iv) the furthest (at more than 3-4 km from the park). For each of these categories, we calculated the average probability of attack over 10 years. The differences were tested with a Mann-Whitney U test (p-value 0.005) (Bates and Maechler, 2010) in R (R Development Core Team 2017).

We compared the average probability of attack during the night versus at daytime using a Mann-Whitney U test. The change in probability of diurnal versus nocturnal boma attacks over the years was studied by calculating the probability of diurnal and nocturnal attacks per year, thereby assuming that every boma has an equal chance of being attacked. Thus, we calculated the number of attacks per night by dividing the total number of yearly attacks by the number of days (365) in that year and multiplying it by the number of bomas (80). The resulting probabilities were tested using a Chi-square test. We also tested diurnal livestock attacks prior to installation flashlights and diurnal attacks after installation using a Chi-square test.

Changes in probability of a boma attack over time in relation to distance to the park were calculated based on yearly mean distance to the park of the attacks. The trend in these distances was tested through a linear regression model using R statistics. Each boma was given a reference number (boma code), which ensured individual bomas could be recognized while protecting the boma owners' identities.

In the absence of accurate local density estimates for prey, we used annual rainfall as a proxy for the prey density, based on the assumption that in wet years, large prey species leave the park and move into community land, driven by access to more equally distributed water and grazing resources (Bauer & De Iongh 2005). The relationship between the amount of rainfall (mm) and the frequency of attacks was analyse using a Pearson correlation (p-value 0.05). We averaged the number of nocturnal attacks by fencing category and applied a Chi-square test.

For the analysis on livestock herd size (shoats and cattle), we used reported livestock herd sizes during the 2016 interviews to average herd size and classified these as "small" when below mean herd size and "large" when above mean herd size. We used a Kruskal test to test the significance.

6.3 Results

A total of 814 livestock were reported killed by lions between 2007 and 2016. Interview respondents reported a total of 413 depredation cases related to lions during this period, and these were confirmed against KWS depredation records. In the 413 reported cases, 308 (75%) cases occurred during the night and 105 (25%) during the day. Of the 43 bomas where flashlights had been installed during the course of this study, 184 (96%) attacks took place prior to flashlight installation and 7 (4%) after flashlight installation (Wilcox paired test $W = 780$, p-value <0.0001, Figs. 3 and S1). The probability of an attack on bomas without flashlights is significantly higher compared to bomas with flashlights (Fig. 6.4; $\chi^2 = 10.37$, df = 4, p-value = 0.035). Twenty-three percent (23 %) of the respondents who reported depredation after flashlight installation had not suffered any previous livestock losses at the bomas and 68% had no flashlights installed. Of the 105 diurnal depredation cases, 21 (20%) occurred prior to flashlight installation (2007-2011) and 84 (80%) after flashlight installation (2012-2016, ($t = 2.47$, df = 61.11, p-value = 0.016). Figure 6.5 shows the shift in time (nocturnal to diurnal) in livestock depredation prior to and after cumulative installation of the flashlights. There appeared to be a pronounced peak in depredation during 2012 (55 cases).

