INVESTIGATING FINE-SCALE CORRELATES AND LOCAL PERCEPTIONS OF MULTI-CARNIVORE PREDATION OF LIVESTOCK IN EAST AFRICA.

By

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ABSTRACT

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Human-carnivore conflict is fast becoming a critical threat to the survival of many globally endangered species, because those most exposed to conflict are prone to extinction. An in-depth analysis of livestock depredation is therefore essential to understand the challenge and promote conservation and coexistence in landscapes where it occurs. This thesis provides insight into human-carnivore conflict based on investigations carried out in the Maasai Steppe of Northern Tanzania. For this study, I chose to incorporate my research at the finest-scale possible, referring specifically to incidences of livestock depredation occurring in the livestock enclosure (a boma) within the Maasai homestead. In Chapter 1, I modeled the impacts of multiple variables suggested to affect livestock depredation at bomas across the Maasai steppe. My results highlight six significant correlates that influence livestock depredation at the boma scale. I discuss the implications of these variables on conflict mitigation and the prevention of livestock kills. In Chapter 2, I evaluate the local communities understanding of the causes and effects of livestock depredation and assess local perceptions of frequencies of negative encounters with large carnivores at the boma. I recommend that future conflict research should incorporate both empirical and perceptual data to generate the detailed information key to the development of effective strategies for resolving the challenge and conserving ecosystems and their inhabitan

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INTRODUCTION

The decline of carnivores across East Africa is coarsely attributed to human population growth coupled with diminishing wild prey base, illegal killing land conversion for agriculture and pastoral activities needed to sustain local communities (Woodroffe 2000; Riggio et al. 2013; Mponzi et al. 2014; Kwamboka 2015; Bauer et al. 2015; Ogutu et al. 2016; Hazzah et al. 2017). As more wildlife habitat is converted to other human uses, people and wildlife are increasingly living in close proximity, expanding the potential for human-wildlife conflict (Kanywana & Mako 2001; Graham 2005; Western & Waithaka 2005; Treves 2008; Hazzah et al. 2017). Human-wildlife conflict occurs when either human or wildlife actions negatively impact the other (Madden 2004, Treves et al. 2006). This has developed into a *wicked problem* due to the complexity involved in implementing sustainable solutions (Hill et al., 2017). Conflicts of this type are particularly common with large-bodied wildlife from the order *Carnivora*. In many areas where large carnivores still occur, herders suffer substantial losses of livestock via depredation (Bauer et al. 2015).

Local pastoralist communities bear severely negative perceptions towards large carnivores, mainly because they are considered a key antagonist of livestock that represent a vital part of their culture (Koziarski et al. 2016). Adverse negative interactions with people foster animosity, often leading to a desire for the persecution of problem animals (Riley & Decker 2000). In many parts of East Africa, livestock depredation is usually followed by indiscriminate retaliatory killing by local communities (Kissui 2008). An innate fear of large carnivores because of their ability to kill humans and livestock, and a cultural hostility from past experiences results in a particularly intense conflict (Dickman 2005; Treves et al. 2006; Ikanda & Packer 2008). The persecution of carnivores by humans, in response to livestock depredation, has been a major factor resulting in large scale population declines of many species across their range (Bauer & Kari 2001; Van Bommel et al. 2007).

Instances of human-carnivore conflict are increasingly common in regions surrounding protected areas (Dickman et al. 2014; Bencin et al. 2016). The risk of local extirpation of carnivore populations is most severe around small protected areas, because of their broad-scale habitat requirements and far-ranging behavior that results in negative encounters with people (Patterson et al. 2004; Treves 2008). In the Maasai steppe of Northern Tanzania, large carnivores such as spotted hyena (*Crocuta crocuta*), lions (*Panthera leo*), and leopards (*Panthera pardus*) are sympatric and responsible for most of the reported livestock depredation (Kissui 2008; Mponzi 2017a). Ultimately, a better understanding of the nature and causes of human-carnivore conflict is needed to promote coexistence through successful carnivore conservation efforts (Mponzi et al. 2014).

Even with a tremendous increase in the amount of attention paid to this multidimensional challenge (Polisar et al. 2003; Ogada et al. 2003; Thirgood et al. 2005; Rosie Woodroffe et al. 2005; Woodroffe et al. 2007; Croes et al. 2008; Ikanda & Packer 2008; Kissui 2008; Karlsson & Johansson 2010; Spira 2014; Hazzah et al. 2017; Montgomery et al. 2018), there is still limited evidence on the effectiveness of interventions to reduce livestock depredation (Eklund et al. 2017). More research on the dynamics of livestock depredation at finer scales is required to minimize human-carnivore conflict and enhance the protection of livestock and carnivore populations (Abade et al. 2014). It is also fundamental to consider the ecology and socio-environmental influences on the behavior of carnivores species of concern (Quigley & Herrero 2005).

Within this thesis, I aim to provide a crucial understanding of the local perceptions and the factors that influence carnivore depredation of livestock at the boma scale in the Maasai steppe. In Chapter 1, I examine the fine scale correlates on livestock depredation in bomas (livestock enclosures) where livestock are housed overnight from predators. A boma is a walled livestock enclosure made of thorny bushes, and occasionally wooden poles (Kissui 2008). I analyzed several predictor variables related to characteristics of the boma, carnivore occurrence, and landscape attributes to determine significant correlates of livestock loss experienced by herders in the Maasai steppe. I report on the level of damage caused by each carnivore species and present models that quantify the influence of significant variables on depredation. In chapter 2, I conducted open ended surveys to investigate local perceptions of the frequencies of livestock depredation by carnivores, and the factors perceived to explain the uneven distribution of livestock loss between livestock owners. Local perceptions of carnivores pose important challenges for conservation (Kissui 2008). Via the combination of these two chapters, I offer possible recommendations for interventionist activities and decision-making that could be relevant to enhance the protection of livestock by pastoral communities. Such information will assist conservation stakeholders should adopt best practices to reduce livestock depredation in the Maasai steppe.

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CHAPTER 1

EVALUATING THE FINE-SCALE FACTORS THAT CORRELATE WITH MULTI-CARNIVORE DEPREDATION OF LIVESTOCK IN EAST AFRICA

Abstract

Depredation of livestock by large carnivores fuels conflict between people and carnivores around the world. To develop sustainable solutions to human-carnivore conflict, it is necessary to diagnose the conditions that are correlated with livestock depredation. Here I examined the depredation of livestock by African lions (*Panthera leo*), spotted hyenas (*Crocuta crocuta*), leopards (*Panthera pardus*), and jackals (*Canis sp.*) in bomas across the Maasai steppe of Northern Tanzania. In this landscape, people keep cattle, shoats (i.e., goats and sheep), and donkeys, all of which are vulnerable to depredation. Among 110 bomas divided across nine different villages in the Maasai steppe I determined total livestock depredation experience, and the livestock depredation of each livestock type, as a function of: *i*) boma characteristics, *ii*) environmental factors, and *iii*) carnivore occupancy. Carnivore depredation of livestock was significantly correlated with the number of carnivores that occurred at the boma, the number of layers in the boma walls, as well as proximity to protected areas, rivers, and roads. Across all livestock and individual livestock type models, the total count of livestock depredated was higher where the occurrence and multiple carnivores increased and was lower in bomas with multiple layered walls. Furthermore, livestock depredation increased farther from protected areas (β = 0.50, SE = 0.10) and rivers (β = 0.39, SE = 0.10) and closer to roads (β = -0.28, SE = 0.11). I recommend that based on the intensity of livestock depredation by carnivores experienced across mixed landscaped such as the Maasai steppe, conflict mitigation measures should be implemented to alleviate conflict should be specific to address the top ‘nuisance’ species affecting each boma.

1.1 Introduction

For as long as humans have domesticated livestock, conflict between livestock-keepers and large carnivores across their range has existed (Treves and Karanth 2003; Woodroffe et al. 2005; Ripple et al. 2014). Human-carnivore conflict threatens the security of livestock and the livelihood of local people (Conover 2002; Ogada et al. 2003; Kissui 2008; Reid 2012; Lee 2017). Furthermore, these conflicts are the primary driver of carnivore population declines which presents an important conservation challenge (Kruuk 2002; Breitenmoser et al. 2005; Thirgood et al. 2005).While conflict of this type occurs around the world, it is particularly common in East Africa where the rangelands are home to millions of pastoral people and vast wildlife populations (Dickman et al. 2014; Hazzah et al. 2017). Most negative encounters between people and carnivores tend to be positioned in landscapes with high human growth rates, high productive forage for both livestock and wild ungulate prey, and an increased potential for competition over grazing and watering areas (Naughton-Treves et al. 2003; Mizutani et al. 2003; Breitenmoser et al. 2005; Thirgood et al. 2005; Kaswamila 2006; Dickman 2008; Loveridge et al. 2010; Reid 2012; Mkonyi et al. 2017a).

Livestock depredation occurs when carnivores that primarily hunt wild natural prey on rangelands dominated by livestock, switch to hunting comparatively naïve livestock with little anti-predator instincts (Polisar et al. 2003; Ikanda & Packer 2008; Inskip et al. 2009; Loveridge et al. 2010). Carnivores such as lions (*Panthera leo*), leopards (*Panthera pardus*), cheetahs (*Acinonyx jubatus*), spotted hyenas (*Crocuta crocuta*), and wild dogs (*Lycaon pictus*), are responsible for much of the livestock depredation in East Africa (Ogada et al. 2003; Patterson et al. 2004; Frank et al. 2005; Kolowski and Holekamp 2006; Woodroffe et al. 2007; Kissui 2008; Mwakatobe et al. 2013). Few studies have reported the impact of small carnivores such as jackals (*Canis spp*.) on livestock depredation. Livestock depredation accounts for between 1%-10% of annual livestock losses in the Maasai Rangelands of Kenya and Tanzania and results in the retaliatory killing or maiming of carnivores deemed responsible (Butler 2000; Frank et al. 2005; Thirgood et al. 2005; Woodroffe et al. 2005; Kissui 2008; Dickman 2010; Loveridge et al. 2010; Inskip et al. 2013; Mwakatobe et al. 2013). Consequently, human-carnivore conflict threatens both human well-being and the persistence of carnivore populations in these systems (Breitenmoser et al. 2005; Ogutu et al. 2005; Dickman 2010; Lichtenfeld et al. 2015).

In East Africa, nomadic pastoralist tribes would traditionally migrate seasonally with livestock between wet and dry season pastures (Reid 2012). Via this seasonal movement of livestock herds, pastoral people avoided disease, and managed the quality and quantity of grazing (Kruuk 2002; Loveridge et al. 2010; Reid 2012). Concerns over carnivore depredation, particularly at night (Ogada et al. 2003; Patterson et al. 2004), encouraged pastoralists to corral their livestock in traditional enclosures called bomas (Frank et al. 2005; Goldman et al. 2010; Reid 2012; Lichtenfeld et al. 2015). Though the primary motivation was to control livestock, a strong secondary consideration was the exclusion of carnivores (Frank 1998; Patterson et al. 2004). Traditional bomas consisted of ringed layers of thorn fencing encircling several livestock corrals constructed with locally-available thorny tree limbs or woven branches (Patterson et al. 2004; Kolowski and Holenkamp 2006; Ikanda and Packer 2008; Manoa and Mwaura 2016). Herded into these bomas each night, livestock were guarded against carnivore attack (Ogada et al. 2003; Patterson et al. 2004; Dickman 2008). Bomas of this type were designed to be temporary as pastoralists moved seasonally across vast grazing landscapes (Reid 2012). Therefore, only a limited amount of time could be invested in the structural integrity (Lichtenfeld et al. 2015). More recently, changes in land-use, development of infrastructure, and habitat fragmentation have impacted the mobility of pastoralists in this rapidly changing landscape (Kahurananga & Silkiluwasha 1997; Kaswamila 2006; Kaswamila 2009; Msoffe et al 2011). With modern perturbations, these historically nomadic people have become more sedentary (Homewood et al. 2009; Western et al. 2009). Many pastoralists now live in permanent settlements defined by a mix of livestock husbandry and small-scale agriculture moving only their livestock herd between pasture (Reid 2012). Via these processes, the spatial location and routine movement of pastoralists and their livestock became more reliable and predictable to opportunistic carnivores (Mizutani et.al, 2005). In settled communities, new and improved measures to fortify traditional bomas, increasing the integrity of these structures against depredation have been developed and recommended. However, cost constraints and maintenance demands have largely disrupted their uptake (Lindsey et al. 2012).

