AN ANALYSIS OF LANDSCAPE CHARACTERISTICS INFLUENCING LIVESTOCK DEPREDATION BY LIONS, HYENAS, AND LEOPARDS IN LOIBOR SIRET, TANZANIA

by

Sam Baraso

Dr. Jennifer Swenson, Advisor
April 2012

Masters project submitted in partial fulfillment of the requirements for the
Master of Environmental Management degree in the
Nicholas School of the Environment of
Duke University

2012

Abstract

The African lion has declined precipitously across its entire range from nearly 500,000 in the early 1900s to roughly 35,000 individuals today. While a multitude of factors contributes to the lions' decline, conflict with traditional pastoralists is one of the gravest threats. Lions, hyenas and leopards opportunistically prey on livestock including cattle, donkeys, goats, and sheep in pastoral regimes. However, lions are disproportionately blamed for livestock depredation and are common targets in retaliatory killings in many communities. Several NGOs including the African People & Wildlife Fund are finding ways to minimize predation incidences and thereby reduce retaliatory killings. Strategies such as corral fortification have reduced predation events within the homestead, however, a significant percentage of attacks are at the pasture. Using 54 months of carnivore/livestock conflict data in the Maasai Steppe of Tanzania, I assess the influence of landscape features to characterize the risk of predation at the pasture. By identifying factors contributing to greater predation risk, strategies to mitigate attacks at pasture can be designed. This way, herders will have greater capacity to protect their primary source of wealth and can better co-exist with predators. I found that proximity to *bomas* (corrals) is the most relevant landscape feature explaining the likelihood of attack across all three carnivores. After accounting for boma proximity, no other variable contributes a significant explanatory role, and attacks cannot be accounted for by landscape features alone. Fifty-three percent of all pasture predation occurs at night. Of these, roughly 71% occur on lost livestock. This study suggests that "lost livestock" represents an area of further research. After, the initiation of the Living Walls corral fortification program, boma predation declined by over ninety percent. Pasture predation also declines, though the causal mechanism is unclear. This study shows that environmental characteristics may be less important than social or behavioral characteristics of the herders in determining livestock predation at pasture.

Keywords: livestock predation, human wildlife conflict, landscape features, spatial, Maasai, Tanzania

Acknowledgements

This project would not have taken place without the support of many people. First and foremost, I would like to thank Dr. Jennifer Swenson, my Masters Project advisor who helped me move beyond the impasse on many occasions. Whose geospatial expertise came handy before I would even understand and whose patience and advice proved most valuable. I would also like to thank Dr. Dean Urban, who provided his vast multivariate expertise, central to this project.

I must give special thanks to Andrew Jacobson (GIS Coordinator, Duke BCI Intern Team), who provided constant input, guidance, and the necessary occasional prod.

I would also like to thank the African People and Wildlife Fund for offering their support during the field study portion of this project. In particular, I would like to thank Dr. Laly Lichtenfeld and Charles Trout whose collaboration in the field provided the rich background for the project. I would also like to thank them for providing the data, input, and ideas necessary to complete this project. I would especially like to thank Dennis Minja, Emily Myron, and Andrew Jacobson, who assisted me during much of the field study, providing much needed comic relief, critique, and camaraderie.

I would additionally like to thank Drs. Stuart Pimm and Luke Dollar for unconditionally bringing me into the BCI family and helping connect me with this project. Countless hours in cramped conference rooms with pizza helped shape many of the ideas presented here.

I want to acknowledge the gracious support of the Nicholas School Internship Fund, the David R. Brower Endowment Fund, the SIDG-Lazar Foundation, and Planet Action, all of which helped support the project. This project would not have been possible without such support.

I would finally like to thank my family who have supported me through all my endeavors.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AIC	Akaike's Information Criterion
APW	African People and Wildlife Fund
DEM	Digital Elevation Model
GLM	Generalized Linear Model
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
LW	Living Wall
NP	National Park
TANAPA	Tanzania National Parks Authority

1. Introduction

Despite being known as the king of the jungle, Africa lion (*Panthera leo leo*) populations have declined precipitously across its entire range from as many as 500,000 in the early 1900s to fewer than 35,000 today (Myers 1975; Riggio et al. unpub data). A population reduction of approximately 30% is suspected over the past two decades and the IUCN Redlist labels the lion as Vulnerable (Bauer et al. 2008). Worryingly, the primary causes of this reduction (indiscriminate killing and prey base depletion) are unlikely to have ceased (Bauer et al. 2008). More lions exist in Tanzania, estimated around 16,000, than any other country (Mesochina 2010). Therefore, Tanzania is the most important country in the world in terms of lion conservation.