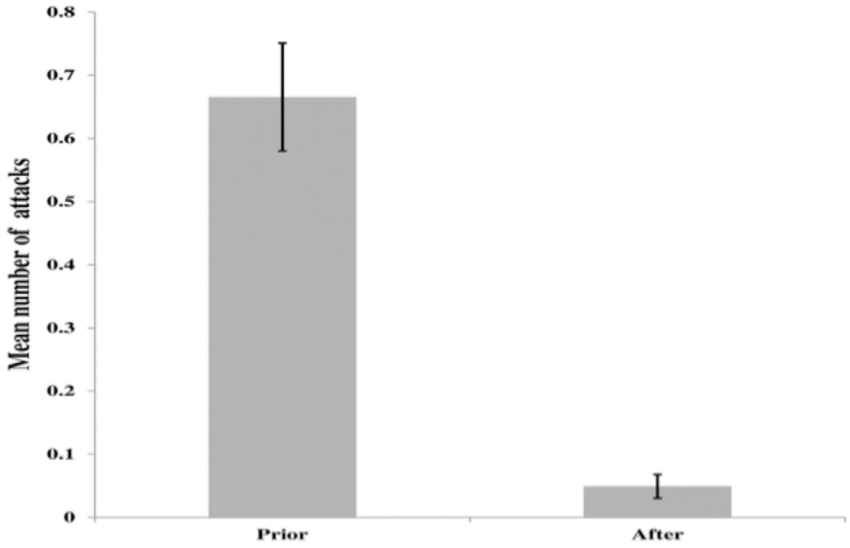

Figure 6.3
Mean number of attacks (±sd) by lions prior to and after installation of the LED flash-light technique based on 43 bomas with flashlights.

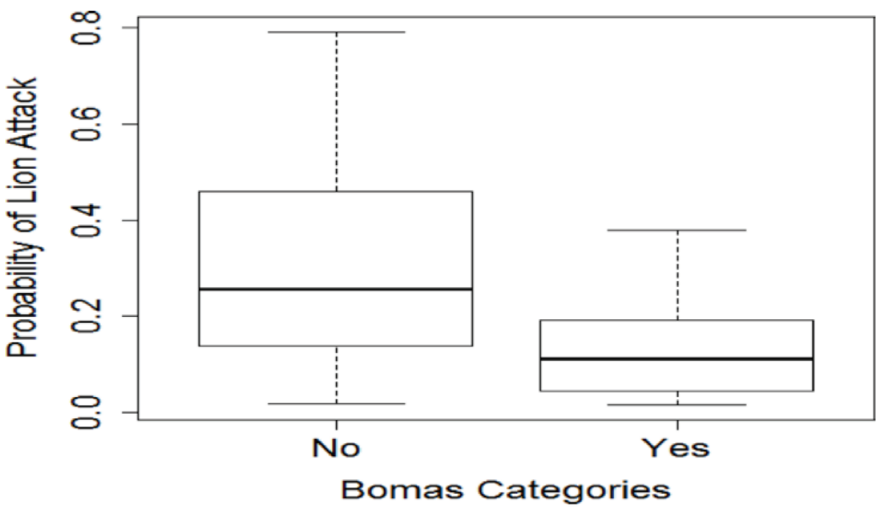

Figure 6.4
Difference in the probability of lion attacks between the two categories of livestock bomas, (Yes = with Flashlight, No. = without flashlight) between 2007 and 2016 based on GLMER model.