Human-carnivore conflict exists at four heirachical spatial scales i.e. regional, landscape, community and boma scale (Montgomery et al. 2018). While scientific research is most often carried out at larger scales, conservation action is more likely to be effectively implemented at fine scales (Jarvis et al. 2015). Thus fine-scale studies are best placed to prescribe interventionists activities meant to alleviate conflict (Lewis et al. 1996; Carter et al. 2012; Montgomery et al. 2018). This study focuses on the boma scale which refers to the fine-scale information retrieved from interactions between carnivores and humans at the level of a singular homestead. Via my synthesis of human-carnivore conflict research, I identified fine-scale patterns in depredation can be predicted as a function of covariates derived from three primary categories of influence. These include; *i*) boma characteristics, *ii*) environmental factors, and *iii*) carnivore occupancy. For example, characteristics in the structural integrity of bomas can elucidate potential points of weakness that afford carnivores the opportunity to break in and attack livestock (Ogada et al. 2006; Kissui 2008). Furthermore, rates of carnivore depredation of livestock can be influenced by environmental factors including the type of habitat, water, and proximity to protected areas (Kolowski and Holekamp 2006; St John et al. 2012; Zarco-González et al 2013). Finally, depredation risk may be higher in landscapes where carnivore sympatry occurs, providing the potential for livestock keepers to experience depredation from a suite of carnivore species (Eklund et al. 2017). However, the ways in which these factors may combine to affect depredation risk remains poorly understood. Thus, an improved understanding of the fine-scale factors that correlate with carnivore depredation of livestock is needed to prioritize the implementation of interventionist activities meant to alleviate conflict (Patterson et al 2004; Lichtenfeld et al. 2015).

Keen to examine the role of boma characteristics, environmental factors, and carnivore occupancy on carnivore depredation of livestock, I sought to examine correlates of carnivore attacks at the finest scale i.e. the boma (Montgomery et al. 2018) . I did so in a part of East Africa that features a number of sympatric carnivores, communities of people maintaining predominantly agro-pastoral livelihoods, and experiences some of the highest rates of human-carnivore conflict globally, the Maasai steppe in Northern Tanzania.

1.2 **Materials and methods**

1.2.1 **Study Area**

The Tarangire-Manyara ecosystem in Northern Tanzania, also referred to as the Maasai steppe, is one of East Africa's most important wildlife areas. This landscape, spanning an area of >25,000 km^2 in Northern Tanzania (Kissui 2008; Fig. 1.1), was occupied by large herds of wild animals and livestock at the turn of the 19th century before a span of rapid human encroachment and modern development (Kaswamila 2006). There are an estimated 350,000 agro-pastoralists currently residing on the Maasai steppe (Nelson 2005, Tz census 2012). The primary ethnic groups are Maasai, Waarusha, and Barabaig. Local people in this region rear cattle, donkeys, sheep, and goats (referred to as shoats; Sachedina 2006) all of which are vulnerable to depredation. As evidence of the sheer amount of livestock, there are an estimated 1 million zebu cattle in this region (Sachedina 2006). In many societies within the Maasai steppe, the number and condition of livestock are signs of relative wealth and of vast cultural importance to agro-pastoralist communities (Ikanda and Packer 2008; Kissui 2008).

The study area was located between 03° 48’ 02’’ and 03° 35’ S, 35° 48’ and 35° 59’25’’W (960 to 1,478 m above sea level) within the Monduli district of the Arusha Region in Tanzania (Fig. 1). Major habitat and land cover types in this area are characterized by ground water forest supported by perennial springs (UNESCO 2002). Tarangire National Park (2,800 km^2) and Lake Manyara National Park (330 km^2) are the two national parks within this landscape. In addition, the Ngorongoro Game Conservation Area (8,292 km^2) is located in this region and is managed by the Ngorongoro Conservation Area Authority. Indigenous communities are allowed to reside and practice pastoralism inside the NCA.. Also within this matrix of publically protected areas is a privately-managed conservancy called Manyara Ranch (141.6 km^2). The study villages occur amidst these different protected areas (Fig. 1.1).

Migratory wildlife move seasonally between and among these protected areas where they pass through adjacent community lands. During the dry season (June–November), migratory ungulates tend to remain inside protected areas but disperse into areas outside protected areas (in communal village lands) for much of the wet season (November–May; Kahurananga and Silkiluwasha 1997). Within this landscape alone, there are no less than 14 traditional wildlife migratory routes (Kaswamila 2006). However, increasingly these routes are being blocked by human population growth and habitat fragmentation (Shemweta & Kidegesho 2000).

1.2.2 **Data collection**

Records of livestock depredation have been collected by the Tarangire Lion Project among 18 villages on the Maasai steppe since 2006 (Kissui 2008). When depredation occurred at the boma level, the number of livestock killed and the carnivore species that were involved in the attack were verified and recorded. To divide the large dataset into homogeneous classes of depredation levels experienced, I first applied the Jenks Natural Breaks algorithm (North 2009) to stratify these 18 villages into groups of high (> 500), medium (100 - 500), and low (<100) conflict based on the total number of livestock depredated by carnivores between 2006 and 2016. I further ranked the top three villages in each category to select 9 villages i.e. Makuyuni, Esilalei, Selela, Oltukai, Naitolia, Mswakini juu, Mswakini chini, Engaruka juu, Engaruka chini where I randomly sampled bomas in each village. Our objective was to determine evident variation in fine-scale patterns that might correlate with depredation risk.

In consultation with village leaders, I conducted semi-structured boma surveys in 12-14 bomas per village from May to July 2017. I generated a boma code identification system, for reference, ensuring that the identity of the boma owners was protected. With the help of a translator and local guide, I presented the surveys in English, Swahili, and Maa languages. At each boma I investigated; *i*) the total number of livestock depredated by type *ii*) the species of large carnivore responsible for these attacks, *iii*) the quality of boma construction, *iv*) and, the types of interventions applied at the boma to decrease carnivore attack experienced over the past three years from 2015 to 2017. These data was collected under the assumption that respondents were able to remember the total livestock loss experienced each year. However I acknowledge this as a source of potential bias because depredation is frequently overestimated (Kissui 2008; Zarco-González et al. 2012) and instead considered the values provided as an indicator of the level of depredation experienced at each household.

To assess the characteristics of each boma, I collected data on the materials used to construct each fence, the total number of fence layers built around the boma, and the diameter of the livestock enclosure in addition to the fence height (Fig. 1.2). At each boma, I marked a GPS location so that I could calculate the proximity of each boma to the nearest; *i*) protected area, *ii*) river, and *iii*) main road. I examined carnivore occupancy by recording all species reported as responsible for depredation at each boma. I developed a geographic information system database in ArcMap 10.3 (ESRI, Redlands, CA) to define environmental factors and carnivore occupancy at the boma scale (i.e., < 10 m; Montgomery et al 2018).

1.2.3 Generalized linear mixed models

I used generalized linear mixed models (GLMMs) to predict the count of livestock depredation, expressed as the total number of livestock reported to be killed at each boma, as a function of boma characteristics, environmental factors, and carnivore occupancy. I selected GLMMs because they allow for the inclusion of categorical covariates and spatial dependencies that can account for potential autocorrelation in the residual process. I fit a series of models predicting; *i*) total livestock killed, *ii*) total cattle killed, and *iii*) total shoats killed. Via model diagnostic tests, I achieved normality of the residuals via a log-transformation of the response variables. Prior to modeling I tested for multi-collinearity among all explanatory variables by generating a Kendall tau rank correlation matrix. Variables that were correlated (i.e., $|r| > 0.5$) were not included in the same model. I also used an independent samples *t*-test to compare total livestock loss in bomas with traditional thorn fences and fortified fences.

I then built a global model that included only significant ($\alpha \leq 0.05$) explanatory variables to test for spatial dependency and to determine whether the inclusion of a spatial correlation term improved model performance (Table 1.1). I ranked models using Akaike Information Criterion (AIC), with the model structure having the lowest AIC value graduating to the next level of the model selection process. I repeated this entire model diagnostic process for each livestock-specific response variable, anticipating that the optimal spatial structure could vary for each model set. Lastly, I developed a candidate model set comprised of combinations of our significant explanatory variables using the optimal model structure identified in our first step. Again, I ranked models using AIC with the lowest ranked model being selected. To visualize the influence of model parameters, I plotted the coefficients included in the top-ranking model. All effect plots were back-transformed from the log scale and reported on the original scale.

1.3 Results

I visited a total of 110 bomas in the Maasai steppe. The majority of bomas (96.4%, n=106 of 110) reported to have experienced carnivore depredation of livestock between 2015 and 2017. Only four bomas reported no attacks or livestock loss. A combined total of 2,774 livestock were reported to be depredated by spotted hyenas, lions, leopards and jackals. Spotted hyenas were responsible for 51.6% (n=94 of 182) of these depredations. The next most common depredator was jackals (24.2%, n=44), followed by lions (19.2%, n=35), and finally, leopards (4.9%, n=9). Shoats were the livestock species targeted in the majority of these attacks (55.4%, n=1539 of 2774). The timing of most boma depredations by lions, leopards, and spotted hyenas occurred during the night (72.1% n= 138), while depredation was more seldom during the day (27.9% n=44), all of which were attributed to jackals attacking juvenile shoats.

Three major categories of fences were identified within the study area. These included traditional thorn fence (made of thorn/ thorn-less brush, or wooden posts; 78.2%, n=13 of 110), thorn fence reinforced with planted trees (18.2%, n=20), and the fortified fence (made of chain-link fencing reinforced with sprouting trees and wooden or metal posts; 11.8%, n=13; Fig. 1.3). I found no significant difference (t (23.78) =1.43, p = 0.16) in the total livestock loss in the traditional thorn fences and fortified fences. Approximately half (49.1%, n = 54 of 110) of the bomas had two walls or layers of fencing, consisting of both an outer and inner fence. Single layer bomas (47.3%, n=53) were enclosures with a single thorn fence. Bomas classified as 'no thorn fence' (3.6%, n=4) were those with no thorn bush layers of fencing but, rather, used chain-link fence.

The top-ranking model predicting total livestock depredated at each boma was significantly (at the $\alpha \leq 0.05$ level) influenced by six main variables from the three categories of effects (Table 1.2). These significant variables included proximity to the nearest *i*) protected area, *ii*) river, and *iii*) main road, as well as *iv*) the number of bomas layers, *v*) the size of the inner enclosure of the boma, and, *vi*) the total number of co-occurring carnivore species (Table 1.3).

