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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Impact of Partial Park Fencing and Costs of Livestock Depredation by Lions (*Panthera leo melanochaita*) around Nairobi National Park, Kenya

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Abstract

We examine the contribution of livestock to lion diet and to investigate the impact of the partial fencing of the park on livestock depredation, to assess the relationship between rainfall and livestock depredation and to determine the number of heads of livestock killed by lion and economic losses incurred by livestock farmers. A comparison was made between a scat sampling method and depredation records.

Our findings show that the presence of livestock remains differs per season and section of the park and that depredation on livestock is probably facilitated by the absence of fences in the south-west part of the park, resulting to a significant livestock depredation and high economic losses to livestock farmers.

We concluded that the partial fencing of parks is not a solution to human-lion conflicts and that the unfenced portion of the park is a corridor for high livestock depredation during the wet season and during the period when livestock is in close proximity to the park. Consequently, this section is

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linked to a higher annual percentage of livestock depredation and economic losses incurred by livestock farmers than the fenced section of the park.

We recommend that the park authority improves park fences, establishes a problem lion control station in the unfenced section of the park for rapid response to problem lions and implements compensation schemes.

Keywords
Panthera leo, Scats, Livestock, Conflict, Nairobi National Park, Community compensation scheme

5.1 Introduction

Across the world, where large carnivores are in contact with humans and livestock, both humans and carnivores have suffered negative consequences (Inskip & Zimmermann 2009; Riggio et al. 2013). Local farmers in the proximity of large carnivores often suffer substantial losses through livestock depredation and such incidents are frequently followed by persecution and retaliatory killings, either by authorities (animal control) to avoid future attacks or by locals (Bauer & De Iongh 2005; Van Bommel et al. 2007). Different authors have defined human-wildlife interaction based on underlying causes, the adverse effects on people and the threat levels to and safety of people (Conover 2002; Inskip & Zimmermann 2009; Young et al. 2010). Redpath et al. (2013) have suggested using the term "impact", when there is interaction between wildlife and people, i.e. instigated by the wildlife, and the term "conflict" when there is interaction with wildlife initiated by people and/or wildlife authorities. It should be noted, however, human–carnivore interactions are not limited to livestock depredation, but also include attacks on humans that result in injury or even death and man-eating report in Tanzania among others (Packer et al. 2005).

This is also true for the lion in Africa (*Panthera leo*): increased human populations and the associated expansion of human settlements have largely confined lions to protected areas (Woodroffe 2000; McKee et al. 2004; Stuart et al. 2010). Human development has resulted in a decrease in lion populations in Africa in recent decades (Bauer & Van der Merwe 2004; Kolowski & Holekamp 2006; Riggio et al. 2013). The interaction between humans and lions may have a negative effect on the livelihood of local communities and it may also result in increased mortality of lions due to retaliatory killing (Sogbohossou et al. 2011).

The level of livestock depredation differs per season and depends on the accessibility of domestic stock to lions (Woodroffe et al. 2005; Sogbohossou et al. 2011; Valeix et al. 2012; Lesilau et al. 2018). Livestock depredation has a significant impact on the livestock owner's economy (Bauer et al. 2010). Livestock owners bear the costs of livestock depredation, but they may receive few benefits from wildlife tourism (Hemson 2003; Winterbach et al. 2013; Hazzah et al. 2014).

Livestock encroachment is now a problem in most protected areas in Africa (Vijayan et al. 2012). In these locations, lions incorporate both wild and domestic prey species in their diet (Table 5.1) (Hayward & Kerley 2005; Tuqa et al. 2015). Where livestock farmers are financially compensated for livestock losses and participate in effort to conserve wildlife, they tend to be more tolerant, which in many cases, it has prevented retaliatory killing of lions (Hazzah et al. 2014; Blackburn et al. 2016).

Table 5.1
Livestock depredation analysis from various parks in Africa

Country	Protected Area	Livestock Contribution to lion diet (%)	Source
Kenya	Tsavo N. Park	5.8	Patterson et al. 2004
Botswana	Makgadikgadi Pans	10-26	Hemson 2003.
Kenya	Samburu N. Reserve	6.2	Ogara et al. 2010
Benin	Pendjari Biosphere Reserve	18	Sogbohossou et al. 2011
Cameroon	Waza N. Park	21.6	Tumenta et al. 2013
Kenya	Amboseli N. Park	6-9	Tuqa 2015
Kenya	Mbirikani group Ranch	7	Maclennan et al. 2009

During 2012-2013, in a scheme to increase local pastoralists' tolerance to livestock depredation around Nairobi National Park (NNP) was implemented to compensate for their losses (http://www.thewildlifefoundationkenya.org). The process for claiming compensation for livestock killed is described in Lesilau et al. (2018). Only confirmed livestock depredation by Kenya Wildlife Service (KWS, 2017), The Wildlife Foundation (TWF) and Friends of Nairobi National Park (FoNNaP) were compensated. In our study, the term 'shoats' covers sheep and goats while livestock is a combination of cattle, shoats and donkeys (Ottichilo et al. 2000). In the area around NNP, the local conservation organization (The Wildlife Foundation) has been compensating one head of cattle at US $150, one head of donkey at US $50 and one head of shoat at US $25. The loss of dogs and pigs was not compensated (www.thewildlifefoundationkenya.org).

Although the compensation offered was only a third (average 64% lower) of the market value of a head of livestock, the purpose was to console owners who had lost livestock to depredation and to reduce the retaliatory killing of carnivores. In another area, the Amboseli ecosystem (Kenya) at the Mbirikani Group ranch, one lion was lost annually due to retaliatory killing, despite the community being compensated for depredated livestock (Maclennan et al. 2009) largely provoked by depredation on livestock, and there is debate as to the usefulness of financial instruments to mitigate this conflict. Intending to reduce local lion-killing, the Mbirikani Predator Compensation Fund compensates members of Mbirikani Group Ranch for livestock depredation at a flat rate (close to average market value. This suggests that, the solution to, addressing human-wildlife conflict may not be purely monetary. A combination of tackling the underlying social problems, compensating economic losses, and evaluating alternative conflict management approaches is required (Redpath et al. 2013)

NNP is partially fenced with a chain-link fence (Steinhart, 1994) and galvanized wire powered by electricity (6 kV). The park has an open access corridor to the Athi-Kaputei Plains (AKP) at the south-west border (Reid et al. 2008). During the 1970s, the park harbored approximately 30 lions in three prides (Rudnai 1974). There are no resident lions in AKP but it is a dispersal area for surplus lions from NNP and serves as a hunting reservoir (Rudani 1979).