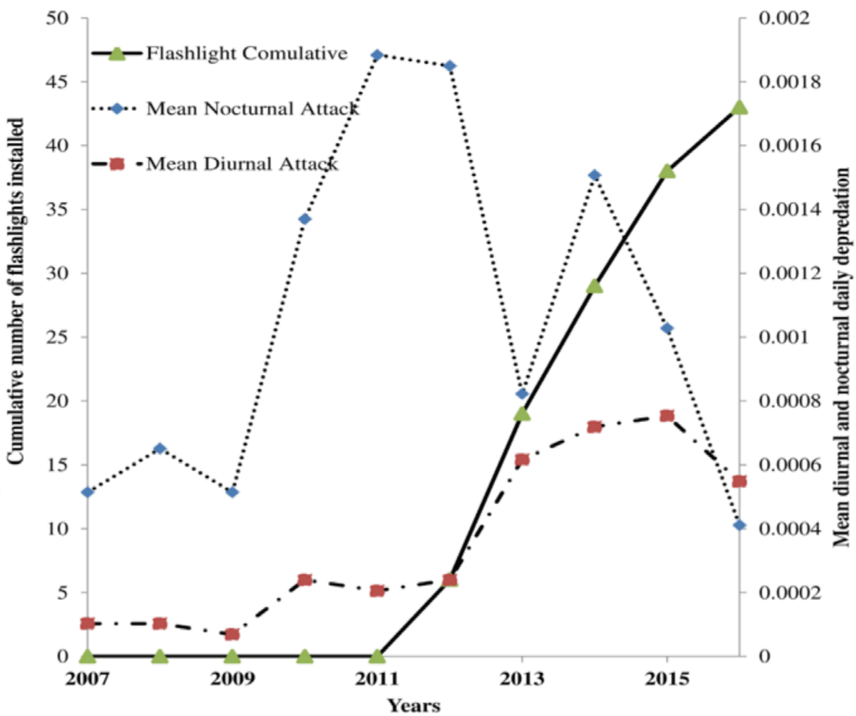

Figure 6.5
Cumulative flashlights installed and Mean nocturnal and diurnal livestock depredation during 2007-2016.

Table 6.1
GLMER showing the significance variables in relation to depredation around the park using likelihood ratio test.

Variables	Df	AIC	LRT	Pr (Chi)	Significance
Flashlight	1	743.92	14.303	0.0001556	***
Years	1	742.83	13.220	0.0002770	***
Mean Rainfall	1	741.64	12.029	0.0005237	***
Park Distance	1	743.95	14.333	0.0001532	***

Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05'.', 0.1 ' ', 1[***] represents the reference variable.
Model 1: Attnight ~ Flashlight + Year + Mean Rainfall + Park Distance+ (1 | Code) + (1 | Years)

The mean rainfall, distance of the boma from the park, years and flashlights were all significant (see Figs. 6.4, 6.5, 6.7, and S1) on each of the variables of attack (Table 6.1). Whereas the period of working flashlights in a boma has high probability of reducing nocturnal livestock attacks, the findings show that the shorter the distance of the boma from the park border, the higher the intensity of attack. The yearly increase in the attacks is due to lions changing their behaviour and searching for bomas without flashlights. The number of boma attacks is related to the presence of flashlights ($\chi^2 = 12.98$, df = 1, p-value = 0.001).

Analyses showed a significant positive relationship between rainfall and the number of attacks on livestock per year (Pearson's correlation test; t = 157.11, df = 725, p-value < 0.001; Fig. S1), with a significantly lower probability of attacks in 2009, which had extremely low rainfall (59.2 mm) compared to 2012, when rainfall was relatively high (102.6 mm).

Bomas at a distance of 3 km or more from the southern park border were attacked significantly less often compared to bomas located closer to the park (Fig. 6.6). The percentage of attacked bomas ranged from 54% (at 0-1 km); 31% (at 1-2 km); 11% (at 2-3 km) to 4% (at >3 km from the park boundary). We also found a significant yearly increase in mean distance of attacks from the park boundary following the application of flashlights in 2012 (Mann-Whitney U test t = 11.291, df = 79.002, p-value = 0.001; Fig. 6.7). The yearly regression with intercept of 2.001+03 and slope of 0.008 shows that every three years, there is 300metres increase in distance of attack.