Parameter estimates in the top-ranked model predicting total livestock depredated, identified that the total livestock depredated was higher in bomas with only a single layer of thorn fence when compared to those with a double layer of thorn fencing (Fig. 1.4a). Additionally, bomas with larger enclosures experienced more livestock depredation (Fig. 1.4b). Bomas farther from protected areas (Fig. 1.5a) and rivers (Fig. 1.5b), and those closest to the main roads (Fig. 1.5c) reported higher levels of livestock loss to multi-carnivore depredation events. Finally, the total number of livestock depredated increased in bomas with multi-carnivore co-occurrence (Fig. 1.5d). Trends on the influence of all significant variable were similarly comparable for models that examined the total cattle depredated and the total shoats depredated (Fig. 1.6). I found that the number of boma fences was most significant in influencing the total livestock- specific depredation. Additionally, livestock models performed better when specific carnivores included as independent variables. Bomas that reported lion attacks, experience more loss to cattle, while those that cited hyena and jackal attacked experienced greater losses to shoats and juvenile shoats respectively.

1.4 Discussion

Positioned in a landscape that experiences some of the highest rates of human-carnivore conflict globally, I explored the role of boma characteristics, environmental factors, and carnivore occupancy on patterns of carnivore depredation of livestock. I found that bomas that incorporated two layers of fence had lower overall livestock depredation than bomas with only a single fence. In addition, bomas of larger size experienced greater livestock depredation in comparison to smaller bomas. The location of bomas relative to natural and anthropogenic features in our study area also influenced the amount of livestock depredated. Bomas that were farther away from protected areas and rivers experienced greater levels of livestock loss, while bomas that were nearer to paved roads experienced more livestock depredation. In addition, a number of bomas that I surveyed reported attacks from multiple carnivore species with some experiencing attacks by as many as three species. Due to this pressure, bomas that experienced attacks from multiple carnivore species subsequently reported greater total livestock loss. In situations where the carnivore guild is diverse, enclosure constructions may be difficult to target multiple species, leading to a reduced total effect of the intervention (Eklund et al. 2017)

In exploring patterns of depredation according livestock type, I found that explanatory variables influencing total depredation for all livestock, cattle, and shoats, displayed relatively similar trends suggesting that patterns in depredation is more likely driven by boma characteristics, species behavior and the surrounding landscape. Similar to other parts of east Africa, regional variation in livestock depredation in the Maasai Steppe can be attributed to presence of multiple large carnivores and weak husbandry practices,

Bomas with two fence layers reported lower total and livestock-specific depredation. I found single-fence bomas to be common in villages located in dominantly open and wooded grasslands habitats while double fence bomas were most common in villages with access to dense thicket habitats (personal observation). This suggests that the construction of a multi-fence boma is not always achievable, as boma structure is largely dependent on the accessibility and availability of local materials which are dwindling due to ongoing habitat fragmentation and desertification (Veblen 2013). In addition to boma layers, boma size also appears to play a role in livestock depredation, where bomas in large and extra-large size classes appear to experience greater livestock depredation in comparison to smaller and medium sized bomas. The precise mechanism driving this pattern remains unclear. Using boma size as a proxy for herd size, our results concur with research conducted in Kenya, that indicated boma owners with larger herds generally experienced more livestock loss than owners with smaller herds (Kolowski and Holekamp 2006). To fully understand the patterns related to boma size, herds and livestock loss, additional fine-scale data are necessary to further elucidate the underlying mechanisms.

I found that several environmental factors significantly influenced livestock depredation. At the boma scale, our research shows that bomas situated farthest from protected areas experienced more livestock loss, which is similar to results from other studies conducted in villages near Tarangire National Park (Mkonyi et al. 2017b). One potential reason bomas farther from protected areas may experience higher levels of depredation could be due to the scarcity of natural prey in the community landscapes. As the human footprint grows in savannas outside protected areas, predictions point to a long-term loss of wildlife and a rise in human wildlife conflicts (Reid 2012). Recent studies report extreme decline of wildlife and contemporaneous increase in livestock numbers in the savanna rangelands (Ogutu et al. 2016; Broekhuis et al. 2017). Similarly, studies done in Northern Tanzania reflect comparable trends, with lower large ungulate densities attributed to the blocking of wildlife corridors and other anthropogenic effects (Ripple et al. 2014; Kiffner et al. 2016; Lee and Bond 2018). Scarcity of prey (e.g., medium and large-sized ungulates) as a result of population declines or seasonal migrations, leads carnivores to increasingly rely on and depredate livestock for survival (Khorozyan et al. 2015). Ifound that bomas in closer proximity to roads, on the other hand, experienced higher levels of carnivore depredation of livestock. However, not many studies have evaluated how roads influence wildlife around protected areas. There are still significant gaps in our understanding of the ways in which wildlife respond to road networks and traffic (Mulero-Pázmány et al., 2016). In contrast, rivers support higher prey densities, particularly in the dry seasons (Nijhawan 2008), in this way the availability of wild prey congregations around water sources might increase the probability of successful hunts by carnivores thereby reducing livestock predation pressure at bomas closest to rivers.

Throughout are study area, I noted that villages were disproportionately targeted by carnivore species. Our results indicate that bomas with increased multi-carnivore occurrence had higher overall livestock loss. Reports of depredation by hyena and jackal were particularly widespread and reported in every village within our study area. This finding aligns with the opportunistic hunting tendencies of hyenas, whose kills often correspond with the vulnerability of their prey rather than relative abundance (Kingdon 2015). Additionally, hyenas and jackals can both thrive in anthropogenic landscapes. For example, hyena densities have been found to be 1.3 times higher in community-owned pastoral ranches than in the nearest protected areas (Ogutu et al. 2005) and common jackal family groups have been shown to flourish in areas offering access to abundant resources (i.e. rubbish tips; Kingdon 2005). Furthermore, several studies have documented a positive correlation between livestock depredation rates and carnivore density in community lands (Stakl et al. 2001; Kolowski and Holekamp 2006). This evidence suggests that high rates of depredation may indicate higher densities of carnivore species around these villages and vice versa.

In exploring depredation by livestock type, I found that bomas that reported depredation by lions experienced higher cattle and donkey losses. Similarly, all bomas that reported attacks by hyena and jackal experienced more losses in shoats and juvenile shoats respectively. All livestock-specific models describing the influence of boma layers, boma size and proximity to roads, rivers and protected areas displayed similar trends expressed in the total livestock models.

1.4.1 Implications for conservation and conflict management

For effective management of human-carnivore conflict, it is imperative that decision makers appreciate and understand the regional variation in local socio-ecological conditions that influence livestock risk (Graham Hemson 2003; Woodroffe et al. 2007; Hemson et al. 2009). To ensure a sustainable future for carnivores and pastoralist livelihoods in these ecosystems, I must understand the dynamics leading to human-carnivore conflicts, factoring in the ecology species of concern (behavior, distribution, movements) and the environmental and social influences on their behavior (Quigley and Herrero 2005; Abade et al. 2014). While many studies have focused their research on human-carnivore conflict at the regional level, more knowledge is needed to assess the factors that may encourage livestock depredation at a fine scale.

Our results highlight the suite of significant variables operating synergistically to influence livestock depredation at the boma scale. This research may be used to inform individual livestock owners on how their choice of boma construction (the number of thorn fences, boma size and location) can influence the rates on livestock depredation at their boma. Livestock enclosures can likely be improved to exclude multiple carnivores if their biology and behavior is considered during boma construction. These results also suggest the need to incorporate ecology and statistical modelling as a foundation for decisions-making in conservation planning, village land zoning and development in areas of high biodiversity. To ensure sustainable livelihoods and long-term conservation across the Maasai steppe, Irecommend that any intervention proposed to address conflict contain solutions that target most if not all of the significant correlates of livestock depredation identified in this study. Such interventions could encourage tolerance and foster coexistence between people and carnivores.

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APPENDIX

APPENDIX

Table 1.1 Description of the data collection methods and covariates developed to explain multi-carnivore depredation of livestock in the Maasai steppe of Northern Tanzania (2015-2017).

Covariate	Description
Carnivores	Documented reports of depredation by four carnivore species considered for the study. These include; lion, leopard, hyena, and jackal.
Hyena	Records of reported attacks attributed to hyena were recorder as 1 (present) and 0 (absent)
Jackal	Records of reported attacks attributed to jackal were recorder as 1 (present) and 0 (absent)
Lion	Records of reported attacks attributed to lion were recorder as 1 (present) and 0 (absent)
Leopard	Records of reported attacks attributed to leopard were recorder as 1 (present) and 0 (absent)
Layers	The number of fences (made of thorn bush or chain link) encircling a boma. A double layer has an outer and inner fence. A boma with single layer has only one fence around the enclosure.
Protected Area	Nearest distance to surrounding protected areas/wildlife refuges from each boma in the study area.
River	Nearest distance to river or streams from each boma in the study area
Road	Nearest distance to main roads from each boma in the study area
Size of livestock enclosure	Size classes were defined as the diameter of the innermost fence, where herds are corralled into at night. These were used as proxy estimates for herd size i.e. small (5-10meters), medium (11-15m), large (16-25meters), extra-large (>25m)

Table 1.2 Top-ranking models describing the influence of boma characteristics, deterrents, and landscape attributes on total and livestock-specific depredation in the Maasai steppe of Northern Tanzania (2015 – 2017).

Response	Model covariates	DF	ΔAIC	*w*
All livestock	Carnivores + Layers + Protected Area + River + Road + Size	12	0.00	0.78
	Carnivores + Layers + Protected Area + River + Size	11	4.58	0.08
	Carnivores + Layers + Protected Area + River + Road	9	4.66	0.08
	Carnivores + Protected Area + River + Road + Size	11	5.46	0.05
Cattle	Lion + Hyena + Road	5	0.00	0.13
	Lion + Hyena + River + Road	6	0.76	0.09
	Layers + Lion + Hyena + Road	6	1.55	0.06
	Lion + Hyena + Protected Area + Road	6	1.63	0.06
Donkeys	Layers + Lion + River	7	0.00	0.12
	Lion + River	6	0.63	0.09
	Hyena + Lion + River	7	1.00	0.07
	Hyena + Layers + Lion + River	8	1.03	0.07
Juvenile Shoats	Jackal + Layers + Protected Area + Size	10	0.00	0.09
	Jackal + Layers + Protected Area	7	0.49	0.07
	Jackal + Layers + Protected Area + River	8	0.87	0.06
	Jackal + Size	8	1.12	0.05
Shoats	Hyena + Layers + Lion + Protected Area + River + Size	12	0.00	0.80
	Hyena + Layers + Lion + River + Size	11	6.90	0.03
	Hyena + Layers + Lion + River + Road + Size	12	7.09	0.02
	Hyena + Layers + Leopard + Lion + River + Size	12	7.16	0.02