As African savannahs are developed or degraded at unprecedented rates, humans and wildlife, particularly carnivores, are coming into increasing conflict (Woodroffe and Frank 2005; Kissui 2008). Over the last 40 years in northern Tanzania, livestock populations have remained relatively consistent, while human populations have grown, resulting in lower numbers of livestock per capita. For the Maasai, who maintain livestock-based livelihoods, it has been suggested that the per capita decline in livestock has resulted in lower tolerance for depredation (McCabe 2003; Ikanda and Packer 2008). Carnivores such as lion, leopard (*Panthera pardus*), and the spotted hyena (*Crocuta crocuta*) prey upon people and livestock. Not surprisingly, such incidences are regularly followed by efforts to retaliate (Lichtenfeld 2005). This unfortunate scenario often results in the disproportionate retaliatory killing of lions (Kissui 2008).

While much research is aimed at understanding and resolving such conflict, many proposed solutions are costly and do not garner local support. Of the many wildlife conflict mitigation strategies proposed or enacted, Ogada et al. (2003), suggest that improved livestock husbandry is a realistic and cost-effective solution. And while several organizations across Africa provide local support to improve livestock enclosures (Figure 1), herein referred to as *bomas*, 25-75% of livestock losses occur outside of bomas during the day (Ogada et al. 2003; Ikanda and Packer 2008).