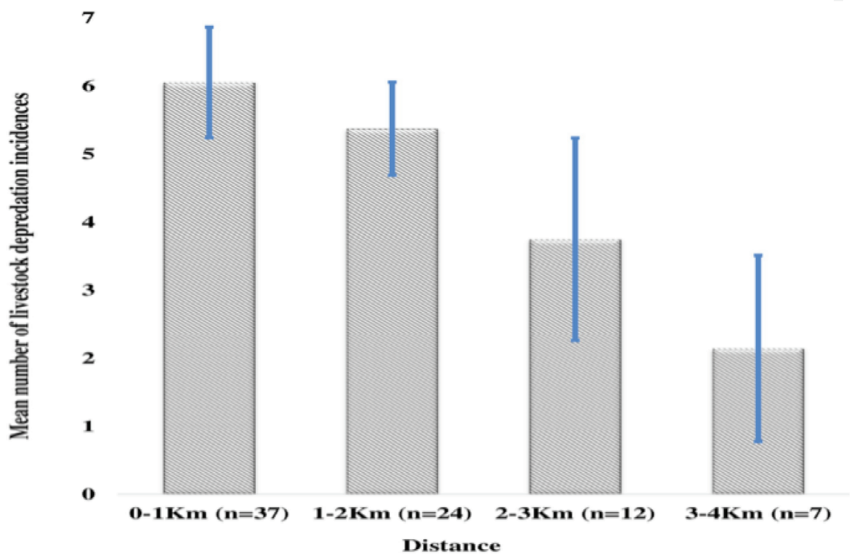

Figure 6.6
Mean number of nocturnal and diurnal boma attacks around NNP between 2007 and 2016 at different distances from the park boundary.

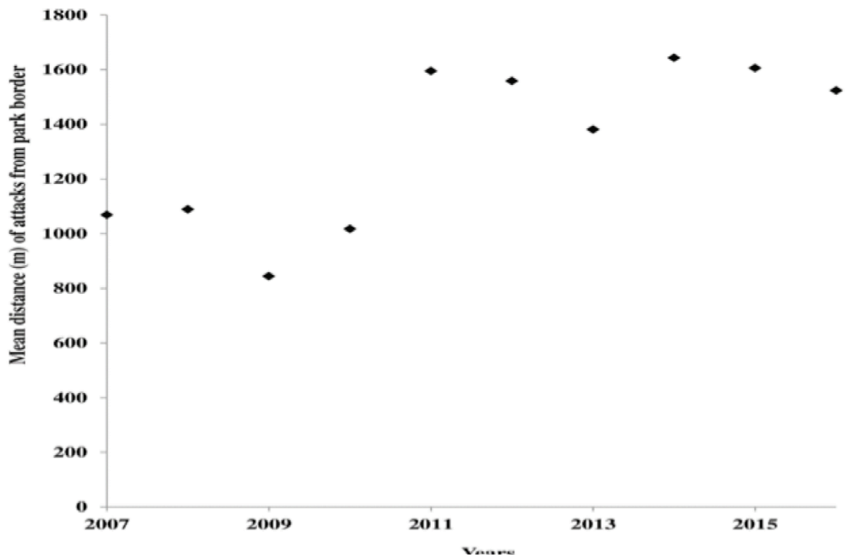

Figure 6.7
Annual mean distance of boma attack from the park boundary since the introduction of the flashlight technique south of NNP.

The fence height in relation to percentages of attack is significant (high = 12%, medium 23%, short = 71% and χ^2 = 8.09, df = 2, p-value = 0.017). This shows that bomas without flashlights and those with short-medium fences are more likely to be attacked by lions than those with flashlights and higher fences. The data normality distribution test was W = 0.87567, p-value < 0.00001.

Bomas constructed with high wooden posts supported by chain-link (χ^2 = 8.11, df = 1, p-value < 0.005) and barbed wire were attacked less frequently than the other categories (p <0.05, Fig. 6.8). None of the other deterrence variables (scarecrow, dogs, spotlight, radio, fire and noise) were significant in depredation prevention (see Table S1). Herd size did not affect nocturnal depredation of shoats (Kruskal test, χ^2 = 21.76, p-value = 0.7) and cattle (χ^2 =25, p-value = 0.6) (see Table S1).