To our knowledge, to date, no study has explored the use of livestock hairs from lion scats to demonstrate the spatial distribution of livestock–lion interactions. The results from our study could help farmers and wildlife authorities to better understand; the spatial distribution of human–lion interactions; the number of heads of livestock killed annually; the economic losses incurred by farmers; and depredation hotspot zones around the park. They can also assist in identifying factors influencing livestock depredation by lions. With these new insights, the management of NNP would take proactive measures to address the negative effects of human–lion interactions in the community land by monitoring and conduct education and awareness program.

Although other large carnivores in NNP, such as leopard *(Panthera pardus)*, cheetah (*Acinonyx jubatus)* and spotted hyena (*Crocuta crocuta*), interact with livestock in the community land as well, our study focuses on lions. During our study, from 2012 until 2018, the park lost 14 lions due to retaliatory killing in response to killing of livestock (Smith 2012; Kushner Jacob 2016; Ombati 2017). The management of NNP believes that problem lion management, in combination with improved knowledge about the lions in NNP, is urgently needed.

Based on our aims we designed the following research questions: (i) Which kind of livestock is killed by lions, based on the scats and official records? (ii) What is the influence of fences and rainfall on livestock raiding? (iii) What is the annual economic losses of livestock for farmers around the NNP? (iv) What is the difference between depredation records and scat sampling? (v) How can knowledge of management on NNP lions be improved?

5.2 Material and methods

5.2.1 Study area

Nairobi National Park (NNP) is located in the south-western part of Nairobi City in Kenya (Owino et al. 2011) (Fig. 5.1). The park was established in 1946 with an area of 117 km^2 (gazette notice No. 48 of 16th December, 1948). It is situated between latitudes 1° 20′-1° 26′S and longitudes 36° 50′-36° 58′ E (Ogutu et al. 2013) within an altitude ranging between 1533 m to 1760 m above sea level (Rudnai 1974; Owino et al. 2011).

Nairobi National Park has three distinct vegetation zones, as described by Foster & Coe (1968) and Rudnai (1974). Dwarf woody plants are a result of controlled burning by park management (Foster & Coe 1968). Kenya has two periods of rainfall, longer wet one from March to May with a mean of 150 mm of rainfall, and a shorter one from October to December with a mean of 90 mm of rainfall. During 1980-1981, the annual mean temperature was 19.6 °C with daily minimum 12- 14°C and maximum range 23-28°C (Deshmukh 1985).

As a result of its location, adjacent to Nairobi city, the National Park was semi-fenced in 1955 (Steinhart 1994) with a chain-link fence and galvanized wire. The fence, which is powered by electricity (6 kV), was erected from the east via the northern boundary to the west in order to separate wildlife from the Nairobi metropolis (Foster & Coe 1968; Reid et al. 2008). The southern boundary is beyond the Mbagathi River and provides open access to the Athi-Kaputiei Plains (AKP) with an area of rangeland of 2200 km^2 (Reid et al. 2008).

The park is home to four species of the so-called Big Five: lion (*Panthera leo)*, leopard *(Panthera pardus)*, African buffalo *(Syncerus caffer caffer)*, and eastern black rhinoceros (*Diceros bicornis*). The blue wildebeest (*Connochaetus taurinus)*, Burchell's zebra (*Equus quagga burchelli)* and associated smaller ungulates such as Grant gazelle (*Gazella granti)*, Thompson's gazelle (*Eudorcas thomsoni)* and warthog (*Phacochoerus africanus*) tend to range into community land during the wet season (Gichohi 1996). Other resident ungulate species include: White rhinoceros (*Ceratotherium simum),* Common eland *(Tragelaphus oryx)*; hartebeest *(Alcephalus buselaphus*); giraffe *(Giraffa Camelopardalis)*; impala (*Aepyceros melampus),* waterbuck (*Kobus ellipsiprymnus),* Bohor reedbuck *(Redunca redunca)* and Common reedbuck *(Redunca arundinum)* (Owino et al. 2011). The park is an important bird area with a high diversity of bird species (see www.naturekenya.org/content/important-bird-areas).

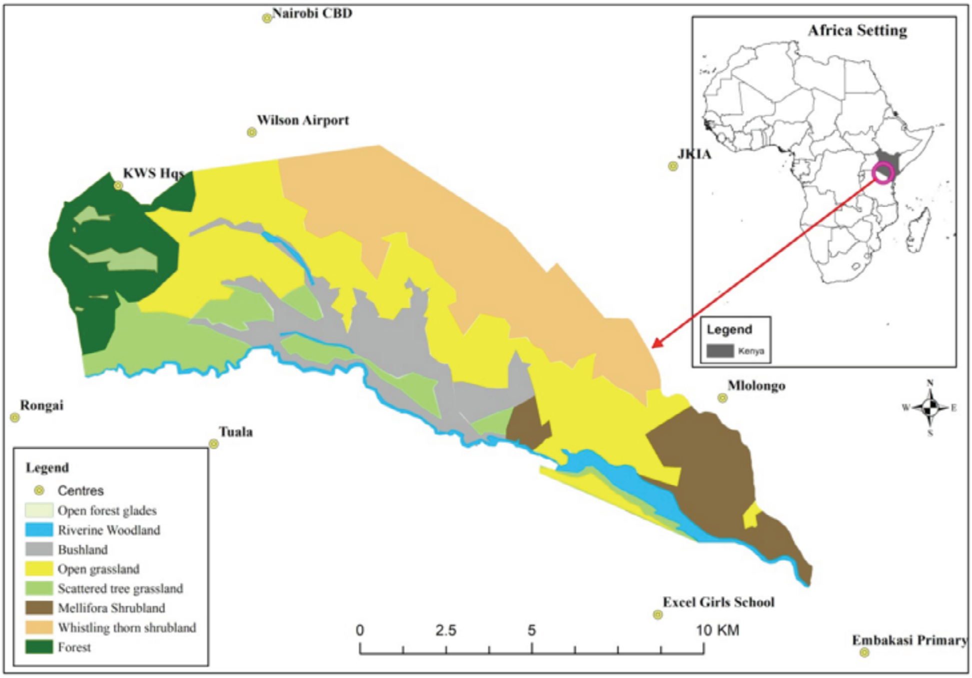

Figure 5.1

Map situating the different habitat types within Nairobi National Park. Vegetation data provided by the KWS GIS and Biodiversity Office (2011). (Designed in Arcmap 10.3.1 (ESRI Software, USA))