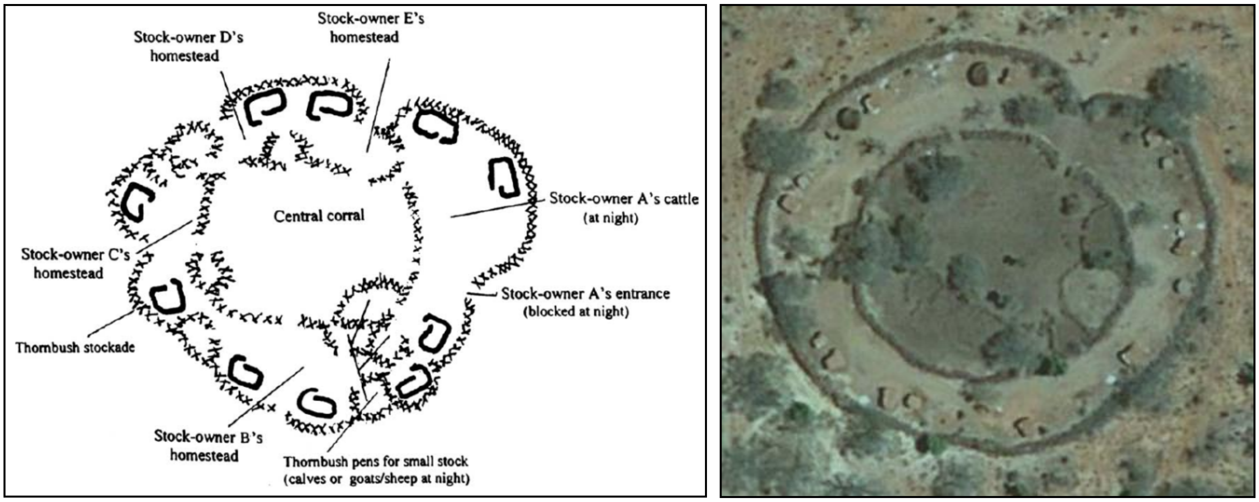


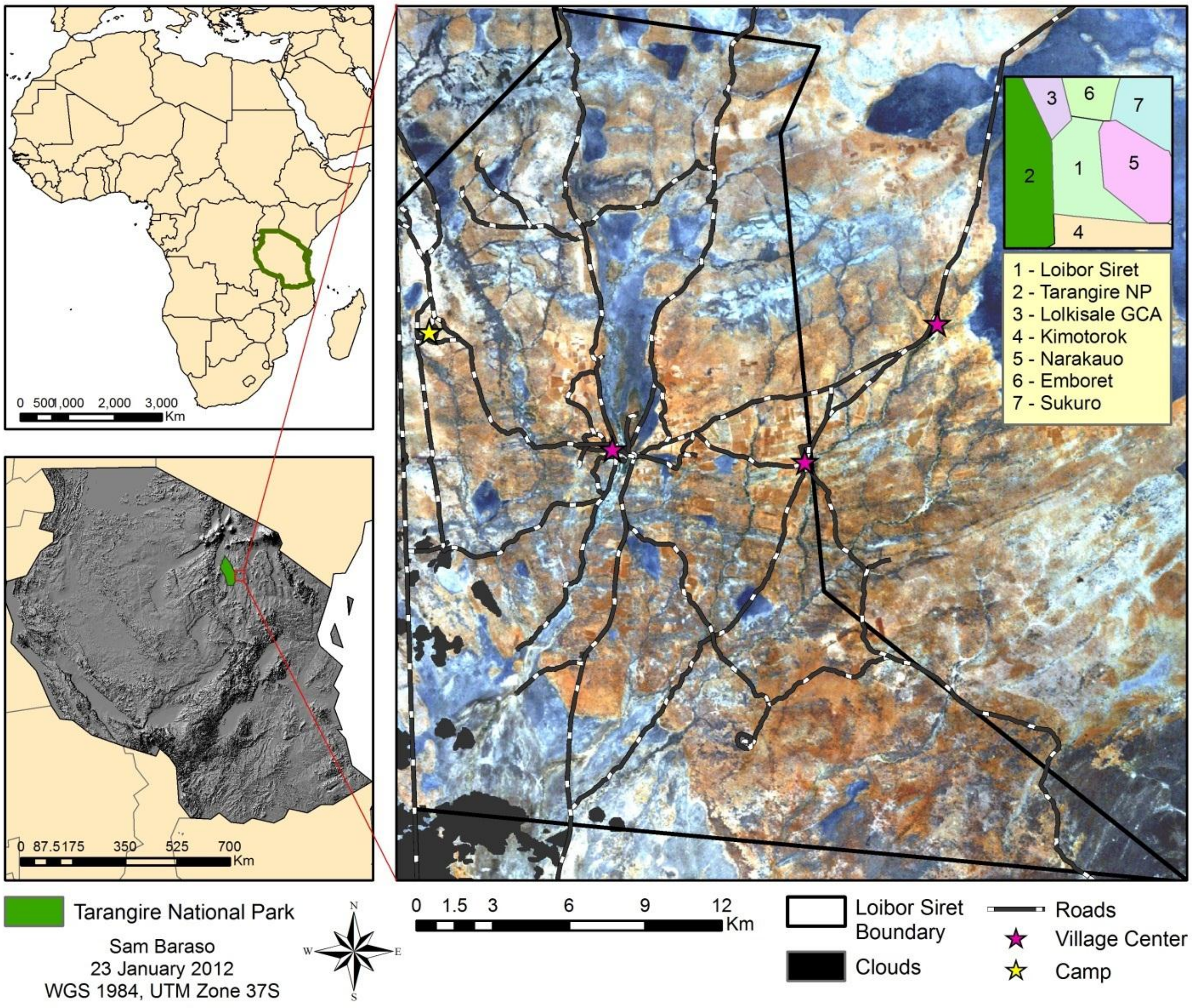
Figure 1: Composition of Maasai boma (left). Cattle from all households are housed together in the central corral. Smaller livestock and calves are sometimes housed in smaller pens either in the central corral or just outside in a small enclosure. Sourced from Kolowski and Holekamp (2006) whom adapted the figure from (Spencer 2003). Google Earth satellite image from 4/22/2012 of a boma in Loibor Siret, Tanzania (right).

The Maasai Steppe is a region of relatively higher elevation in northern Tanzania, covering around 25,000 km^2 (Kissui 2008). Two national parks form the core dry-season refuges for wildlife, Tarangire National Park (2,850 km^2) and Lake Manyara National Park (330 km^2) (TANAPA).The Maasai-Steppe hosts the second-largest population of migratory wild ungulates in East Africa (Msoffe 2011). An estimated 350,000 pastoralists inhabit the Maasai Steppe and herd roughly one million cattle (Sachedina 2006). Further, human population growth is 4% for this region (Arusha, National Bureau of Statistics 2006).

The study area is the village of Loibor Siret, on the southeastern border of Tarangire NP in the Manyara region (Figure 2). The village covers an area of approximately 550 km^2. Maasai is the predominant ethnicity. Maasai are pastoralists and semi-nomadic, keeping indigenous zebu cattle as well as other cattle breeds, donkeys, and small livestock. The other main ethnic group is the Waarusha who are agricultural. However, virtually all Maasai households now practice some degree of cultivation (Lichtenfeld 2005). Over 3700 people live in Loibor Siret and they herd ~30,000 head of cattle and an equal number of sheep & goats.

Human/lion conflict for areas east of Tarangire NP is high relative to the rest of Tanzania (Mesochina et al. 2010). Kissui (2008) found an annual loss to predation of 1% for cattle in the

Maasai Steppe and 4% loss for goats and sheep. This is higher than many areas worldwide with Graham et al. (2005) reporting losses ranging from 0.02% to 2.6% per year. This is also higher than other local areas such as the Maasai Mara, Kenya (Kolowski and Holekamp 2006). Such losses can be quite costly to pastoralists. In ranches neighboring Tsavo National Park, 300 km to the northwest in Kenya, each ranch lion (26 lions total) was responsible for $290 in livestock losses annually (Patterson et al. 2004). Of the ranch's total annual livestock loss to predators of $8749, lions accounted for the majority of attacks and over 85% of the annual economic loss (estimated at $7532). Patterson et al. (2004) further revealed that livestock constituted roughly 5.9% of the prey needed to support lions in the area.



*Map of Tanzania above is hill-shaded for elevation.