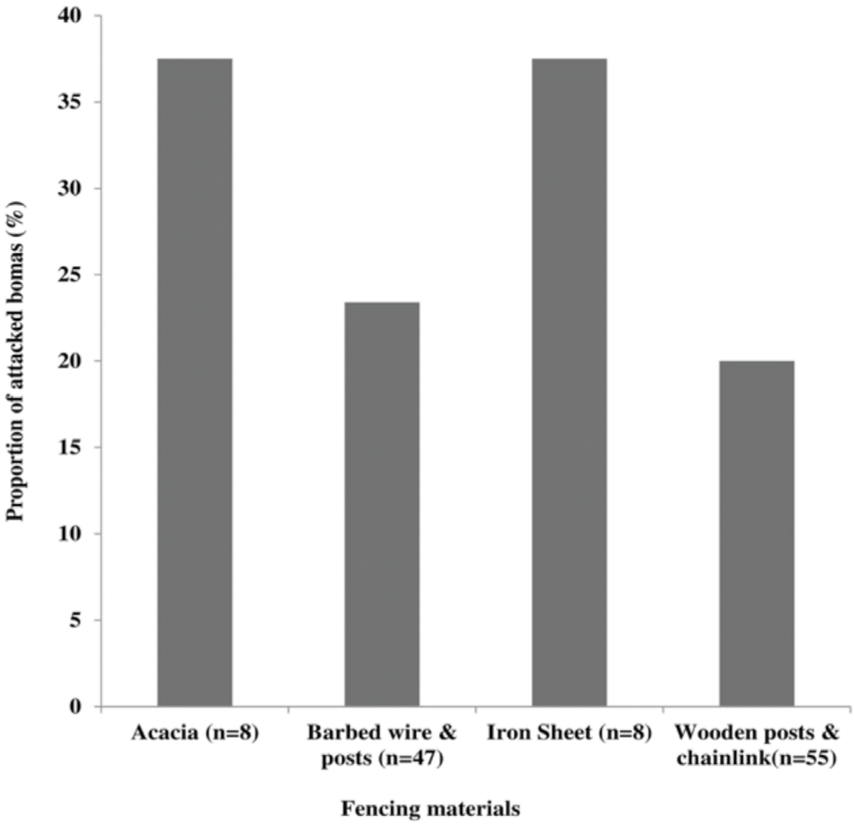

Figure 6.8
Proportion of reported attacks on bomas at night for each type of livestock fencing materials.

When respondents were asked an open question about what they believed should be done to resolve human–lion conflicts around NNP, (Appendix I, question 13), most respondents (92%) had one or more suggestions (Table S3): "flashlight installation" and "some form of compensation" were by far the most mentioned suggestions, followed by measures that would prevent lions from roaming outside the park boundaries. Although "fencing the park" was sometimes mentioned, 62% of the respondents did not believe that complete fencing of the park would resolve the human–lion conflict. Further suggestions included measures that could rapidly detect and relocate freely roaming lions back into the park, which, according to some, will become an even more important strategy when the announced plans for the construction of a railway through NNP (in the northern area) eventually take effect.

6.4 Discussion

The highly significant decline (96%, Figs. 6.3 and 6.4) in lion attacks on bomas with flashlights installed, confirmed by positive experiences from the majority of interviewed owners of such bomas (92%), support the hypothesis that flashlights reduce the probability of nocturnal lion attacks at livestock bomas. Secondly, we found a change in lion behaviour, which shifted their attacks to attacking non-flashlight bomas or a shift from nocturnal attacks to diurnal attacks (Fig. 6.5)

At the same time, lions covered greater distances from the park boundary, towards areas where bomas had no flashlights installed (Fig. 6.7). This, in combination with the shift in timing from nocturnal to diurnal attacks (Fig. 6.5), suggests that lions in the study area actively search for livestock bomas with no flashlights installed, thereby avoiding those with flashlights. Our findings have great implications for livestock owners in the region, especially for those who have no flashlights installed at their bomas. The losses suffered as a result of the shift from nocturnal to diurnal attacks, however, are generally small and could be addressed by relatively simple changes in herding strategies during the day by avoiding livestock grazing close promixity to protected area and use of mature human guardian (Woodroffe et al. 2007; Kuiper et al. 2015; Miller et al. 2016).

Similar to results from other studies (Van Bommel et al. 2007; Tumenta et al. 2013; Abade et al. 2014), our findings show that increased rainfall is related to higher livestock depredation frequencies. This is a common phenomenon that is associated with a greater dispersal by both lions and their natural wild prey species during the wet season due to an increased and more widespread availability of both water and pasture after the rains (Bauer & De Iongh 2005). Rainfall in the study area was highest during the 2011-2012 season, which was also the peak for livestock depredation.