5.2.2 Data collection[3]

Lions live in family units and prides at the apex of their social organization (Stander 199; Bauer et al. 2003; Elliot 2017). Each adult member of a pride marks their territory using scats, urine and scents (Schaller 1972). As a result, scats from lions are commonly found throughout NNP. The scats were searched for at previously sighted lion resting sites, around prey carcasses

3 This section is partly from section 4.2.2.

killed by lions, along the roads while driving, and at opportunistic encounters with lions (Bisceglia et al. 2008; Tuqa 2015). Lion scats have a number of distinguishable features; they can be blackish, pungent smelling, segmented appearance, turning white when dry due to bones (Stuart & Stuart's 2000). The scats identified in the field were collected before sun drying and stored in a labelled zip-lock bags in a secure enclosure in order to prevent the samples from curious baboons, following Tuqa (2015). Microscopic hair identification was prepared according to the procedure used by Reynold & Aebischer (1991) and Ramakrishnan, Coss & Pelkey (1999). We made a Prey Reference Hair Collection (PRHC) from fresh prey carcasses in NNP by collecting hair specimens from stuffed animals in the Natural History Museum, Naturalis in Leiden, The Netherlands, and from livestock encountered around the NNP. Prey hair items were identified using hair structure (cuticle scales) and color and by comparing them with previously prepared PRHC morphology (Corbett 1989; Tuqa 2015).

The livestock depredation data of 2012-2016 were obtained from the Kenya Wildlife Service (KWS 2017), The Wildlife Foundation (TWF) and Friends of Nairobi National Park (FoNNaP) depredation database. When livestock owners reported a depredation incident it was recorded in the Service incident book, after which a team of Problem Animal Control experts was dispatched to the scene of depredation to verify the report (i.e. determination of predator by claw marks on the kill, paw prints on the ground, scats, predator hairs) and to take GPS coordinates, scene photographs and details of the property owner, time and location of the incident. Further details on data collection for this database are described in Lesilau et al. (2018).

ArcGIS 10.3.1 (ESRI Software, Redlands, CA, USA) was used to determine the length of fenced and unfenced sections of the park (Fig. 5.2). We used GPS locations of 12 collared lions for lion distribution, and movement, and location of pride (Lesilau inprep). We also conducted a bi-annual lion survey to visually identify individual lions in the months of February-April and July-September in 2012 and again during 2014-2018 inside the park (Lesilau inprep). We obtained rainfall data from Wilson Airport Meteorological station through Kenya Meteorological Department (KMD, 2012, 2014-2016). Taking into account the high altitude of NNP and high rainfall, we chose a mean of 30 mm of rainfall per month as our cut-off point between the wet and the dry seasons.

Several authors have applied different techniques to determine the costs of livestock depredation. Patterson et al. (2004), for example, used weights and retail economic value, while Butler (2000) used economic value survey techniques and Woodroffe & Frank (2005) used average market prices. The livestock market price data for our study area (Kitengela livestock market, Kenya) was not available. Therefore, we used existing livestock prices from Loibor Siret market in Tanzania based on the average livestock market prices recorded by Lichtenfeld et al. (2015), since Kitengela livestock market in Kenya and Loibor Siret market in Tanzania are similar (Table 5.2). The inhabitants of our study area (around NNP) and those in Loibor Siret belong to the same ethnic community (Maasai) and due to the nomadic nature of this community, they have unrestricted access to both markets.

Table 5.2
Economic loss caused by lions for different livestock types. Cumulative livestock depredation data from 2012-2016

Livestock	No. of Livestock predated	Percentages (%) of livestock predated	Average prices per head of livestock (US$)	Total value of livestock loss	Percentages (%)
Cattle	296	19.4	450	133,200.00	66.9
Donkeys	36	2.4	200	7,200.00	3.6
Goats	241	15.8	50	12,050.00	6.1
Sheep	933	61.1	50	46,650.00	23.4
Dogs	20	1.3	0	0	0
Total	1526	100		199,100.00	100

The average livestock market value is from Lichtenfeld et al. (2015)

5.2.3 Data analysis and statistics

The scats were grouped into seasons of data collection (wet and dry season). The occurrence of hair items from each prey species in all scat samples was expressed as presence or absence of the prey species within the scats (Reynold & Aebischer 1991; Bisceglia et al. 2008; Tuqa 2015). Presence of prey remains (hair, bones, nails, teeth, feathers, and scales) were identified to genus or family level only (Pearson 1995; Bisceglia et al. 2008). Each identified prey hair was grouped as either of livestock or wildlife origin and classified based on the species weight according to Bauer et al.'s (2008) classification. We used the frequency of occurrence of the prey hair item in the lion scats as an indicator for the contribution to lion diet, rather than the number of prey hair items or body mass. We used a Chi-square test to determine differences in occurrence of prey species (livestock vs. wildlife) between sections and seasons.

We used two methods to identify recorded events of livestock attacks and to determine the risk of an attack. The first one were the actual recorded attacks, irrespective of the number of livestock killed, so that each attack was counted as a single event (Kissui 2008). For the second one, we analyzed and plotted GPS coordinates, whenever there were available, at every report from villagers, confirmed by KWS rangers and research, of the presence of a lion, irrespective of an actual attack or no attack. We emphasized events, rather than attacks, since not all inhabitants around the park own livestock. We have witnessed two incidences of "mass – killings" and each is treated as a single event. "Mass-killing" refers to a situation where lion kill many livestock either in a boma or in the grazing field. Thus, an event is a single incident where a lion killed livestock or has been observed in the community land. The Fishers Exact Probability test was used to establish the difference between the number of prey hair items per species and the number of depredation records per species.