Figure 2: Study Area, Village of Loibor Siret (November 4, 2009 Landsat TM5 Imagery in background)

As innovative and improved fortified boma enclosures are virtually eliminating attacks at the boma, there remain attacks at pasture (Lichtenfeld unpub data). Several studies have indicated increasing herder knowledge of safe areas may reduce predation events and the resulting retaliatory killings. One such strategy is the clearing of woodlands near pasture borders (Chardonnet et al. 2010). This project serves to further examine this research area by assessing landscape features influencing depredation.

2. Local Partnership

The African People and Wildlife Fund (APW), a non-profit organization locally known as the Tanzanian People and Wildlife Foundation (TPW), was founded in 2001 by Dr. Laly Lichtenfeld and Charles Trout. While APW's official headquarters are in New Jersey, USA, its regional operations are based out of the village of Loibor Siret, Tanzania. APW initially focused on applied research and carnivore conservation; however, its scope has expanded to support greater integrated conservation and village development through the years. In 2002, Lichtenfeld and Trout began collecting livestock depredation event data with Maasai community member Saruni Moses, including but not limited to geographic location, predator species, and livestock taken. In 2010, with support from AWELY, a French non-profit aiming to mitigate human-wildlife conflict, APW expanded their collection of wildlife conflict data by hiring Elvis Kisimir as coordinator. Elvis's team now collects data on all human/wildlife conflict including crop-raiding incidences.

3. Motivation

Over 700 lions are estimated to live in the Maasai Steppe (Mesochina et al. 2010). This makes it the fifth largest population of lions in East Africa (Riggio et al. unpub data). However, the two unfenced protected areas cover only ~10% of the ecosystem. Data from multiple sources indicates that this population has been under pressure since at least the early 2000s, with 17 to over 40 lions killed each year (Lichtenfeld 2005; Maddox 2003). Pastoralists killed 85 lions around Tarangire NP between 2004-2005, while at least 120 lions were poached between 2005 and 2009 (Kissui 2008; Mesochina et al. 2010). The majority of these killings were retaliatory resulting from livestock predation. According to Kissui (2008), lions are most vulnerable to retaliatory killings among the common stock-raiders. This is because lions attack more cattle than goats and sheep (Lichtenfeld 2005). Cattle are more valuable to the Maasai, both economically and culturally (Kissui 2008). Additionally, lions more-often attack during the day, making themselves easier targets for retaliation (Kissui 2008).

Although the majority (exact percentages vary greatly by location and season) of attacks on livestock occur at the boma at night, APW has an effective and locally popular strategy for preventing these attacks. Predation at bomas has been eliminated with APW's unique Living Walls approach (Lichtenfeld unpub data). Living Walls (LWs) are fortified bomas (Figure 3). Specifically, they are fortified with chain-link fencing with a native tree species, *Commiphora africana* used for pole structures. New growth is woven back into the chain-link to minimize visibility and add additional layers of protection. The use of Living Walls eliminates the constant need to cut down Acacia thorns to maintain bomas. Additionally, *Commiphora africana* is propagated through cuttings. With over 100 Living Walls installed in the most high-risk areas, and some in place for over two years, there have been zero successful attacks thus far at these locations (Lichtenfeld unpub data). Therefore, the only remaining livestock depredation occurs during the day at pasture. I aim to provide insight into the spatial and temporal dynamics influencing livestock predation at the pasture. Livestock depredation is mostly preventable (Ogada et al. 2003). With the elimination of depredations at night and a minimization of attacks by day, there should be far fewer retaliatory killings of lions and other carnivores (Ogada et al. 2003, Kissui 2008).

Figure 3: Boma Fortifications: Living Wall in dry season (top), Living Wall in rainy season (bottom-right; photo credit: Laly Lichtenfeld), Acacia thorn (bottom-left)

4. Objective

I assess landscape features, pastoral practices, and seasonality to examine them with respect to their influence on carnivore depredation, with particular focus on the African Lion.

Elucidating landscape features associated with depredation could offer mitigation strategies by improving human knowledge in the rapidly changing environment. Such information may be used to influence herders' activities to decrease likelihood of attack. APW will share insights from this report with local communities to decrease depredation events and thereby reduce retaliatory killing of carnivores. Surveys conducted in 2002 in the villages of Loibor Siret and Narakauo indicate that 80 percent of individuals are interested in information on how to protect their livestock from lions (Lichtenfeld 2005).

I anticipate that this research will be integrated into community outreach, conservation education, and other distribution materials targeting local herdsman.