Despite the great variation in reports on the importance of boma characteristics and construction materials (Ogada et al. 2003; Woodroffe et al. 2007; Abade et al. 2014) in the prevention of attacks on livestock by large carnivores, it is generally agreed that improved enclosures as well as both nighttime and daytime vigilance reduces the rate of livestock depredation (Patterson et al. 2004; Woodroffe et al. 2007; Bauer et al. 2010; Sogbohossou et al. 2011). The improved fencing techniques used in studies such as "Living walls bomas" (Abade et al. 2014; Lichtenfeld et al. 2015) and "predator-proof bomas" (Manoa & Mwaura 2016) demonstrated success rates similar to those found after flashlight installation: a 90% to 99.9% decrease in nocturnal lion attacks. However, the outcome of the use of dogs by the community around NNP contradicts the findings of Van Eeden et al. (2018), who found that use of animal guidance to prevent livestock attack. Our study further demonstrated that boma attacks by lions could, to a certain extent, be prevented by using wooden fencing materials, reinforced with chain-link perimeter fencing material, provided that these were constructed at a height of at least 2.5 meters and when livestock visibility from outside was poor. Respondents with few shoats (<20) used iron sheets, or concrete walls and roof covered bomas to minimize the chances of lions climbing over.

In individual cases, replacing traditional thorn-bush fencing with high concrete or chain-link materials has been reported to actually increase the losses of livestock. During the course of our study, a lion was observed by the principal author climbing over a chain-link fence of 2.5 meters surrounding a boma where no flashlights had been installed to predate on the livestock that was kept inside. Several additional reports of attacks on bomas that were covered by roofs of chain-link material described cases in which a lion would climb the chain-link roof and then fall through the chain-link barrier into the boma, where the livestock was trapped. While livestock would still be able to escape from a boma that is built with thorn fencing, thereby minimizing catchability and number of casualties, the chain-link fence and roof offer no escape route. A lion trying to escape a death trap like this is likely to kill and injure even more livestock in the boma.

Whereas in our study livestock herd size did not influence nocturnal boma attacks by lions, the findings of Van Bommel et al. (2007) suggest that the number of livestock present in a village is directly related to the number of lion attacks. Woodroffe et al. (2007) also found that a large livestock herd is associated with a higher risk of diurnal depredation. Although the frequency of attacks on livestock is generally higher closer to the park boundary (as was found for e.g. Waza National Park in Cameroon (Van Bommel et al. 2007), Serengeti National Park (Holmerna, Tomas, Julius Nyahongoa, Røskafta 2007) in Tanzania and Kweneng in Botswana (Schiess-Meier et al. 2007), lions would cover up to 20 km per day in search of prey (Tuqa 2015), thereby entering high-risk, human-dominated areas to kill livestock (Ogada et al. 2003; Oriol-Cotterill et al. 2015).

The ability of NNP lions to adapt their behavior to the installation of flashlight bomas, by targeting non-flashlight bomas futher away from the park boundary and shifting from nocturnal to diurnal attacks, could eventually lead to a decrease in the damage suffered by livestock owners. This positive effect is expected to also promote a further increase in the number of flashlight bomas.

6.5 Conclusion and recommendations

Despite the effectiveness of our proposed LED flashlight technique in deterring lions from livestock bomas around NNP, its successful implemenation in a different situation is not guaranteed. Conflict mitigation techniques that are effective in one place could fail in another and, even at a local scale, measures could become less effective over time, due to changes in e.g. environmental or social factors (Miller et al. 2016). Eklund et al. (2017) suggested that a single intervention is usually not a long-term solution to human–wildlife conflicts. Livestock owners should be aware of this and ensure they have multiple anti-predation techniques in place at any given time (Miller et al. 2016; Treves et al. 2016). Working together with local authorities in managing such techniques, but also the implementation of rapid response mechanisms and simply ensuring that faulty flashlights are serviced, are all additional aspects that can be crucial for any mitigation measure to be effective (Miller et al. 2016). Whereas evidence-based lethal control measures to ban lions from villages have historically been recommended (Treves et al. 2016; Van Eeden et al. 2018), for the pastoralist communities around NNP this certainly has no preference. The majority of livestock owners we interviewed suggested non-lethal techniques could and should be used to effectively reduce livestock depredation rates in the area.