For spatial analysis, we divided the park arbitrarily into two parts: the North-West (NW) section and the South-West (SW) section (Fig. 5.2). We plotted the GPS locations of the twelve collared lions and the scats using ArcGIS 10.2.2 and projected these into the Universal Transverse Mercator (UTM) WGS-84, zone 37 ° S. The Spatial Analyst tool and Geospatial Modelling Environment software were used to determine lion movements and location of scats (www.spatialecology.com/gme/). We used the frequency of lion observations during surveys and sightings to determine individual pride members, age composition and group size in the park (Lesilau inprep). We did not determine livestock density since these animals are not allowed to graze in the park and sometimes they illegally grazed at night. The NW section borders an urban environment with high human settlement. This area does not provide a wildlife dispersal corridor, while the SW section borders a rural environment with a wildlife dispersal corridor. Both sections were semi-fenced but the surface of the unfenced portion of the NW section is much smaller than the SW section. We compared livestock prey hair items in the scats from the northern section with those from the southern section that is partially fenced and has some open access to the surrounding rangelands. We classified prey hair items in the scats as being from the "NW section" or the "SW section", based on the GPS location where the scats with livestock prey hair items were collected.

We determined a possible relationship between monthly precipitation, livestock attacks and the number of incidences of lions being outside the park (KWS 2017). We log-transformed the monthly rainfall data to normalize distribution (McKee et al. 2004; Kolowski & Holekamp 2006; Kuiper et al. 2015) and applied a linear regression model to determine the relationship between rainfall and log-number of livestock depredation events. We calculated the value of every head of livestock predated by lions and multiplied this by the number of livestock killed and then by the livestock market price to determine the economic losses incurred as stated in Lichtenfeld et al. (2015). We then divided the cumulative value of livestock predated by five years to get annual expenses incurred by the farmers around NNP. We excluded dogs, since they have no market price.

All statistical tests were carried out using the software R version 3.3.2 (R Foundation, Vienna, Austria). A significance level of ($p < 0.05$) was used for all tests. In all cases, normality was tested using the Shapiro-Wilk test.

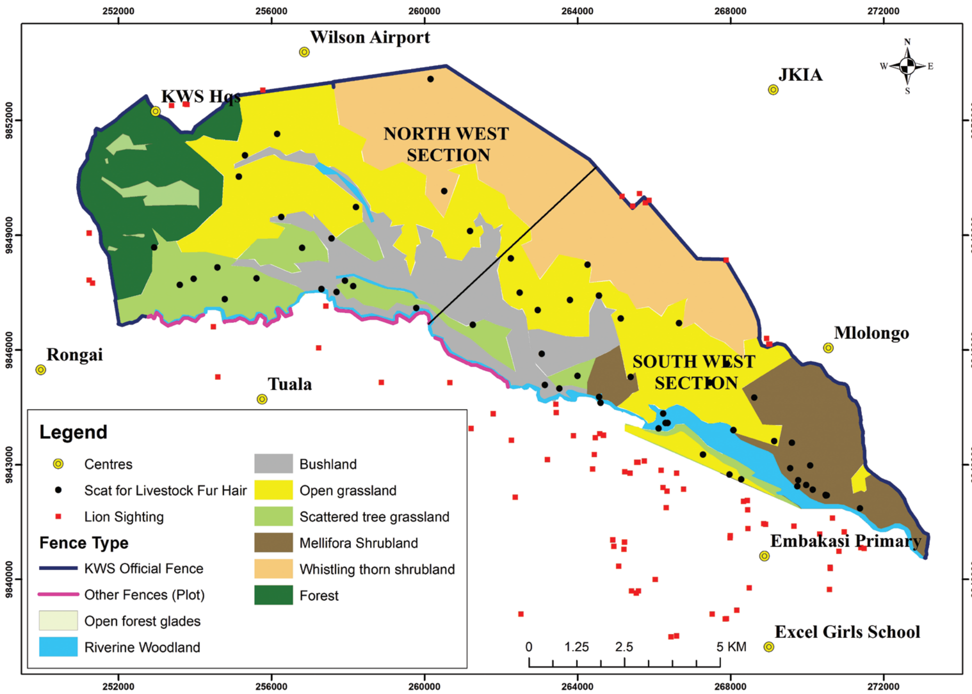

Figure 5.2

Locations of scats containing livestock prey hair items and the locations of livestock attacks or events of a lion being outside the NW and SW sections of NNP (based on data from 2012, 2014-2016). The black dots = GPS locations of scats with livestock prey hair items; red squares = GPS location of lion attack or report of a lion being outside the park.

5.3 Results

5.3.1 Livestock presence in lion scats

Of the 390 scats collected, 61 contained livestock items. The total number of prey hair items found in the scats was 442, of which 69 were livestock items. A total of 3 scats with inaccurate GPS locations were excluded from analysis.

Our analysis focused on prey hair items of different prey in each lion scats with verified GPS location, resulting in a total of 66 (15%) of all the scats items with livestock prey hairs from 58 scats used for analysis.

We identified six different livestock prey species based on hair identification in the lion scats (Fig. 5.3a). We found 40 (61%) livestock prey hair items in the dry season and 26 (39%) in the wet season, which represents a significant difference (Fig. 5.3e & f; $\chi^2 = 47.91$, df = 1, p-value =<0.001). The most predated livestock by lions around NNP are shoats (72%) followed by cattle (12%), donkey (9%), dogs (5%) and pig (2%) (Fig. 5.3a). Furthermore, 73% of livestock prey hair was found in the SW section of the park and 27% was found in the NW section of the park, which is also a significant difference (Fig. 5.2, 5.3c and d; $\chi^2 = 18.45$, df = 1, p-value < 0.001).