5. Predation Theory

Lions, hyenas, and leopards are large predators requiring 7 kg, 4 kg, and 3.3 kg of meat, respectively per day (Rapson and Bernard 2007, Henschel & Tilson 1988, Bailey 1993). Additionally, these species selectively favor prey that is half to twice their mass. Leopard and Spotted Hyena prefer prey ~40 kg, whereas lion prefer prey in the range of 100 – 900 kg (Owen-Smith and Mills 2007). Despite such preferences, leopards and hyenas have taken larger species such as zebra and buffalo, while lions have taken prey <40kg. Based on optimal foraging theory, these species will seek food resources in order to maximize net caloric intake per unit time (Pyke et al. 1977). In Loibor Siret, this implies that predators will choose a type of animal, an area to feed, a forage speed, and forage pattern in order to maximize net intake. However, the foraging landscape is dynamic based on prey species' availability and competing predator presence. Hence, each species will attempt to consume the greatest amount per day while spending the least amount of time foraging, subject to constraints (Pyke et al. 1977). In this context, livestock present a tasty meal for all three predators given their size, concentrated distribution, predictable presence, and commonness across the village. However, there is also an implied cost associated with retaliation from herders. Therefore, predators should preferentially attack livestock when risks are lower.

Lichtenfeld (2005) noted that younger lions were the bolder engaging in risky, marauding behavior. This is due to a lack of risk perception. In Loibor Siret, lions, leopards, and hyenas may preferentially predate on livestock in areas of dense thickets where herders may not see the predator. Additionally, predators may attack along roads, offering easier access to livestock, albeit with heightened risk. Predators could also preferentially attack near bomas or in woody savannahs where livestock are either concentrated or dispersed.

Previous studies have observed greater predation at night, during periods of increased rainfall, and during instances when younger herders are tending livestock (Patterson et al. 2004; Kissui 2008; Ikanda and Packer 2008). In this study, I examine several of these points.

6. Fieldwork

Between the months of May and August 2011, I spent 85 days in the village of Loibor Siret, Tanzania working with APW in order to address some of the threats facing carnivores and the local Maasai community. This involved a host of activities including the training of four village game scouts in wildlife count techniques, global positioning system (GPS) unit operation, and natural resource monitoring protocols. Additionally, I spent significant time with Lichtenfeld, Trout, Moses, and Kisimir exploring the history of predation events that have occurred in the village. Together, we discussed possible relationships between landscape variables and livestock depredations. Based on these discussions as well as predation theories, I mapped relevant landscape features in the village with the help of the recently trained game scouts, Dennis Minja, Emily Myron, and Andrew Jacobson.

7. Methods

7.1 Study Area

The study area, the village of Loibor Siret (Figure 2), is characterized by semi-arid mixed grassland savannah. Landcover in the study area is composed of agriculture, dense thickets, woody savannah, open savannah, and swamp. In addition, the landscape contains a riverine network (locally called *korongos*), appearing like dense gullies, creating a mixture of a rolling hill terrain and flat savannahs with a few dominant hills defining village boundaries.

The village of Loibor Siret is on the southeastern boundary of Tarangire NP. To the north are the Lolkisale Game Controlled Area and the village of Emboret. To the east is the village of Narakauo, and to the south is the village of Kimotorok.

Mean annual precipitation in Loibor Siret is 688 mm, with marked wet season and dry seasons, from November – April and May – October, respectively. The unimodal seasonal pattern determines the seasonal distribution of wildlife, with slight variation (< 30 days) in the start/end date of each season. Tarangire National Park to the east serves as the dry-season refuge for northern Tanzania's second highest concentration of large mammals (Lichtenfeld 2005). At the onset of rains, migratory wildlife leave the park, using the few passable routes east through the village lands of Loibor Siret, Sukuru, and Kimotorok among others (Kahurananga and Silkiluwasha 1997).

7.2 Data and Software

After a literature review and discussion with human/wildlife conflict officers, 18 variables were selected for the analysis (Table 1).

Table 1: Variables used in analysis

Depredation Variables	Landscape variables
Predator type	Proximity to village center
Attack location (coordinates)	Proximity to boma
Attack area (pasture/boma)	Proximity to Tarangire NP
Attack time (day/night)	Proximity to riverine network (gullies)
Lost status (when attacked)	Proximity to roads
Season	Proximity to cattle tracks
Monthly rainfall	Proximity to waterholes
Herder age	Landcover at point
Herder numbers	Landcover (%) in 500m radius

ArcGIS 10 was used to plot all depredation events and landscape variables (e.g. location of water holes). All variables were projected into WGS 1983 UTM Zone 37S projected coordinated system. “Proximity to” variables were calculated using the Euclidean distance tool in ArcGIS, while vegetation class is sampled from the vegetation layer to the incident point. Vegetation percentage per area is also sampled using the Focal mean tool.

The land cover analysis was conducted using Exelis’s ENVI EX 4.8 imagery analysis software. All statistical analysis was conducted using R statistical software (R Development Core Team 2011).

7.3 Depredation Events

APW has monitored livestock depredation events in Loibor Siret intermittently since 2002 (Lichtenfeld 2005). I assess data collected from 2006-2011, with a gap in monitoring during 2009. This amounts to 54 months covering over 178 separate events in the village of Loibor Siret

(Table 2; Table 3). APW has also monitored depredation events in the neighboring villages of Narakauo and Kimotorok, however, this is outside the scope of this project.