The recent increase in the number of lion attacks at unprotected bomas has a great impact on the livelihoods of local communities. In fact, six recent reports of lions sighted in the suburbs of Nairobi City prove that today's challenges associated with human encroachment around NNP are greater than ever. In the current situation, the pressure on bomas without flashlights, further away from the park boundary or in new areas that have experienced very few or no lion attacks to date, is likely to further intensify, unless the proposed LED flashlight technique is implemented and reinforced throughout the lions' dispersal range by national and county governments. Future studies on the effectiveness of our technique should take this behavioral adaptation of lions into account and ideally should include a control sample of bomas with no flashlights installed.

The usefulness and applicability of the LED flashlight technique in other parts of the world, and thus to other species of large carnivores, is worth exploring. Although differences in behavior, habitat and range use must be considered, we believe this technique, after location-specific adaptations, has the potential to effectively reduce attacks on livestock by other conflict-prone carnivores, such as spotted hyenas (*Crocuta crocuta*), leopards (*Panthera pardus*), tigers (*Panthera tigris*) or even coyotes (*Canis latrans*) and foxes (*Vulpes vulpes*). The loss of these apex predators would have a cascading effect on ecosystem functioning, economic services and an intrinsic value, which they either contribute to directly or indirectly (Ripple et al. 2014).

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Author Contributions

Concept and design of field work: FL, CM, GDS, and HDI. Fieldwork: FL, MF, MG. Data analysis: FL, MF, and MG, KM. Materials/analysis tools: MZ, *C. J. M*, GAP, GDS and HDI. Author of paper: FL

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Supporting information

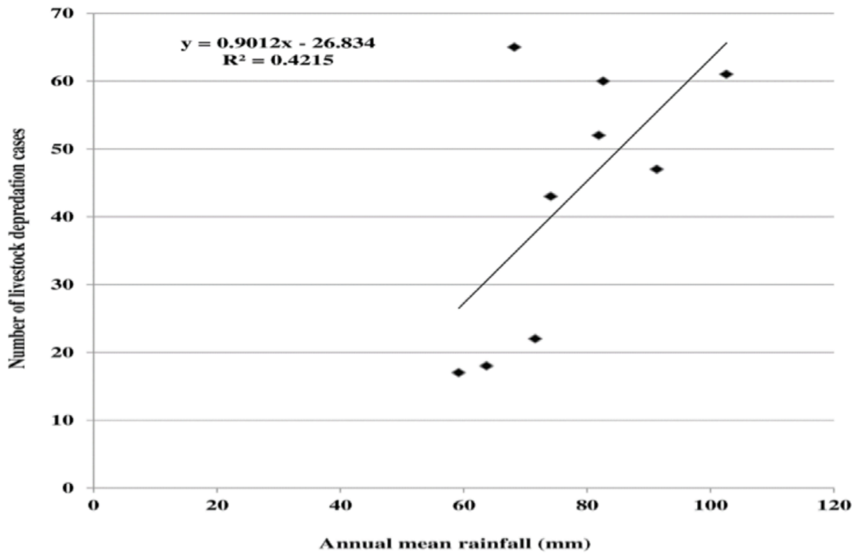

Figure S1

Annual mean rainfall (mm) correlation with total number of annual livestock depredation cases by lions from 2007-2015 in the southern part of NNP.

Table S1

Complementary depredation defense deployed by livestock owners at night, based on 2016 interviews.