The relative contribution of 26 (39%) livestock hair prey items in the dry season and 40 (61%) livestock hair prey items in wet season in relation to the total number of 150 prey hair items in the dry season and 292 prey hair items in the wet season is 8.9% and 26.7% respectively (Fig. 5.3e and f). Relative to all prey hair items identified, 18 (4%) livestock prey hairs were found in the NW section and 48 (11%) livestock prey hair were found in the SW. This means that, there is relatively more livestock consumption by NNP lions in the wet season than in the dry season and more in the SW than in the NW section. Simultaneous to the larger percentage of livestock prey hair items in lion scat during wet season compared to the dry season, the wild prey carcasses biomass in the park during the dry season is larger (8,20 kg/km^2) and this drops to 3,837 kg/km^2 in the wet season (Lesilau in prep).

5.3.2 Livestock depredation

Official records reported a total of 1,088 lion depredation events during which 1,526 heads of livestock were killed, around NNP during 2012-2016 (Fig. 5.3b). The annual average of depredation is 305±128.1 (range = 227-560). We found five categories of livestock prey species in the records. The majority of the attacks were on sheep (61%), followed by cattle (20%), goats (16%), donkeys (2%) and dogs (1%) (Fig. 5.3b). In one case, the depredation records and the local news media (Kiplagat 2018) reported the depredation of 110 shoats by a pride of lions in a single night. The Fishers Exact Test shows a significant difference between livestock depredation in official records and livestock prey hair items in the scats in relative to number per species ($p < 0.001$). There are more species variety in the scats than in the depredation records.

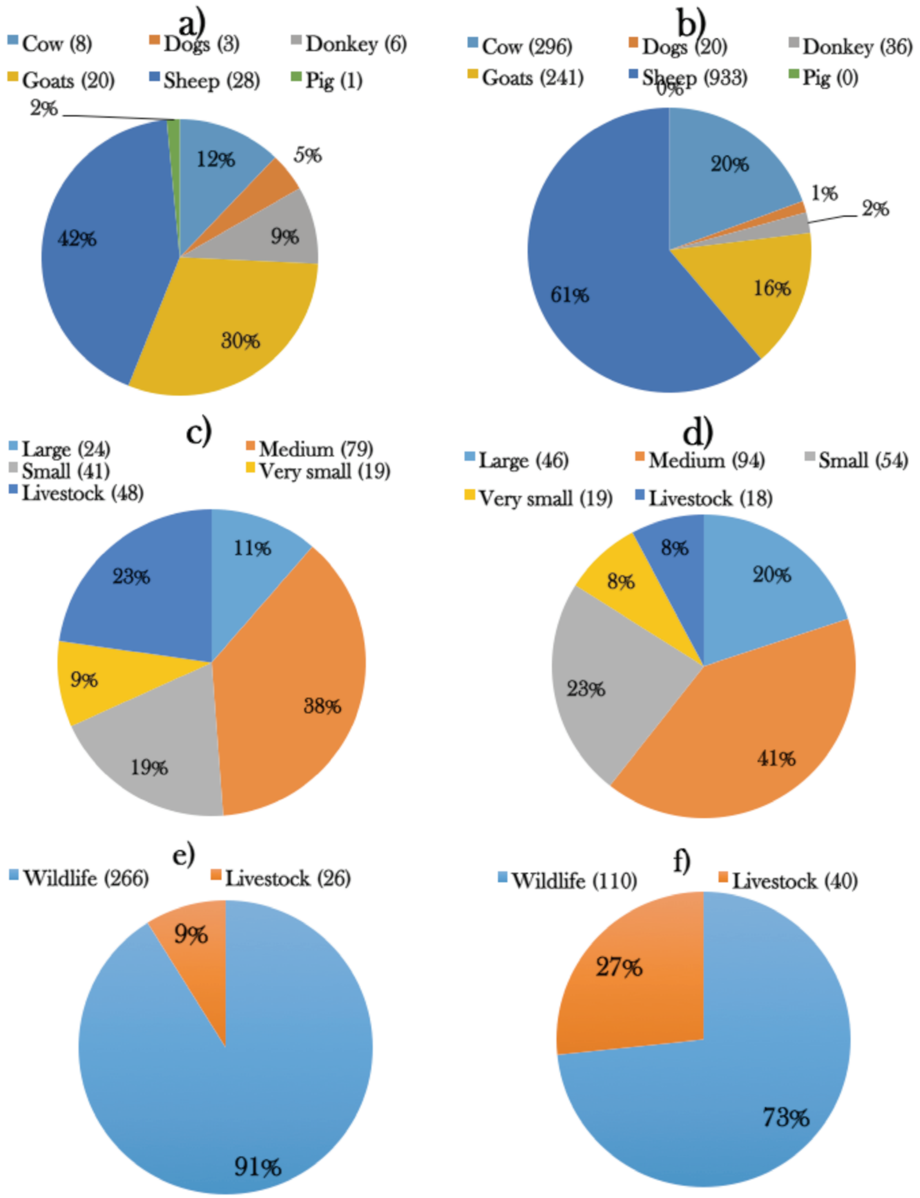

Figure 5.3

Comparison based on the percentage analysis of livestock prey hair items and different categories of prey species of different body mass between sections: (a) livestock prey hair items found in scats; (b) predated livestock records; (c) NW section; (d) SW section; e) relative contribution of wildlife and livestock prey hair items in dry season, and f) relative contribution of wildlife and livestock prey hair items in wet season. The figures in brackets = livestock depredated and prey hair items found in lion scats. Species category is based on Bauer et al. (2008) (Large is 200 kg, medium 50 – 200 kg, small <5 - 50kg and this study on very small < 5 kg).

5.3.3 Impact of fencing and rainfall

The park's perimeter (64.7 km in total) is fenced over a stretch of 36.3 km (56.1%). This fence encompasses 21.5 km (59.2%) of the NW section perimeter and 14.8 km (40.8%) of the SW perimeter (Table S1). However, the lions could still detour some of the fences through the valleys and thus have access to livestock. The log-transformed number of depredation events and the log-transformed rainfall per month in the park were significantly correlated (Fig. 5.4; r = 0.87, p-value = 0.001) to depredation. Livestock depredation is generally higher in the wet season, compared to the dry season (except in 2013; Table S2). During 2012-2016, there were 905 reported cases of lions being outside the park in the wet (83%) of all cases, which is significantly more than the 183 (17%) in the dry season depredation cases (Fig. 5.5) in which lions ventured beyond the park's perimeter with a mean of 217.6 (range = 149-299), which was significant (χ^2 = 1262.7, df = 1, p= 0.001). Based on Satellite Collars' GPS locations of lions, shows a spatial shift into the community area at the south-west of the park on 1005 (44%) occasions in the dry season and on 1263 (56%) occasions in the dry season (Fig. S4; χ^2 =29.35, df = 1, p = 0.001), with a mean of 567 (range 300-972).