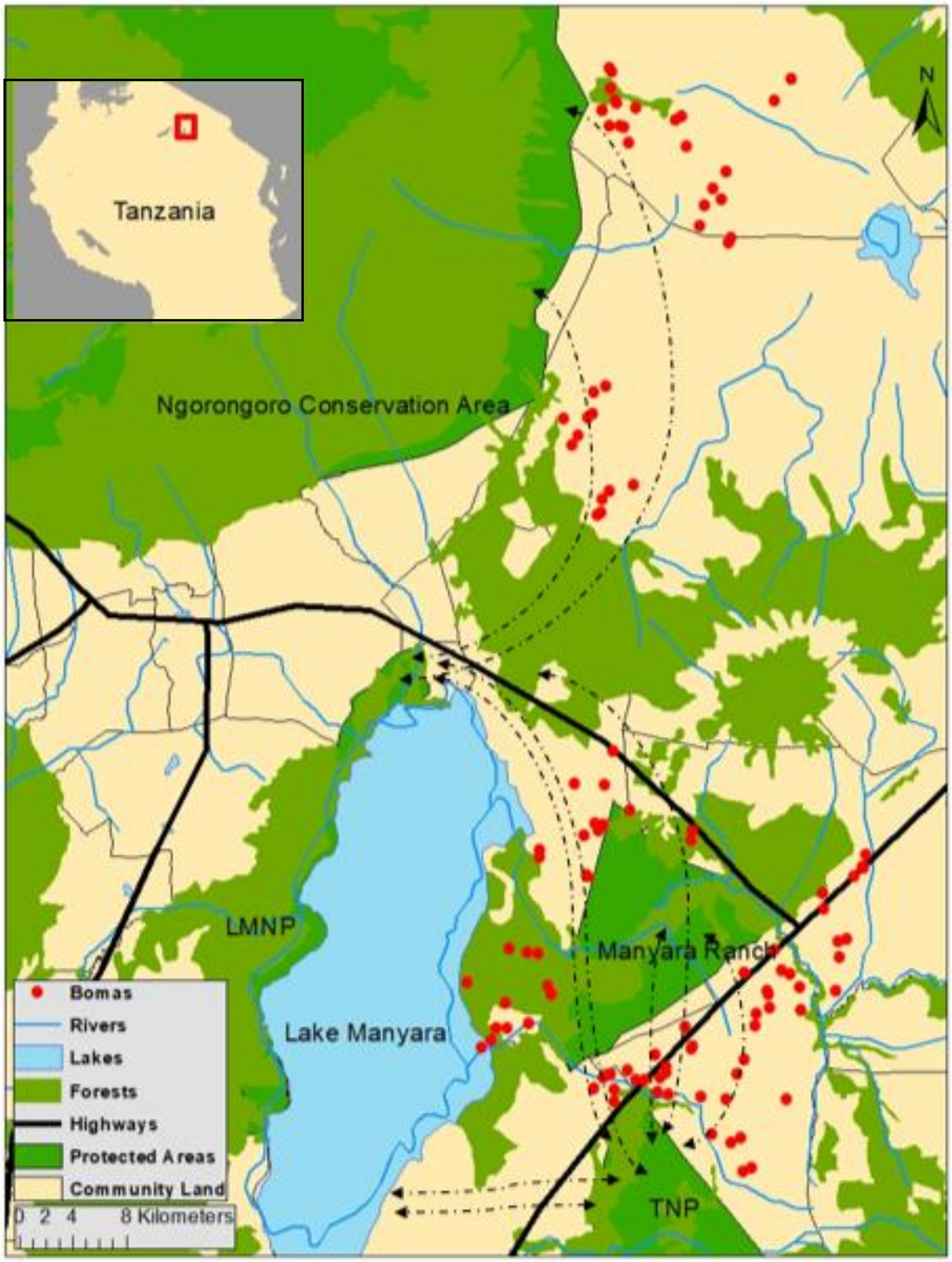
DF = degrees of freedom; *w* = AIC weight for each model

Table 1.3 Model-averaged coefficients and standard errors estimating the influence of boma characteristics, environmental factors, and carnivore occupancy on the total and livestock-specific depredation in the Maasai steppe of Northern Tanzania (2015-2017).

Covariates	All livestock		Cattle		Donkeys		Juv. Shoats		Shoats	
	β	SE	β	SE	β	SE	B	SE	β	SE
Carnivores (1)	1.41*	0.46	-	-	-	-	-	-	-	-
Carnivores (2)	2.28*	0.46	-	-	-	-	-	-	-	-
Carnivores (3)	2.91*	0.48	-	-	-	-	-	-	-	-
Hyena	-	-	0.66*	0.25	-	-	-	-	1.11*	0.24
Jackal	-	-	-	-	-	-	1.74*	0.19	-	-
Layers	-0.49*	0.19	-	-	0.21	0.13	-0.31	0.20	-0.74*	0.20
Leopard	-	-	-	-	-	-	-	-	-	-
Lion	-	-	0.58*	0.20	0.39*	0.14	-	-	1.24*	0.22
Protected Area	0.50*	0.10	-	-	-	-	0.22	0.13	0.34*	0.11
River	0.39*	0.10	-	-	0.23*	0.09	-	-	0.35*	0.11
Road	-0.28*	0.11	-0.23*	0.09	-	-	-	-	-	-
Size (2)	0.01	0.21	-	-	-	-	-0.17	0.23	0.09	0.20
Size (3)	0.66*	0.25	-	-	-	-	0.24	0.29	1.00*	0.28
Size (4)	0.43	0.37	-	-	-	-	0.36	0.39	0.36	0.42

*indicates significance at $P < 0.05$ threshold

Figure 1.1 The map of the study area depicting randomly selected boma locations and wildlife corridors within the Manyara-Tarangire-Ngorongoro Ecosystem commonly referred to as the Maasai steppe of Northern Tanzania (2015-2017).



*Wildlife Corridors *Source* (Mwalyosi 1991; Shemweta and Kidegesho 2000; Kaswamila 2006)

Figure 1.2 A Google Earth aerial image of one of the bomas that experience multi-carnivore depredation of livestock in the Maasai steppe of Northern Tanzania (2015-2017).

Figure 1.3 Examples of boma construction in the Maasai steppe, Tanzania. Panel a) shows a traditional thorn fence, panel b) displays a traditional fence that has been reinforced with planted trees, panel c) displays a chain link fence boma, and panel d) displays a chain link fence reinforced with planted trees.

Figure 1.4 The generalized linear mixed model regression plots depicting the total livestock lost to carnivores on the Maasai steppe, Tanzania (2015-2017) as a function of; a) the number of fence layers per boma and b) the size of the boma. Points represent the predicted mean total livestock loss and whiskers depict 95% confidence intervals.

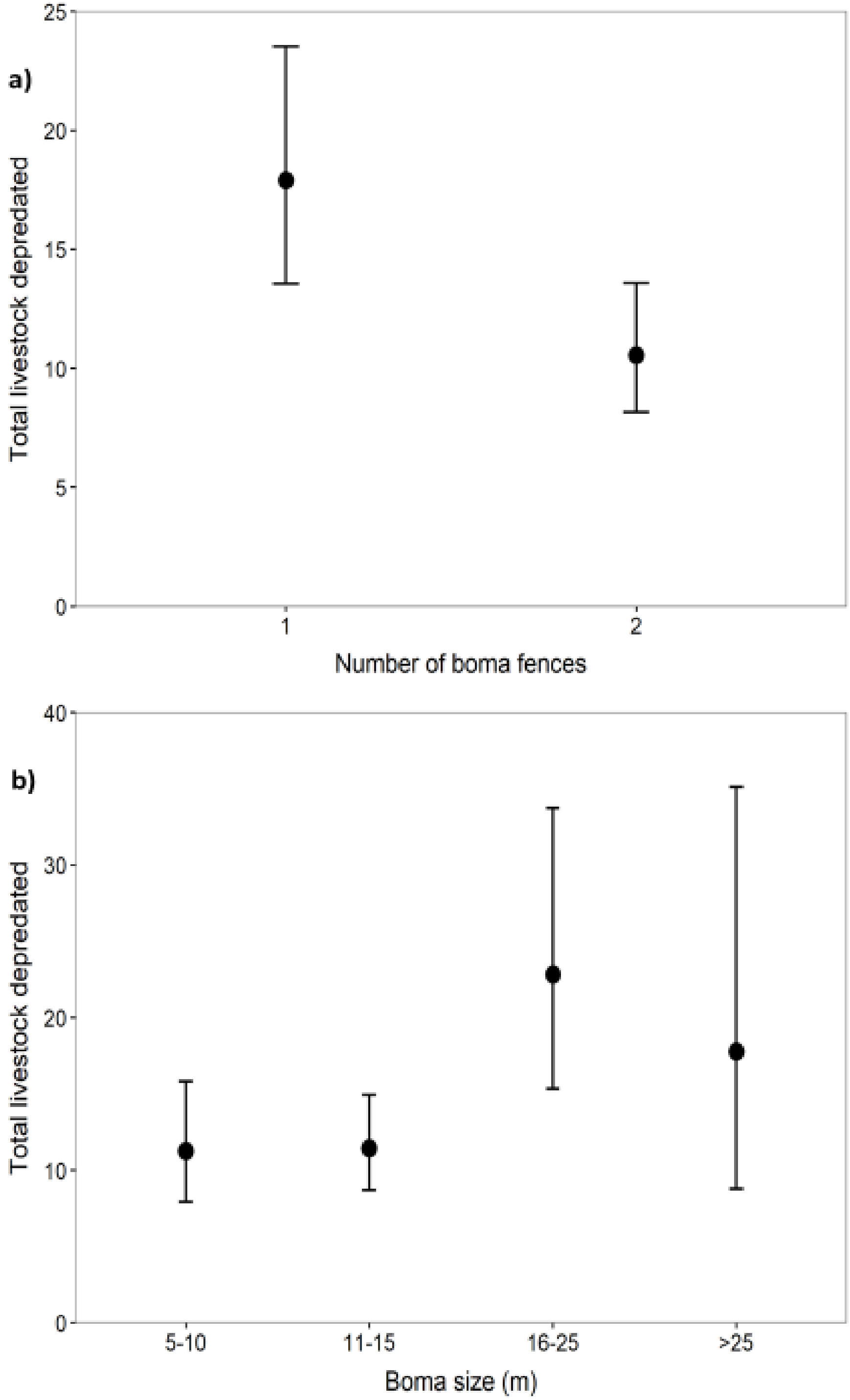


Figure 1.5 The generalized linear mixed model regression plots depicting the total livestock lost to carnivores on the Maasai steppe, Tanzania (2015-2017) as a function of nearest distance to; a) protected area, b) river, and, c) main road. The gray shaded areas depict 95% confidence interval.