Through an informal network of informants, conflict officers are contacted anytime a depredation event occurs. The data reveal that officers met those involved within two days following a predation event, with a majority of the conflict assessments occurring within the same day as the depredation event. It must be acknowledged that while all in the village are now aware of the conflict officers and their role in mediating conflict, some depredation incidences during the initial period of monitoring may not have been captured in the data. We are confident that most depredation events in subsequent years have been captured and recorded.

During the first period of monitoring, which ranged from March 25, 2006 – November 13, 2008 (based on recorded depredation events), conflict officers met with livestock herders shortly after learning of a depredation/attempted depredation at the site of the incident. Officers would first verify that a depredation event took place by assessing remains of the predated animal and/or tracks at the scene. Predation events are considered those with positive signs of a predator (lion, hyena, leopard, jackal, wild dog, or cheetah) attempting to predate on livestock, whether or not livestock is actually killed. Using a Garmin GPSmap 60/62, the officer would record the location (WGS84 lat/long coordinates) of the event, create an incidence code, and conduct an interview with the herder. The following information was acquired in the interview:

- date of depredation event, geographic location, predator species, time of event coded as day or night, number and type of livestock lost, area of event (whether at pasture, travelling, outside boma, or at boma), and a depredation event narrative

The second monitoring period, which is ongoing (as of 4/11/12), represents data collected from March 2010 – December 2011. During the second period, APW with the support of AWELY's Red Cap Program, recommenced the collection of human/wildlife conflict data, including crop raiding incidences by herbivores. Data collected during conflict incidences include all measures collected during the initial period, with the addition of several other records. Additional records used in the analysis include:

- season, herder ages, and herder numbers

While similar data was collected during both periods, records reflect differing level of details. For instance, the time metric during the second period was recorded as morning (5:00-7:00), daytime (7:00-17:00), evening (17:00-20:00), or night (20:00-5:00). To make this consistent with data collected during the first period of collection, morning, daytime, and evening are all coded as day, while night remained night.

Another variable of importance for us was whether livestock were stray or lost when predated. As depredation narratives for each incident reflect such knowledge, a variable coded lost/not lost was added for each incident based on narratives. It is likely that there is a bias towards "not lost" in the second data recording period due to underreporting. This will be elaborated in in the discussion section.

Table 2: Data collection efforts through December 31, 2011

	Year	Months of Monitoring	Predation Events	Events/Month
Period 1	2006	9	45	5.0
	2007	12	52	4.3
	2008	11	48	4.4
Period 2	2010	10	17	1.7
	2011	12	16	1.3
	Total	54	178	3.3

Note: Depredation data does not exist for 2009

Table 3: Predation numbers per species per year at the pasture (and boma)

	2006	2007	2008	2010	2011	Total per Species
Lion	3 (12)	4 (9)	13 (4)	4 (2)	5 (0)	29 (27)
Hyena	15 (10)	19 (11)	7 (12)	6 (0)	3 (1)	50 (34)
Leopard	2 (2)	1 (2)	7 (5)	3 (0)	6 (0)	19 (9)
Jackal	1 (0)	6 (0)	0 (0)	1 (0)	0 (0)	9 (0)
Other	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	2 (0)
Total per Year	21 (24)	30 (22)	27 (21)	15 (2)	15 (1)	108 (70)

7.4 Seasonality

A season metric was not collected for data during the initial period of collection. Given our speculation that this will influence the nature of livestock predation, I added a season metric for period 1. As there is no standard criterion for defining season due to high spatial variability, I coded seasonality based on monthly rainfall data recorded by APW (via rainfall gauge) at their headquarters in Loibor Siret since 2006. The monthly mean rainfall is 57 mm, therefore months with 2 month trailing rainfall exceeding 57 mm are considered wet season, while those with 2 month trailing rainfall less than 57mm are considered dry season. Norton-Griffiths et al. (1975) employed a similar categorization in their study of rainfall patterns in the Serengeti ecosystem 250 kilometers to the north.

In addition to a season metric, I also added monthly rainfall as a variable of interest. By looking at monthly and 2 month trailing rainfall amounts per incidence, I am able to ascertain finer relationships than the broader seasonality. Western (1975) suggests that 40-50 days of rainfall variation provides the best correlation with mammal biomass. I, therefore, suspect the 2 month trailing rainfall will exhibit the strongest relationship predation incidences. Further, since rainfall varies across the village, this only represents approximate area rainfall per incident.

7.5 Landscape Variables

A majority of the landscape variables were collected in the field between June 2011 and August 2011 as part of an initiative to establish a natural resource monitoring protocol. This includes roads, bomas, village centers, riverine networks (korongos), waterholes, and land cover by location. The field team (myself, Andrew Jacobson, Emily Myron, Dennis Minja, and Loibor Siret village game scouts Samson Beah, Gerald Matinda, Meliyo Irmakasen, and Sokoine Teme) collected GPS data on roads, waterholes, landcover, and village centers. Elvis Kisimir was invaluable in providing boma locations as part of a village census conducted in July 2011.