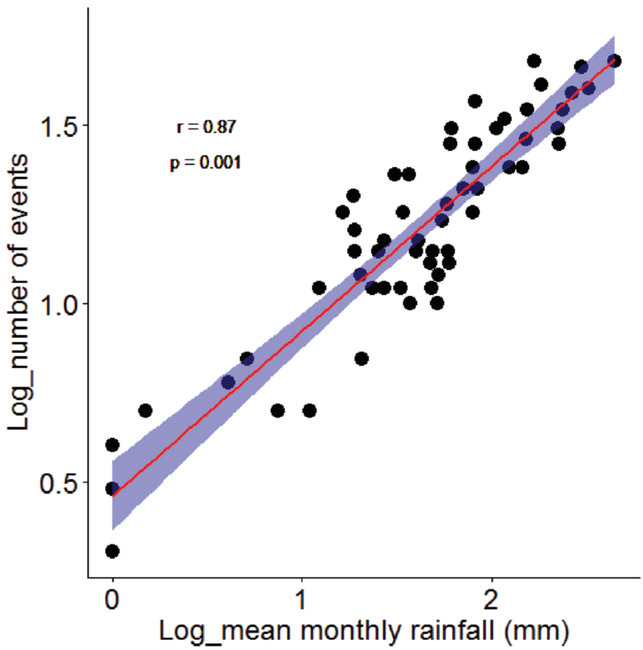

Figure 5.4

Relationship between the logged monthly mean rainfall and monthly logged number of events of lions outside NNP during 2012-2016. The shaded grey band = 95% confidence band; black solid line at the center of the grey = the regression line; black dots = events.

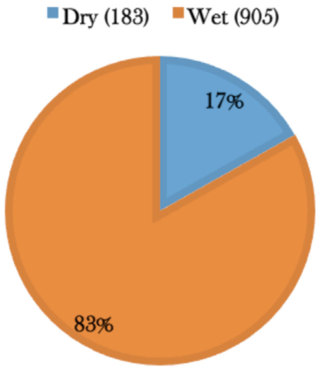

Figure 5.5
The number of confirmed reported cases of lions sighted in the community land, either by community members or the wildlife authority. In some cases, the lions attacked *bomas*; in others, they were chased into the park or sedated by veterinary personnel and released in the park.

5.3.4 Costs of lion attacks

We found that in terms of 'economic loss', among the categories of livestock, cattle (66.9%) were the most valuable (Table 5.2). The farmers around NNP incur livestock depredation losses, amounting to 39,820 USD annually due to lions alone. Shoats contributed only 29.5% to the total losses of depredation.

5.3.5 Comparison with depredation data from scats

The scat results showed that domestic pigs are eaten frequently but not often reported as being killed by lions. Dogs and donkeys are the least reported depredations. In terms of both scats and depredation records, shoats are common prey for all livestock species. We compared the prey hair items per month a particular species of predated livestock per month and found a significant ($p < 0.001$) relationship between predated shoats and the prey hair items of livestock in the Fishers Exact Test (Fig. S1). The data of other livestock species like pigs, donkeys and dogs, were too few to be analyzed.

5.4 Discussion

5.4.1 Depredation on livestock based on hair analysis

Our findings from the scat analysis show a significant contribution of livestock to the NNP lions' diet. We found a broad spectrum of livestock prey hair in the scats, including cattle, shoats, donkeys, pigs and dogs (Fig. 5.3a). Larger wild prey contributed more to the lions' diet in the NW section compared to the SW section of the park (Fig. 5.3c and d) due to fence restriction in the north and not body mass. This suggests that, the pride in the SW section of the park supplement their wild prey diet in this area with livestock (Fig. 5.3c, d and S4). The higher frequency of livestock items found in scat in areas adjacent to the unfenced portion of the park is most probably the result of this easy access for lions to the surrounding rangeland. Our results confirm that measuring the contribution of livestock hairs in lion scats is a good indicator of depredation (Fig. S1).

A number of studies have identified lions as major livestock predators, often killing more and larger livestock compared to other large carnivores, such as leopard and spotted hyena, which generally prefer goats and sheep (Hemson 2003; Bauer & De Iongh 2005). Although it was not recorded in the depredation data, the presence of pig hairs in the lion scats shows that lions going through the fence into sub-urban area also depredate pigs. Moreover, hairs from domestic dogs were found in the lion scat. In addition to observing domestic dogs in the park, on one occasion we encountered dogs scavenging a lion kill either in the park or in the community land on 14 July 2015 (Fig. S3), thus dogs make themselves vulnerable to lion depredation.

5.4.2 Livestock depredation

We found that the most predated livestock around NNP are shoats (Table 5.2). Lions mostly predate at night, sometimes even killing shoats inside bomas. A lion can kill as many as one hundred shoats in a single night, partly as a result of the panic caused by the attack, resulting in multiple fatalities among the stampeding herd (Lesilau et al. 2018).

Although Bauer et al. (2008) and Kissui (2008) stated that lions prefer medium-sized prey such as cattle and donkeys, the small-sized shoats were the most targeted in our study area. The fact that lions can jump over the livestock boma fence while carrying this relatively small prey, may have attributed to this. Furthermore, killing shoats requires a lower energy investment by the lions. The fact that some livestock, like sheep, lack a distress call to alert human guardians could be a further contributing factor to the lions' preference for shoats in our study area, as it gives lions more time in the boma to continue killing (Lesilau et al. 2018).