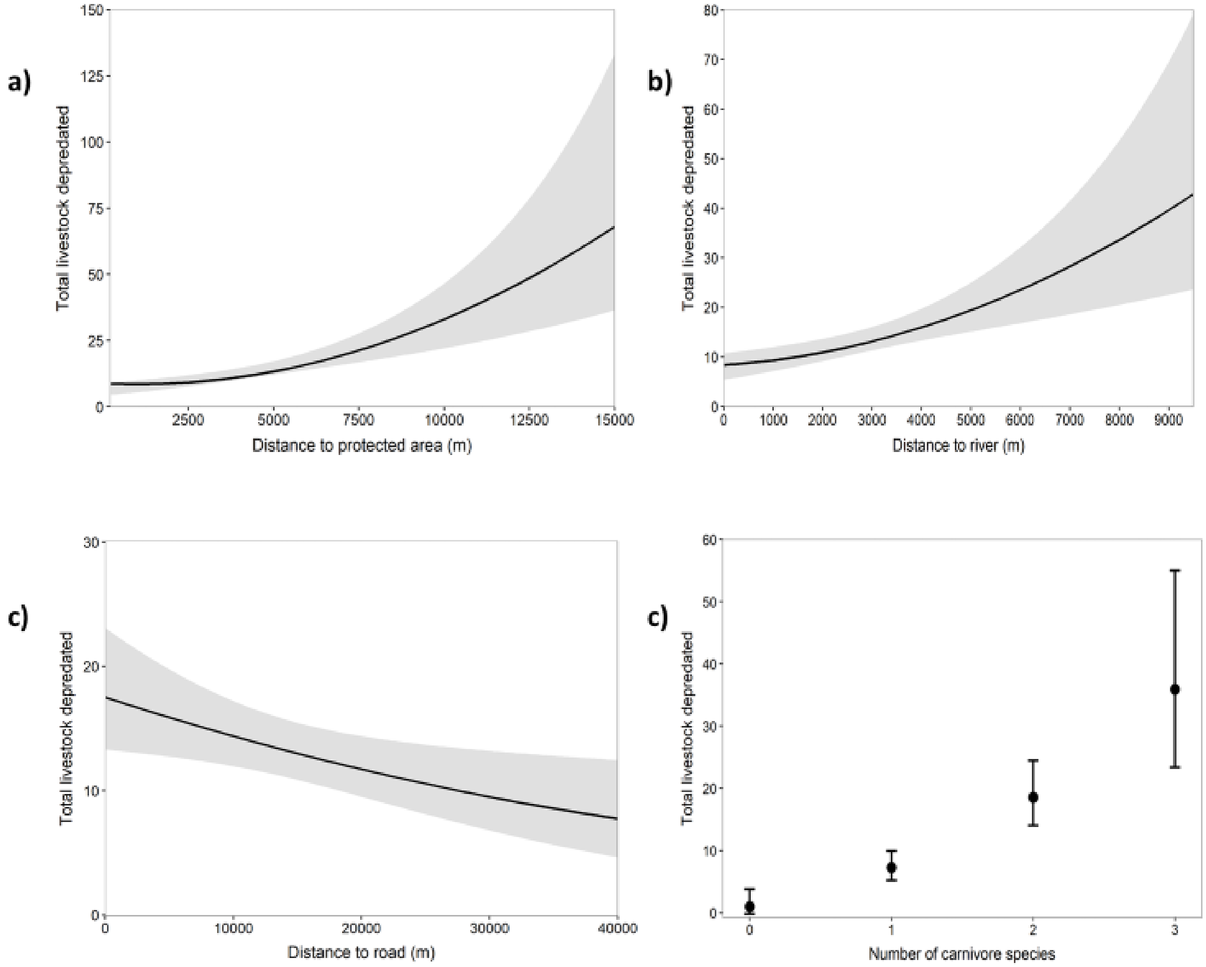
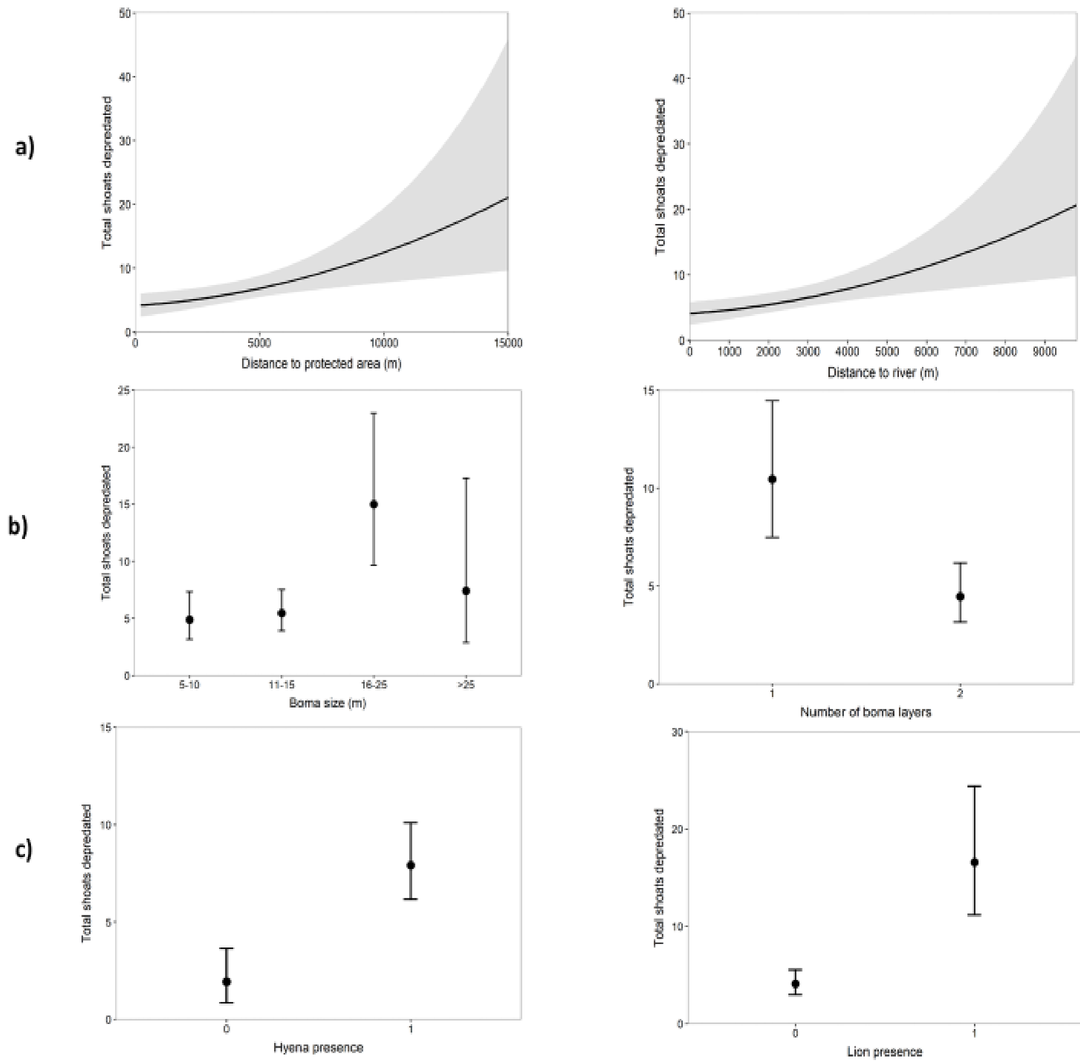


Figure 1.6 Generalized linear mixed model regression plots depicting the specific livestock (cattle & shoats) lost to carnivores on the Maasai steppe, Tanzania (2015-2017) as a function of; a) environmental factors, b) boma characteristic and c) carnivore occupancy. Points represent the predicted mean total livestock loss and the whiskers depict 95% confidence intervals.



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CHAPTER 2

LOCAL PERCEPTIONS ABOUT LIVESTOCK DEPREDATION BY LARGE CARNIVORES IN THE MAASAI STEPPE

Abstract

Negative encounters with carnivores can affect a local people's sense of danger which influences the perception of carnivore species. Scientific research should account for the complexity of local perceptions of wildlife in the solutions provided. This information can be vital to mitigation strategies designed to address human-wildlife conflict. Here I explored human perceptions of livestock depredation by large carnivores in bomas (livestock enclosures) in the Maasai steppe of Northern Tanzania. I evaluated the perceived frequency of carnivore attack of livestock (experienced between 2015 and 2017) among nine villages in the Maasai steppe. I then compared the perceived frequencies to concurrent data collected on livestock depredation experienced in the bomas in the study. I also assessed local understanding and knowledge of husbandry practices and ecological factors that explain the variability livestock depredation rates across the Maasai steppe. As local people's perceptions of negative encounters with carnivores shapes their attitudes towards conservation, I argue that to it is vital to incorporate perceptions investigations into ongoing research studies that aim to promote sustainable conservation solutions to this conflict.

2.1 **Introduction**

Negative interactions between people and wildlife pose a variety of risks to humans all across the world. Communities living with wildlife often harbor real insecurities relating to the risk of injury or damage to personal property that can result from interaction with wildlife (e.g., attack, livestock depredation, crop raiding, and zoonotic disease transmission; Messmer, 2000; Madden, 2004; Gore, 2005; Gore, 2009; Decker, 2010; Lee, 2017). Human-wildlife conflict results from intense competition for land, water, and food among carnivores, domestic ungulates, and people (Treves & Karanth 2003; Thirgood et al. 2005; Treves 2008; Dickman 2008; Lewis et al. 2016). It is among the most critical threats to the conservation of wildlife and it has accrued substantial interest among wildlife ecologists as well as legal, social and environmental policy makers (Knight, 2000a; Graham et al., 2005; Lee, 2017). Despite increased attention to this challenge, conflict still persists between local people and wildlife. Conflict is particularly apparent for people sharing landscapes with large carnivores in Africa (Dickman 2010).

People form their attitudes about wildlife based on the nature of their interactions which may be firsthand or vicarious (e.g., through print and electronic media; Gore, 2005; Decker 2010). Real or perceived threats associated with human-carnivore interactions often lead people to regard wildlife negativistically (Hazzah, 2017; Bencin et al., 2016). Perceptions of risk is comprised of a set of value-based judgments formed by people about the perception of relative threats (Gore, 2005) stemming from a combination of personal experiences, instinctual predispositions, and anecdotal influences (Thirgood et al., 2005). The perception of risk thus may substantially affect people’s images of a given species and consequently their support for conservation initiatives (Gore, et al 2009; Bencin, et al. 2016). The concept and understanding of risk, as well as reactions to it, are also heavily influenced by social and cultural perceptions, history, and ideology (Dickman, 2010). Because perceptions influence beliefs, attitudes, and support for wildlife management (Gore, 2005), it is vital to take into account their impact when developing strategies for conflict mitigation. Understanding how people perceive encounters with wildlife is a key element in management planning and is usually of interest mainly to policy makers dealing with safety issues (Decker et al., 2010). Biological science alone does not provide a complete understanding of solutions to conflict (Madden, 2004). Perception studies can also be valuable in examining the complex nature of human–wildlife interactions and can help inform our understanding of conflict (Dickman 2010).

In East Africa, decreased support for wildlife conservation may rise from direct interaction with wildlife resulting in devastating impacts on local livelihoods as well as from restrictions on the use of grazing lands and water near protected areas (Messmar, 2000; Peterson *et al.*, 2013; Lee, 2017). Numerous factors additionally make each human-wildlife conflict or coexistence situation unique, these include biological, geographic, political, economic, social, financial, cultural, and historical factors (Madden, 2004). Admittedly, very little is known about the influences that shape local people's attitudes and perceptions of wildlife including; past experiences, socio-demographics, physiological, and economic factors (Bencin et al. 2016). A major challenge with this is that researchers often make important assumptions about human attitudes and behavior when deciding how to tackle conflict, the mismatch between assumed and actual behavior of local people is often startling (Dickman, 2010). Several empirical studies have demonstrated that people's 'social acceptance capacity' for wildlife is both a byproduct of their beliefs about wildlife, and their perceptions around wildlife-related risk (Gore et al. 2005; Decker et al. 2010; Bencin et al. 2016; Lee 2017).