	Attacked	Not Attacked	X2	Df	P -value
Radio	2	5	0.01	1	0.920
Fire	7	12	0	1	1
Prayers	16	36	1.2	1	0.27
Flashlight	1	28	12.975	1	0.0003
Scare Crow	3	7	1.205	1	0.2723
Noise	15	35	0.499	1	0.479
Spotlight	2	6	2.26e-31	1	1
Wood	11	55	8.113	1	0.00439
Wire	11	47	0.5996	1	0.4406
Acacia	3	8	0.0846	1	0.7711
Sheet	3	5	0.8463	1	0.7711

Table S2
Livestock herd size, number of attacks and cases without attack.

Categories	Shoats	Attacked	No Attack	Total	Cattle	Attacked	No Attack	Total
Below average	>100	13	27	40	>35	11	31	42
Above Average	<101	4	19	23	<36	6	15	21

Table S3
Participants' opinions on how to resolve human–lion conflicts.

S/n	Measures to be taken to resolve human–lion conflicts in NNP	% on opinion
	Flashlights installation	26.1
	Compensation	22.8
	Keep lions in park	12.0
	Prompt response by KWS	7.6
	Stop construction in NNP	6.5
	Proper fencing of bomas	4.3
	Cooperation between community and KWS	3.3
	Keep wild prey in park	2.2
	Herding	2.2
	Watch cattle at night	2.2
	KWS to patrol at night in the community land	2.2
	Translocation of problem animals	2.2
	KWS to monitor lions	2.2
	Reduce lion numbers in NNP	1.1
	Monitor collared lions and bring them back to NNP	1.1
	Train people from the community and let them monitor lions	1.1
	Feed lions if hungry	1.1

S1 File
Questionnaire

Additional questions of 2014 in italic

Name:

Age:

Sex: m/f

Education level: none/ school/ high-school/ college/ other:

Ethnicity:

Date:

GPS Coordinates:

1 *Do you keep all your livestock in bomas at night, or only part of it?*
All livestock/ part of it (______ %) / none

2 *If none at night, where do you keep your livestock at night?*

3 *Do you keep all livestock in one boma or in several bomas?*

4 Could you describe the boma(s) construction materials and properties?

3a Is livestock visible through the boma structure?	Yes visible
	Partially visible
	Not visible
3b How high is the boma structure?	0 – 1 meters
	1 – 2 meters
	more than 2 meters
3c What is the thickness of the boma?	0 – 0.25 meters
	0.25 – 0.5 meters
	More than 0.5 meters
3d From which material is the boma constructed?	Bush (acacia)
	Fence (chain-link/barbed)
	Stone (stones/bricks/cement)
	Sheets (metal/wood)
	Wood (offcuts/posts/poles)
	House (inside house)
	Mixture of the above (specify which)

5 Has your boma(s) suffered any attack in the past two years? (to be filled in Appendix II)
- When (dates and time of the day)?
- Which predator was responsible for the attack?
- Who witnessed the predator?
- Which animals and how many did the predator kill?
- Did you report the attack? To whom (KWS, Area Chief, FONNAP, Game Scout)?

6 Do you think the attacks could have been prevented? How?

7 Do you have flashlights installed in your boma(s)? y/n

8 If yes, when was the flashlight installed?

9 Has there been any depredation since the flashlight was installed? y/n

10 If yes to Q7, are you happy with the functioning of the flashlights? y/n

11 *Could you name what other preventive methods against livestock depredation do you use at day/night?*

	Preventive method	Day	Night
1	Radio		
	Dogs		
	Fire		
	Human guards		
	Scarecrows		
	Herding		
	Noise		
	Prayers		
	Flashlights		
	Others		

1 Do you think fencing the southern border of the park could help prevent lion attacks? y/n

2 In your opinion, what do you think can be done to resolve human-lion conflict in this area?

3 *Are you aware of the satellite collaring of lions by the Nairobi lion project? y/n*

4. *What is your opinion on the satellite collaring of lions?*

   very good/ good/ no opinion/ bad/very bad

5. What is your main source of income?

   (livestock/ farmer/ employed/ business (e.g. grocery)/ other _________)

6. *How many livestock do you intend to keep?*

7. How many livestock do you currently have?