Little energy is needed to find shoats when they are housed inside permanent bomas, therefore the profitability is high. In such a situation, the benefits of livestock raiding are high and as long as they outweigh the energy costs, livestock attacks are likely to continue. The costs of livestock raiding for lions rise from risks involved in encounters with humans, the energy spent on travel, and the energy spent on entering well-protected bomas and crossing the park's fence. The risk of being killed or wounded by humans is the highest cost and this is reflected in the lions' hunting behavior i.e., usually depredate at night when human activity and visibility is low (Valeix et al. 2012; Oriol-Cotterill et al. 2015). The localized high abundance of livestock and their highly predictable distribution in combination with their inability to escape bomas, make livestock a favorable type of prey for lions in our study area.

Although depredation data reveal significantly more attacks during the wet season compared to the dry season, our NNP scats analysis indicates that livestock is included in the diet of the lions irrespective of the availability of wild prey. We speculate that initial livestock depredation events will occur during periods of low prey availability. Once livestock raiding has proved to be an efficient and beneficial hunting strategy, it seems to be practiced by lions even when wild prey is more commonly available. The higher than expected livestock depredation revealed by the scat analysis in comparison to reports of depredation events during the dry season could also be a result of illegal livestock grazing inside the park during the dry season at night. In this case, it is likely that lion events are underreported, since pastoralists are aware of the illegal nature of their activity. By making the costs of livestock depredation higher than the benefits for the lions, it may be possible to force them to adapt their prey choice to focus on wild prey. This is possible with improved herding, predator-proof fencing of park sections and installing flashlights at bomas (Lesilau et al. 2018; Manoa & Mwaura, 2016; Woodroffe & Frank, 2005) largely through conflict with people. Here, we quantify the impact of lethal control, associated with livestock depredation, on a population of African lions (Panthera leo.

5.4.3 Impact of fencing and rainfall

We found that complete or partial fencing of the protected areas is not a guarantee solution to address human–lion conflict. Our analysis shows that the partial fencing of NNP allows lions to access livestock in the surrounding rangelands through the southern corridor or to make a detour at end of the fence (Figs. 5.2 and S4). For complete fencing, Massey, King, & Foufopoulos, (2014) showed a temporal change in wildlife population numbers, biomass, and species richness decline after the complete fencing of the Aberdare N. Park.

Although our data show minimal human-lion interaction in the fenced section compared to that in the partially fenced section of NNP (Fig. S4), interaction is intensified and affects locals neighboring partially fenced section. Evidence suggests that the welfare of local communities and wildlife conservation status are threatened when fences are erected because access to common resources and other facilities such as water bodies and roads are also restricted (Redpath et al. 2013).

Although fencing has become a quick-fix therapy to human–wildlife conflict and to parks with high surrounding human population numbers, high livestock densities, bushmeat hunting and logging activities (Packer et al. 2013; Redpath et al. 2013); it cause a decline in wildlife species as it limits the migration of some species to breeding and grazing grounds (Harris et al. 2009; Poor et al. 2014) and burden human communities by denying access to resources and disrupt ecological processes (Massey et al. 2014; Pekor et al. 2019; Redpath et al. 2013). By contrast, the community around NNP did not suggest fencing as an option in resolving the human-lion conflict situation (Lesilau et al. 2018). This imply that the community around NNP are pro-conservation of wildlife.

As areas near fences are often avoided by wildlife, it causes species "bunch-up" against resources, which ultimately alters the ecological processes in the park (Loarie et al. 2009; Vanak et al. 2010). By contrast, in partially fenced areas, the species adopt a more directional movement towards open corridors, thus only intensifying interactions with surrounding communities. In NNP most lions reside in the park, also during the wet season, and only make small trips via the SW to feed on livestock (Figs. 5.5 & S4). Due to the availability of livestock in close proximity to the NNP borders (Lesilau et al. 2018), there is no need for the lions to continue following their migratory prey during the wet season, as livestock is a perfect substitute with minimal travelling costs (Valeix et al. 2012).

The significant correlation between the amount of rainfall and the number of incidences of lions being outside the park and subsequent levels of livestock depredation demonstrates that when an area receives more rainfall, the intensity of livestock depredation and the incidences of lions leaving the park may increase (Fig. 5.4). This is also confirmed in other parks, such as Tsavo NP (Patterson et al. 2004), Amboseli NP (Tuqa et al. 2014), Waza NP (Tumenta et al. 2013), and Nairobi National Park (Lesilau et al. 2018).

5.4.4 Costs of lion attacks

The number of predated heads of livestock and the market price may not be a good indicator of the magnitude of livestock depredation and conflicts in an area. A better indicator is the monetary value and the social impact on human livelihoods. A compensation scheme for livestock owners around NNP was implemented for a limited period (2008-2012) but as a result of rapid urbanization and the difficulties of sustaining such a program it was not considered a success (Matiko 2014). Although, in terms of numbers, most of the depredated species are shoats, in terms of economic losses, livestock farmers bear the socio-economic burden when cattle are killed (Table 2). The market price and the cultural value of cattle in the community tradition contribute to a vengeful attitude of herders towards lions after a kill (Hazzah et al. 2014). Groom & Harris (2006) suggest that, this is especially the case in the absence of wildlife benefits to livestock owners. To share and spare some land, land scarcity and commodity production, intellectual value must be accommodated in the debate (Fischer et al. 2014).

5.4.5 Added value of scats and predation records

Our comparison of different livestock prey hair items in each scat and the numbers of livestock actually predated revealed a relationship between the number of predated livestock and proportion of livestock prey hair items from the scats (Fig. S1). Consequently, the category of livestock prey hair items from the scat was higher than the category of depredation incidents reported. This is not unexpected because a pride of lions could share one livestock prey and pride members or hunt alone, and may subsequently defecate at different locations within their territory.

It also demonstrated that non-herded livestock, such as domestic dogs, pigs, and donkeys, are least reported after depredation by lions or other predators (Fig. 5.3). They are found in lion scat but are not included in the official depredation records. Traditionally, these non-herded livestock are more vulnerable to attacks as they are not held in bomas and are free to stray into the park during the day as well as at night (Fig. S3). The results of our research demonstrate that cultural and economic values to certain domestic species by local residents. We suggest that livestock species without guardians are easy prey for lions and hence function as a “predator magnet”. Once lions discover the ease of depredating dogs, pigs and donkeys, they may be more inclined to attack nearby bomas.