The boundary for Tarangire National Park was digitized based on coordinates (ARC 1960) from a paper copy of 2007 updated park boundaries from the Tanzania National Parks (TANAPA). The relevant boundary for Loibor Siret is lined by a road used primarily by park staff.

The riverine network was mapped across the village using a combination of field collection, digital elevation map-based stream networks, and digitizing on the Google Earth software platform with both September 21, 2009 GeoEye (~1 m resolution) and 2009 SPOT (2.5 m resolution) imagery. The field collection involved hiking 14 km of riverine networks collecting

GPS coordinate points. This was compared against a stream channel network created from an ASTER Global Digital Elevation Model (DEM) at 30 m-resolution by commonly accepted methods suggested in Tarboton et al. (1991). DEM-modeled stream networks and stream beds visible in Google Earth were assessed against field collected streams. While the modeled stream network roughly followed stream beds seen in Google Earth, there were several instances where the modeled network diverged from field data by over 1/3 km, likely due to the medium-resolution DEM. The stream beds as seen from Google Earth lined up with the field collected data within the recorded GPS measurement error of 2-4 meters. I therefore digitized the remaining stream beds in Google Earth.

Given the associated accuracy and efficiency of Google Earth, we employed the same method to record wildlife trails and waterholes not captured in field collection. Further, spatial accuracy of digitized layers was assessed against additional SPOT imagery (2.5m color, dated 8/30/2008) obtained through SPOT’s associated Planet Action Grant Program.

I created a land cover classification based on Landsat TM5 imagery acquired on November 4, 2009 (Path 168, Row 63; L1T Format; WGS84 UTM 37S) obtained from USGS’s Earth Explorer image acquisition platform. After ensuring geometric accuracy, the image was both radiometrically and atmospherically (ENVI FLAASH-based) corrected. Subsequently, both traditional supervised pixel-based classification and more recent object-based classification approaches were conducted. Fifty GPS land cover points aided the selection of training data.

Land cover was sampled at the point of the predation incident, majority land cover within 100 m of the incident, and percentages of land cover within 500 m of the incident. Land cover within 500 m of the incident was assessed based on Stander (1992) noting that lions encountered and stalked prey when within 500 m of them. While substantially lower effective distances have been predicted by Elliot et al. (1976), in Ngorongoro Crater, 500 m is reasonable given landscape and lower alertness associated with livestock vs. wild prey. While hyenas are known to engage in longer chases, from .75 – 4 km, data on prey detection are not available and as a result, I use this 500 m threshold for hyenas as well (Holekamp 1997). Bailey (1993) did not observe leopards using scent to track prey; instead they rely on vision and sound cues. While there were certain locales within the village where one could see beyond 1 km from a higher vantage point, visibility across the landscape ranged from 20 – 200 m. Allowing for greater range in vocal perceptibility, I use 500 m for possible prey detection by leopards as well.

7.6 Statistical Analysis

7.6.1 Modeling Approach

The objective of this project is to determine landscape features influencing livestock predation. As we are dealing with location points indicating the occurrence of predation, our dependent variable will take a binary form, 1 for a predation incidence, 0 for a predation absence. In modeling the likelihood of predation, we are therefore modeling a probability ranging from 0 to 1. After exploration of various modeling approaches, I chose to model predation incidence from the landscape variables with a generalized linear model for each predator species. I use the common generalized linear model (GLM) as it has the most practical value for conservation and management.

Linear model component of the GLM:

$$u = Linear\ Predictor = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_jx_j$$

Logit link:

$$Linear\ Predictor = \log\left(\frac{u}{1-u}\right)$$

where u *is equal to the probability of 1, predation, and* $(1 - u)$ *is equal to the probability of 0, non-predation. The two summed should equal 1.*

Firstly, the generalized linear model avoids many of the assumptions associated with the linear model. It allows the response variable to deviate from normality. In our case, the response 0 or 1 will take a binomial distribution via a link function, specifically a logit link (commonly called “logistic regression”) (Franklin 2009). Further, GLM coefficients are easily interpretable. As the aim is to supply herders with manageable environmental handles indicating risk, the GLM is straightforward. Similar approaches are used in comparable spatial assessments of human wildlife conflict in Kolowski and Holekamp (2006) and Wilson et al. (2006).