In comparison to the number of studies that quantify livelihood risks and economic costs, most studies infrequently address the perceptual drivers of conflict (Lee 2017). To effectively manage human-wildlife conflict and ensure the persistence of threatened species of conservation concern, more studies are needed that offer a broader understanding of how local perceptions shape actions and reactions to human-wildlife interactions across a variety of contexts (Madden, 2004). Here I assess the perceptions of livestock depredation by carnivores across the Maasai steppe in Northern Tanzania from 2015 to 2017. I compared the perceived frequency of negative encounters in the form of livestock depredation across four carnivore species (lion, hyena. leopard, and jackal). I further related these perceptions to the rates of livestock loss encountered at each participating boma (Chapter 1). Additionally, I examined the local understanding of the causal factors in husbandry practices and ecology that explain the variability seen in livestock depredation across the Maasai steppe

2.2 Material and Methods

2.2.1 Study Area

This study was based within the Monduli district of the Arusha Region in Tanzania. This ecosystem is also known as the Maasai Steppe. Major habitat and land cover types in this area are ground water forest supported by perennial springs (UNESCO 2002). Tarangire National Park (TNP; 2,800 km^2) and Lake Manyara National Park (LMNP; 330 km^2) both fall within this landscape. Indigenous residents also manage the Ngorongoro Game Conservation Area (NCAA; 8,292 km2) for multiple uses including conservation, tourism, and pastoralism. The study villages lie among these different conservation areas. This landscape, spanning an area of >25,000 km^2 in Northern Tanzania (Kissui 2008), was occupied by large herds of wild animals and Maasai livestock at the turn of the 19th century before rapid human encroachment and development (Kaswamila 2006; Kissui 2008). There are an estimated 350,000 agro-pastoralists on the Maasai steppe (Nelson 2005). The primary ethnic groups are Maasai, Waarusha, and Barabaig. These pastoralists keep cattle, donkeys, sheep and goats (referred to as shoats; Sachedina 2006) all of which are vulnerable to depredation. The large number and condition of livestock, including an estimated 1 million zebu cattle (Sachedina 2006), signify the relative wealth and immense cultural importance of agro-pastoralism in these communities (Ikanda and Packer 2008; Kissui 2008).

2.2.2 **Interview Protocol**

When depredation occurred at a boma (Fig 2.1; a traditional livestock enclosure, characterized by circular thorn fencing), data was recorded on the number of livestock killed and the carnivore species that were involved in the attack. To select a representative random 50% sample of villages in the Maasai steppe to conduct the survey, I first divided the large dataset into homogeneous classes of depredation levels based on the number of reports recorded in these villages from 2006 to 2016. I applied the Jenks Natural Breaks algorithm, a tool in ArcMap 10.3 (ESRI, Redlands, CA). This data-clustering method stratified all 18 villages into three categories of; high (> 500), medium (100 - 500), and low (<100) depredation levels. This classification method is designed to determine the best arrangement of values into different classes as it seeks to reduce the variance within classes and maximize the variance between classes (Jenks 1967; North 2009). To sample participating bomas distributed across nine villages in the Maasai steppe, I randomly selected three villages from each the depredation category. In consultation with local leaders and guides, I further randomly sampled 12-14 bomas equitably distributed across all sub-villages in each village.

At each boma, I generated a boma identification code ensuring the boma owners' identities were protected. For anonymity, I coded bomas numerically, and respondent identities were recorded only upon request to receive results from the study. The surveys were translated from English into both Swahili and Maa languages. As most respondents were non-literate, the questionnaire format was described and verbal consent was obtained before the start of each interview. The interview protocol was reviewed and approved to meet the conditions for exemption from Institutional Review Board (IRB) review, under Type B, Category 2 of the U.S. federal code 45 Part 46 on human subjects protections in research at Michigan State University (IRB: X17-439e).

The survey comprised of a set of open-ended questions (Appendix A) regarding the perceptions of negative encounters between people and four carnivore species; lions *(Panthera leo*), leopards (*Panthera pardus*), spotted/stripped hyenas *(Crocuta* sp.), and jackals (*Canis* sp.) at the boma. I investigated the perceived frequency of negative encounters with carnivores at their boma (i.e. how often the respondent believed the species was causing livestock loss in the boma). I used a Likert five-point frequency scale (Vagias 2006) to record the respondents' perceived frequency of negative encounters with each carnivore species (Table 1). Perceptions were scored on a scale of very often to never. I also recorded: *i*) the total livestock loss experienced for each livestock species and the carnivores responsible from 2015-2017; *ii*) probable causal factors for depredation related to husbandry practices; *iii*) knowledge of carnivore behavior related to depredation; and *iv*) materials used to build the livestock enclosure. The data was collected to compare the presence of absence of actual depredation events at the boma, to the response given for the perceived frequencies of attack. I tested for correlation between these variables using Pearson's r correlation and analysis of variance (ANOVA).

Significance was defined as P < 0.5. Additionally, I used descriptive statistics to compare the perceived frequencies of depredation by each carnivore species to the actual loss experienced.

2.3 Results

I conducted 110 open-ended surveys in bomas across nine villages from May to July 2017. I spoke with all adults present at each boma I surveyed. Most of these individuals tended to be livestock owners. Across all villages most of the total livestock lost (n=2774) to depredation included shoats (67.7%, n=1539), followed by juvenile shoats (34%, n=775), cattle (14.5%, n=330) and donkeys (5.7%, n=130; see Fig. 2.2). The number of carnivore species responsible for alleged livestock loss differed across the nine villages (Fig. 2.3). Only three villages reported depredation events by all four-carnivore species in this study. All villages experienced attacks by a minimum of two carnivore species (i.e. respondents reported depredation by hyena and jackal across all nine villages). Six villages reported depredation by lion, and five villages experienced leopard depredation. Livestock depredation was most often attributed to hyenas (n=57 of 110), 51.6%). The next species reported to be responsible for depredation was jackals (24.2%, n=27), followed by lions (19.2% n=21), and finally leopards (4.9% n= 5).

Similarly, a majority of respondents (91.8%, n=101 of 110) perceived that depredation by hyenas occurs almost daily, with hyenas again being responsible for the greatest frequency of livestock depredation events from 2015 to 2017 (Fig. 2.4). Jackals were believed to be predominant cause of depredation of juvenile shoats (61.8% n=51). The perception of livestock depredation by lions varied according to the boma's proximity to protected areas and therefore prime lion habitat. Although 78.2% (n=86) of respondents reported that depredation by lions occurred sometimes, rarely, or was never experienced in their boma during the study period, more lion events were reported to occur during the wet season. Finally, 69.1% (n= 76) of respondents rarely or never experienced livestock depredation by leopards in their village.

I found a positive relationship between the presence or absence of depredation events at any one boma and the responses about perceived frequencies across all species. The perceptions of frequencies of attack by jackals ($|r| = 0.23$, $p < 0.05$) lions ($|r| = 0.48$, $p < 0.5$) and leopards ($|r| = 0.07$, $p < 0.5$) were significantly correlated to the presence or absence of attacks to a livestock enclosure. The perceived frequencies of attack by hyena however were not significantly correlated to the actual attack ($|r| = 0.16$, $p > 0.05$).

Several causal factors were perceived to explain the variability in livestock losses to depredation at the boma (Fig. 2.5). A majority of respondents (80.9%, n=89) cited that a poorly constructed boma was the primary factor responsible for livestock depredation. Bomas with poor quality thorn fences (i.e. a low fence with wide gaps) were thought to increase the likelihood of entry by a carnivore into the enclosure. On the other hand, a well-constructed livestock enclosure with high fences, densely packed thorn and/or chain link would minimize the chance of intruding carnivores. Though a majority believed that weak thorn bush fence was ineffective in preventing access to livestock by carnivores, of all bomas only 11.3% (n=13) had fortified chain-link fences to enhance the structural integrity of the enclosure. Of the boma owners with a thorn bush fence (52.7% n=58) had double layer fencing. The location of a boma in proximity to the nearest protected area was another top reason (63.6%, n=70) suggested to affect livestock depredation rates. Over half (62.7%, n=69) attributed livestock being locked out of the boma at night to depredation events. Additionally, more than half of respondents 60.9% (n=67) cited that subsistence slaughter of livestock for meat would lure carnivores to a boma was supported.

Respondents reported that the scent of blood from slaughter around the boma increased the likelihood of depredation events.

All respondents noted a belief in the influence of various ecological factors in the variability of depredation. A majority (77.3%, n=85) of respondents identified that some opportunistic carnivores stalk livestock herds back to the boma from the grazing lands by following known livestock paths in search of lagging livestock. Similarly, most (77.3%, n=85) respondents discussed the role of seasonal variation (i.e. wet season) on increased wildlife populations on community lands and therefore on depredation events. On the other hand, only 17.2% (n=10) perceived no distinct difference in depredation events between the wet and dry seasons, and 5% perceived more attacks in the dry season. Additionally, 59.1% (n=65) proposed that wild ungulate species are drawn to human settlements during the night for safety from preying carnivores, bringing them near to livestock in bomas. Other explanations for the variability in depredation events included the presence of a water source near bomas, attracting prey and carnivores alike and the understanding that when prey is scarce, carnivores kill livestock more frequently.

2.4 Discussion

Along with empirical knowledge, understanding local people's knowledge about negative encounters with wildlife and their perceptions towards large carnivores, is essential for mitigating human-wildlife conflict (Berkes, 2004; Treves et al., 2006; Dickman, 2010). My study assessed pastoralists’ perceptions on the frequency of depredation by carnivores as well as husbandry and environmental factors explaining the variability in livestock depredation across the Maasai steppe between 2015 and 2017.

In the Maasai steppe, multiple carnivores depredate livestock among bomas in the villages. With the wild prey source spread beyond protected areas, carnivores hunting in the village lands may opportunistically switch to hunting livestock, to the detriment of livestock herders (Polisar et al. 2003; Ikanda & Packer 2008; Inskip et al. 2009; Loveridge et al. 2010). This study reveals that in most cases, an individuals' perceptions towards a specific carnivore is related to the level of negative encounters with that occur at the boma. Based on the number of negative encounters experienced by bomas in each village, it is evident that livestock depredation events were primarily attributable to two carnivore species. Depredations by hyenas and jackals on shoats (both adult and juvenile) were particularly widespread across all villages and were responsible for a majority of the depredation events at the boma. Similar to results from comparative studies conducted in the Maasai steppe, hyenas were responsible for most of large carnivore attacks recoded on bomas (Kissui 2008; Lichtenfeld et al. 2015). Perceived frequencies of depredation by hyena were not significantly correlated to the presence of negative encounters occurring at a particular boma. Similarly, the respondents' perception that frequencies of attack by leopards rarely occur, was also significantly correlated to the low number of negative encounters with leopards at most the bomas. The perceptions of frequency of depredation by jackals and lions was similarly positively correlated to the actual loss experienced in the study area. Despite the higher rates of depredation by hyenas and jackals, lions in the Maasai steppe were particularly vulnerable to retaliatory killing. This result is in keeping with other evidence that demonstrates that lions are persecuted more frequently due to cultural practices and to the perception that they are responsible for more damage to livestock (Ogada et al., 2003; Kissui, 2008; Hazzah et al., 2009). This increased resentment towards lions may be because the Maasai place a higher value monetary and cultural value of the cattle that lions kill, over the small stock that hyena, jackal and leopards kill (Dickman 2005; Dickman et al. 2014). The loss of cattle arouses a much stronger emotional response, and stimulating greater resentment against lions (Kissui, 2008). These results highlight that based on boma reports of depredation events, it is important to design mitigation strategies tailored to address both species-specific and multi-carnivore depredation that occurring different rates between sites with varying habitat characteristics.