5.5 Conclusion

Our study demonstrated partial fencing of parks intensifies human-wildlife interaction in one part of the park, causing higher losses for communities in that section compared than the other sections. We recommend that NNP management improve the park perimeter fence to decrease the losses of livestock depredation by lions and compensate livestock farmers for depredated animals.

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Supporting information

Table S1
Lengths of fenced and unfenced sections of Nairobi National Park in km (%)

No.	Type of Fence	NW section	SW section	Total length in NNP
1	KWS Official Fence	21.5 (0.33)	14.8 (0.23)	36.3 (0.56)
2	Other fences (Plot)	4.1 (0.06)	0.6 (0.01)	4.7 (0.07)
3	Completely unfenced	5.6 (0.09)	18.1 (0.28)	23.7 (0.37)
	Total	**31.2 (0.48)**	**33.5 (0.52)**	**64.7**

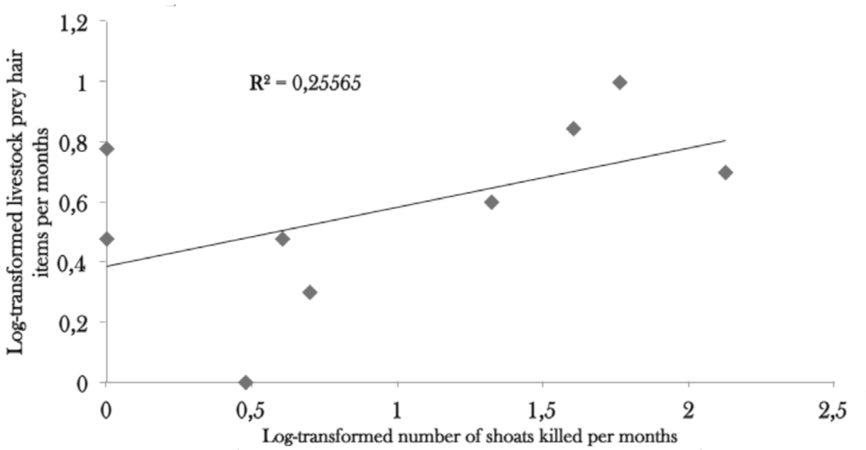

Figure 5.5
The number of confirmed reported cases of lions sighted in the community land, either by community members or the wildlife authority. In some cases, the lions attacked *bomas*; in others, they were chased into the park or sedated by veterinary personnel and released in the park.

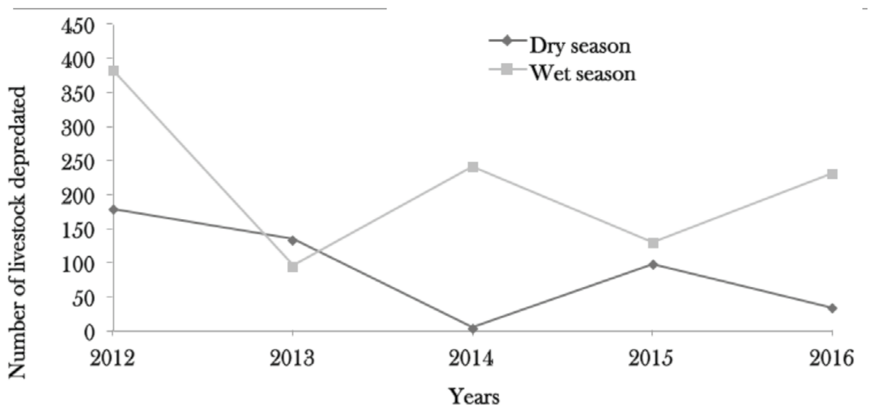

Figure S2
Seasons and level of depredation around NNP based on depredation data of 2012-2016

Figure S3

A domestic dog scavenging on a male impala carcass killed by a lion in Nairobi National Park (14 July 2015).

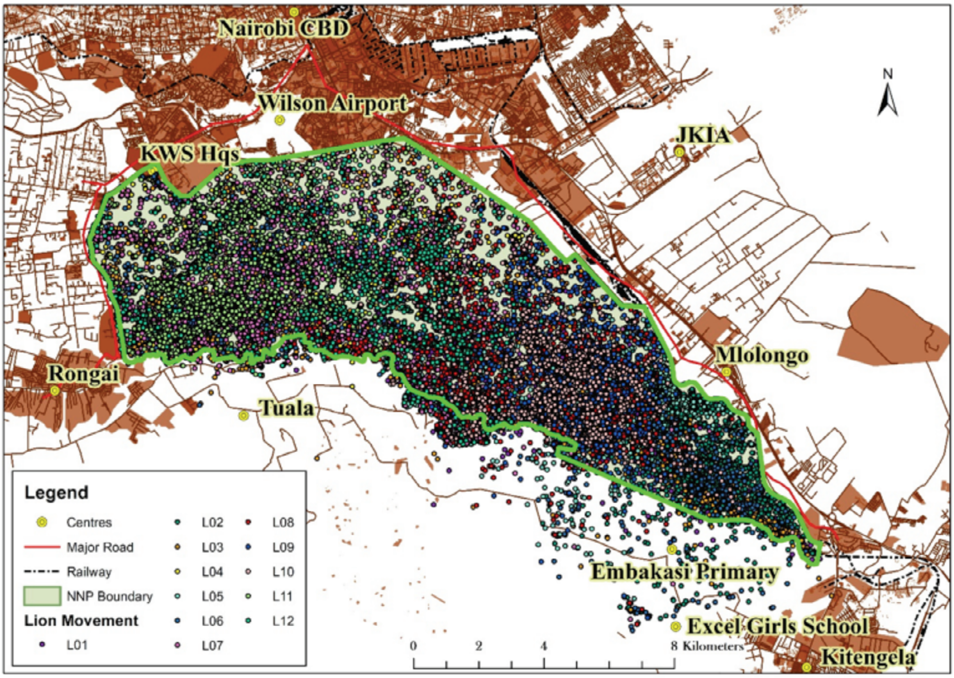

Figure S4

Movement of collared lions in NNP, 2014-2017 based on GPS locations from the satellites collars. L01-L12 signifies the code of the collared lions