My study reveals a keen recognition of the influence of husbandry practice on the rates of depredation experienced in this study area. There was majority consensus that a poorly constructed livestock enclosure would increase the likelihood that a carnivore could penetrate the thorn barrier to kill livestock. Previous studies have shown that poor husbandry practices particularly pertaining to characteristics of the boma fence, are positively correlated to livestock lost to depredation events, and have recommended various strategies to fortify traditional fences with chain-link. (Ogada et al. 2003; Woodroffe et al. 2007; Kissui 2008; Lichtenfeld et al., 2015; Manoa and Mwaura 2016; Mkonyi et al. 2017; Chapter 1). In comparison to the empirical results on boma characteristics analyzed in the first chapter, the majority of respondents still rely on single- layer thorn bush fences to keep their livestock safe. Even though, research has shown that chain-link fencing is a cost-effective material reducing the impact of large carnivores on pastoralists (Kissui, 2008). Most boma owners seemed unwilling to invest in fortification out of pocket. This could be due to the heavy dependence on conservation research and non-governmental donor support to establish fortify chain-link fences at bomas. Several donations have been made to select livestock owners, and this has fueled the perception that mitigations solutions are provided as hand-outs to the community. Even with a cost-sharing schemes offered by some organizations, a majority seem unlikely to invest in fortification of their livestock enclosures.

There are many factors specific to a particular environment (e.g. patterns of animal behavior) that likely affect the intensity of damage caused by wildlife and the cost of conflict to people (Dickman 2010). For example, the empirical results generated in the first chapter of this thesis are in direct contrast with several perceptions identified in this study, particularly the perception that bomas closer to protected areas experience more depredation events, whereas through analysis I can infer that the opposite is true. This shows a clear mismatch of between perceptions and the actual correlates of conflict influencing depredation at a fine-scale. Overall, there was large consensus that wildlife migration patterns in the ecosystem play a critical role in influencing livestock depredation.

Across the Maasai steppe, over two-thirds of our respondents directly linked changes in negative encounters with carnivores to seasonal rainfall patterns which leads to an increase of wild migratory prey and carnivore presence in communal village lands. Previous ecological studies conducted in this region have found that depredation increases during seasonal migration of species livestock depredation around the Maasai steppe (Kahurananga & Silkiluwasha 1997; Kissui 2008). During the wet season, tall vegetation observed near bomas was perceived to provide opportunities for carnivores to hide from herders, and heavy rainfall, made it harder to guard livestock overnight outside shelter. Livestock depredation during the dry season was perceived to occur at low frequencies as the scarcity of quality grazing causes multiple deaths of both prey and livestock, to the benefit of carnivores. Additionally, it was commonly believed that ungulate species would use the communal village lands for the protection from predation that proximity to humans afforded. This phenomenon is described as the predator shelter hypothesis or the human shield hypothesis where behavioral studies have shown that some ungulates use human presence as a potential refuge from predation risk (Berger 2007; Shannon et al. 2014). In this way, human settlements have the potential to alter predator-prey interactions. These results provide a deeper insight about the relationship between seasonal variability in wildlife movement, livestock loss and its impact on risk perception particularly during the wet season.

The dynamic nature of human-livestock-predator systems dictates the need to continually evaluate the state of human-carnivore conflict over time (Dickman 2010). This can be done by further analysis the impacts of people's perceptions of, and attitudes towards large, carnivores (Dickman 2010; Inskip & Zimmermann 2016). My research shows that an in-depth understanding of human-wildlife interactions should be informed by the systematic application of not only biological, but also social and cultural, knowledge into conservation practice. Beyond this, communities should be empowered to use their own traditional knowledge to make management recommendations. Local people are those best placed not only to define and prioritize their own problems but also to identify, generate, and implement effective and sustainable solutions to those problems (Homewood et al., 2009).

2.4.1 **Conclusion**

In this chapter, I contend that successful mitigation of human carnivore conflict cannot be fully achieved without understanding the influence of local knowledge traditional and current perceptions of a community’s negative and positive interactions with wildlife. The incorporation of traditional knowledge in conservation could ultimately foster greater tolerance between people and carnivores ensuring sustainable livelihoods and long-term conservation across the Maasai steppe. Considering the influence of local communities’ beliefs and values on their perceptions of conflict, current monitoring, evaluation, and human-wildlife interaction research should include socio-cultural and historical components in addition to ecological factors such as those described in this study. Such assessments may be more effective when incorporated into management, policy development and future conflict mitigation research. Local involvement in decision making can allow the incorporation of local knowledge and entails greater interest in and ownership of conservation interventions by the community (Waylen et al. 2010). Long-term conservation success requires community and stakeholder support, commitment and the incorporation of different stakeholder values, attitudes and beliefs in the policy-making process. (Messmer, 2000; Hill et al., 2017).

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APPENDIX

APPENDIX

Table 2.1 This table contains descriptions to the response anchors used in Likert 5-point scale for perceived frequencies of livestock depredation by carnivores in the Maasai steppe from 2015-2017.

Points	Response Anchor	Description
1	Never	This carnivore has never attacked my boma.
2	Rarely	On very few occasions. Livestock depredation events by carnivore in infrequent, but still occur.
3	Sometimes	Occasionally. Livestock depredation by carnivore take place seasonally. It occurs over a few months in a year.
4	Often	A moderate amount. Regular livestock depredation events by carnivore. Occurs multiple times in a month
5	Very Often	A great deal. Livestock depredation events by carnivore, occurs multiple times a week, almost daily.

Figure 2.1 Examples of thorn bush livestock enclosures commonly used in the Maasai steppe, Tanzania. Panel a) shows the interior of a traditional thorn fence panel while panel b) shows the exterior of a thorn bush fence

a)

b)

Figure 2.2 Total depredation by specific livestock type for each village in Maasai steppe region of northern Tanzania from 2015-2017.

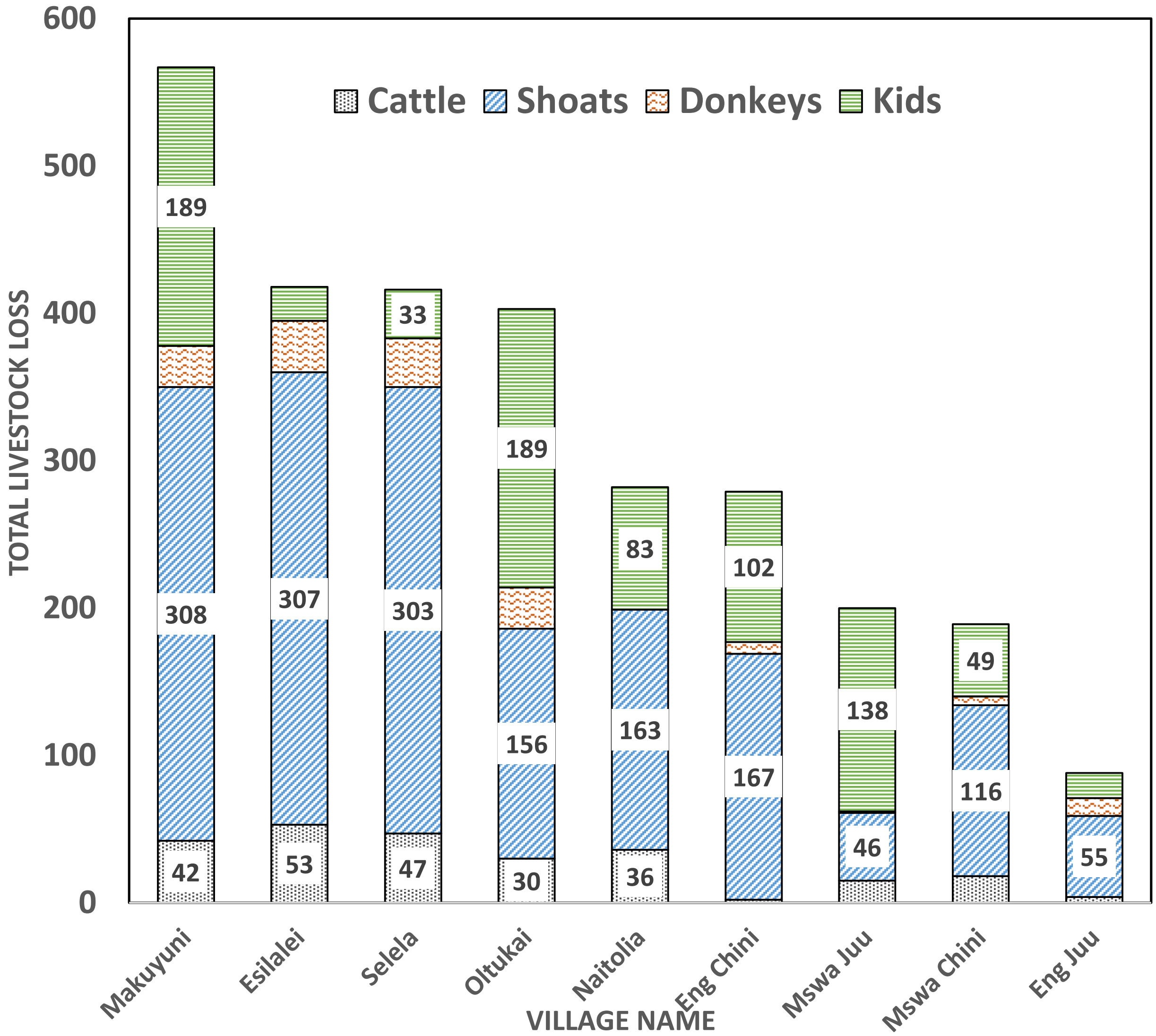


Figure 2.3 This clustered column chart shows a comparison of the presence of depredation events by four carnivore species experienced at the village level from 2015 to 2017.

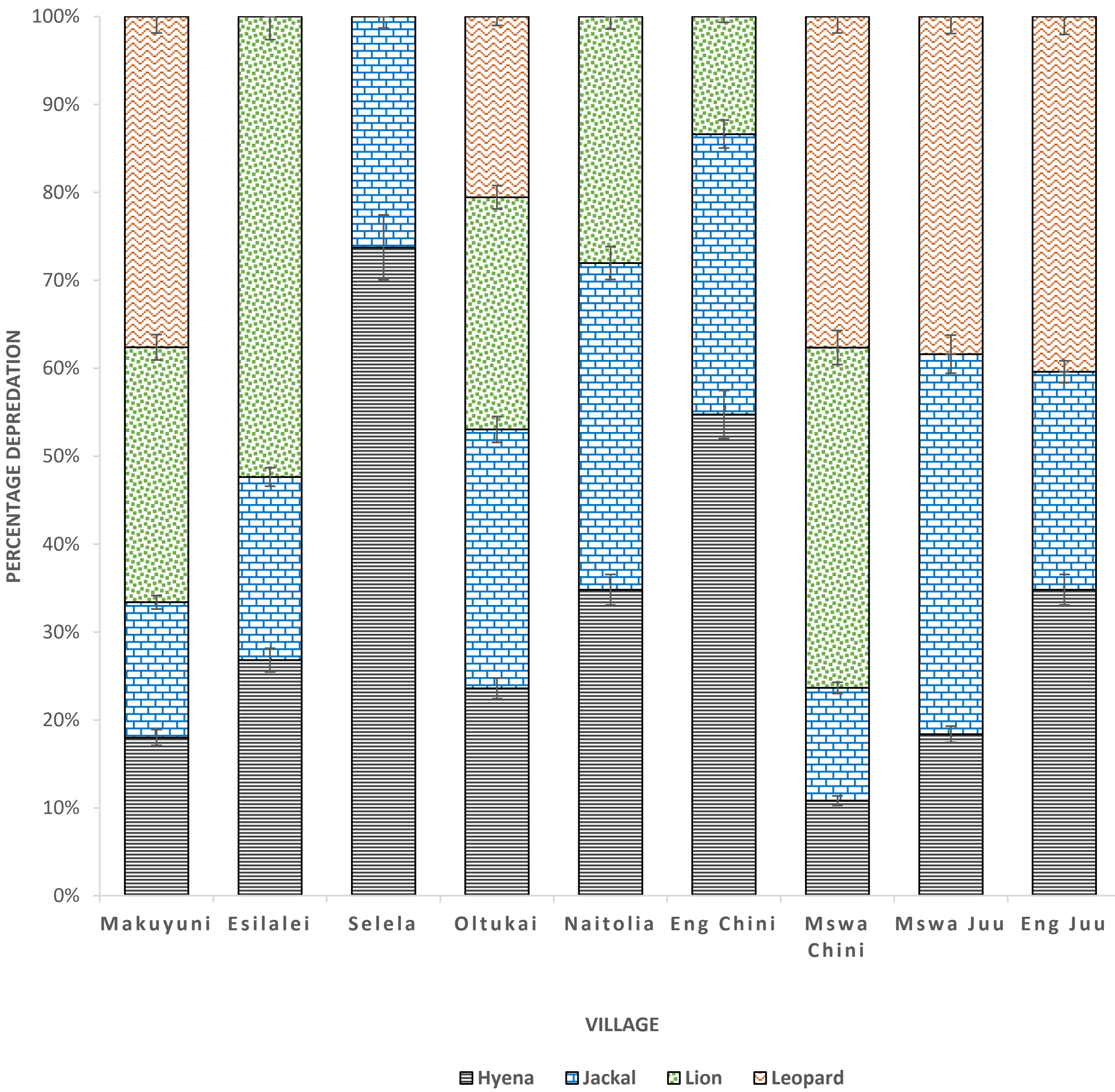


Figure 2.4 This figure describes the perceived frequency of negative encounters with carnivore species at the boma in all villages across the Maasai steppe from 2015 to 2017.

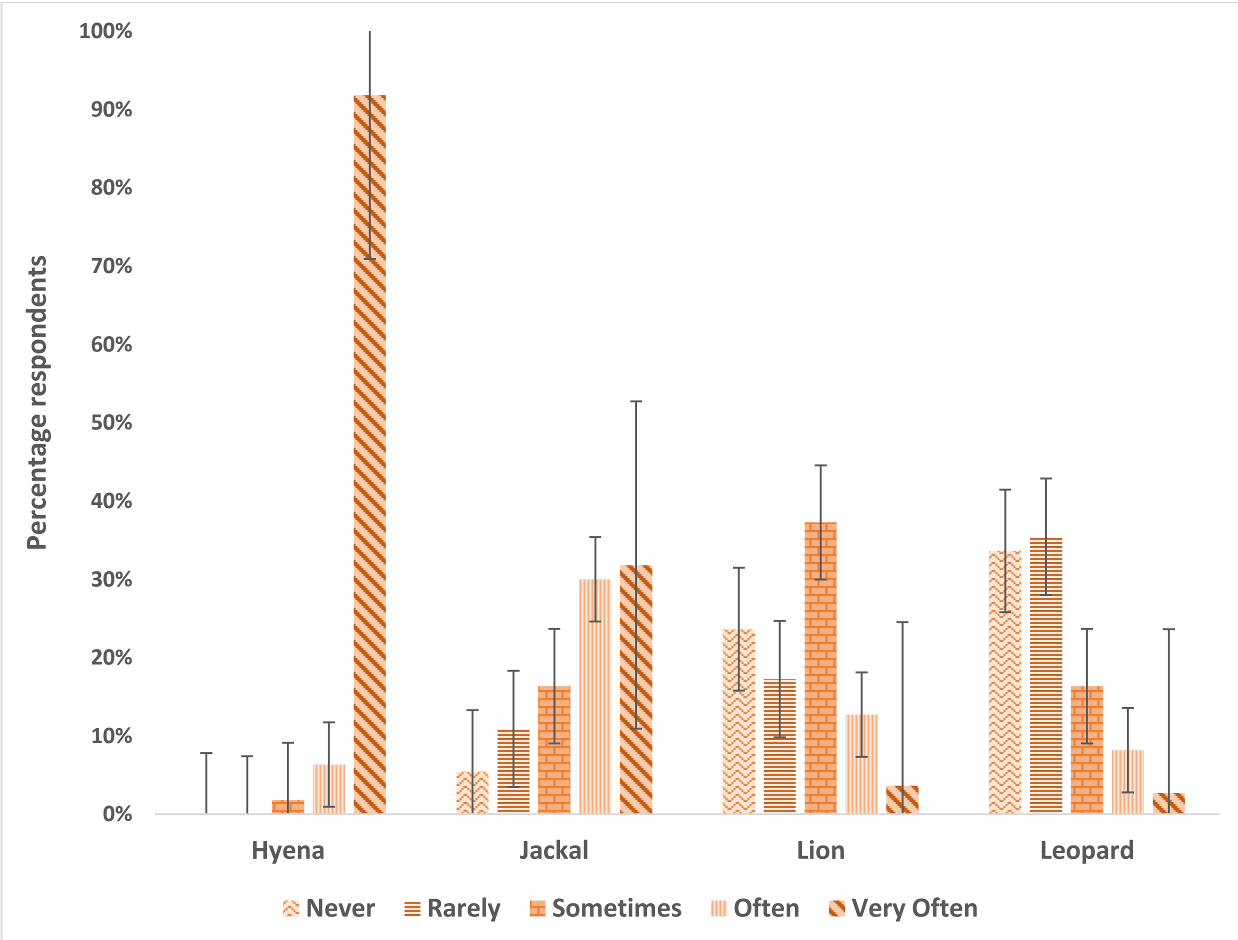
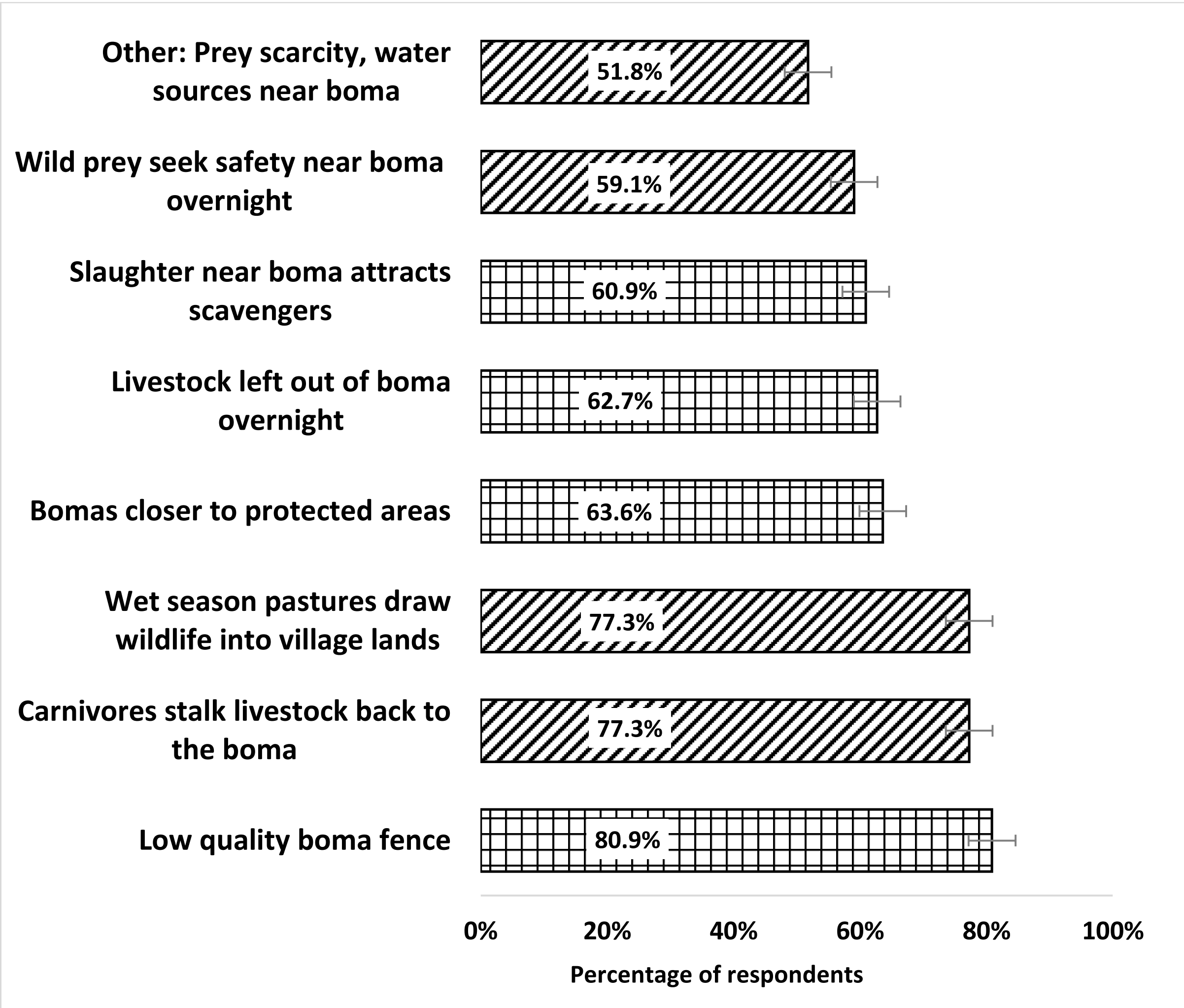


Figure 2.5 Column bar graph shows causal factors in husbandry practices (dark orange bars) and ecological factors (cream bars) perceived as most influential in explaining the varying rates of livestock depredation experienced at boma in villages



*Squared bars represent Husbandry related factors; *Stripped bars represent ecological factors perceived to influence depredation.

Supplementary Information – Research Questionnaire

Carnivore/Livestock Data

1. a) How many livestock of each type do you currently own?
   b) Which carnivore species do you think visits your boma most often? Is this rate in a month/year?
   c) How often is your neighbor attacked? By which species?

	Very Often (Mara nyingi sana)	**Often (Mara Nyingi)**	**Sometimes (Mara chache)**	**Rarely (Mara chache sana)**	**Never**	**Describe: How many times a week? month**
Lion						
Hyena						
Leopard						
Jackal						

c) How many livestock of each type have you lost to carnivore depredation?

Type	**Estimated total number in boma**	**Killed this year**	**Killed last year**	**Killed in the past two years/previous years**	**Carnivore**
Cattle					
Shoats					
Donkeys					
Kids					
TOTAL:					

Why do you think your boma is attacked frequently? Give reasons.

Weak Fence	
Lions Follow Cattle Home	
Cattle/Shoats left out of boma	
Wildlife (ungulates around your boma)	
Proximity to wildlife area	
Slaughter near the boma attracts scavengers	

In which season do you

	Wet	Dry	Details
See more carnivores in the community?			
Experience most attacks in the boma?			

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