In order to predict the likelihood of a predation incident, actual predation incidence locations must be compared to locations where attacks did not occur. To do this, I created 200 random points to reflect the null hypothesis which assumes conflicts expected at random on the explanatory variables (Wilson et al. 2006; Keating and Cherry 2005). These random absence locations, called pseudo-absence (as they are not true absences), are sampled within the area enveloping all depredation incidences in the village of Loibor Siret with a 1 km buffer (Figure 4, herein referred to as analysis extent). This constrained random points to areas used by predators in livestock attacks as well as pasture areas where pastoralists actively graze livestock (based on personal observation). I selected 200 points in order to ensure that the random points are representative of the landscape within the analysis extent (200 points across 360 $km^2 \approx 1/2$ pt/km^2). Additionally, I weighted random observations so that their contribution to model degrees of freedom and coefficients is equal to that of the observed points. For example, there were 29 pasture predation incidences by lions; each random point was therefore weighted by a value of 0.145 (=29/200). This is consistent with methods used by Wilson et al. (2006) and Mattson and Merrill (2004) in studies of grizzly bear conflict and habitat. Because the random points contribute equally to model specification, the resulting logits can be interpreted in straightforward odds. Values >0.5 indicate sites where odds of predation incidences are greater than expected by chance (Mattson and Merrill 2004).

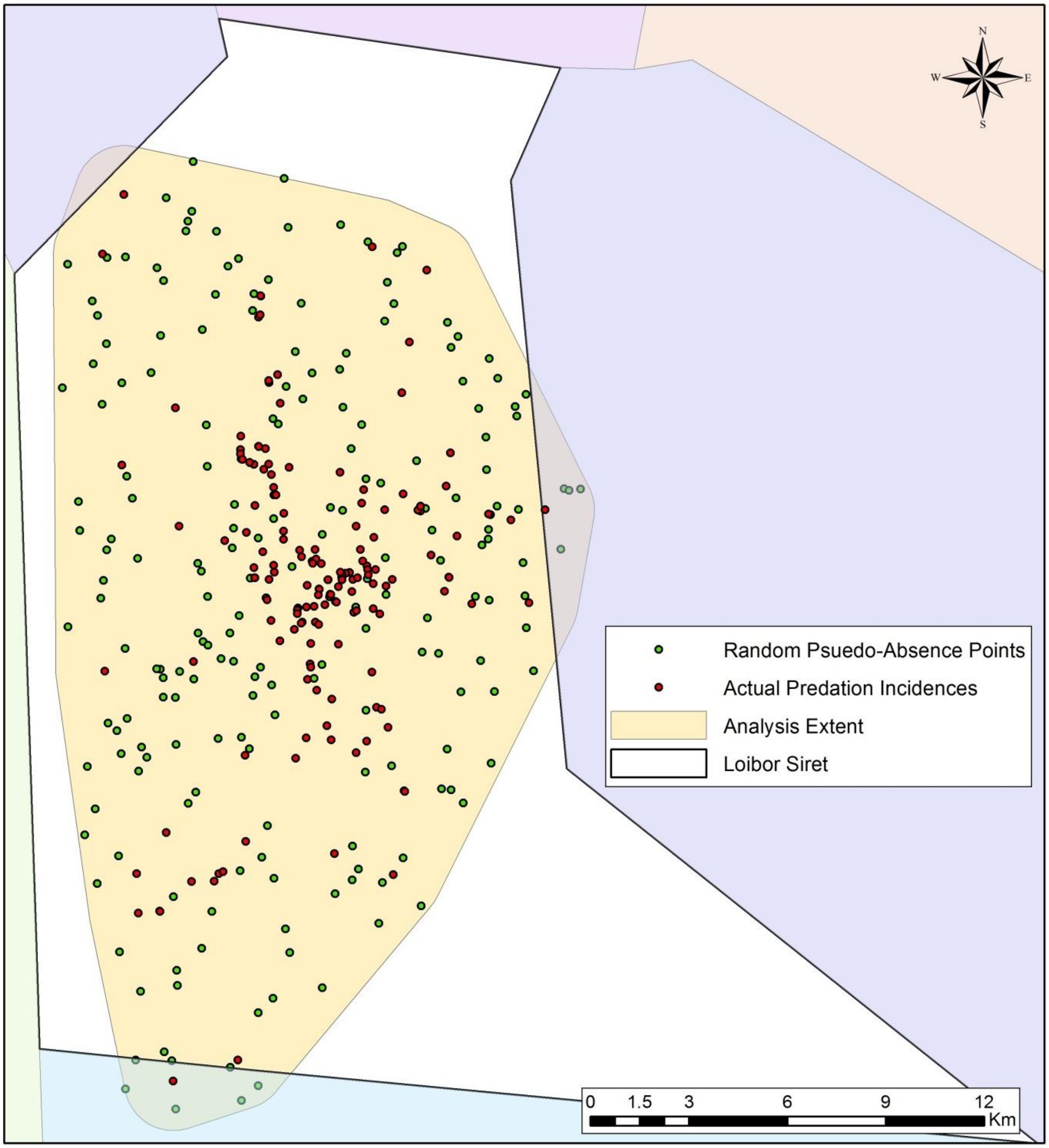


Figure 4: Analysis extent, region sampled for pseudo-absence locations. Actual predation incidences are in red, with random points in green.

7.6.2 Data Sub-setting and Model Selection

As lions, hyenas, and leopards have quite different foraging behaviors, I modeled each species separately. I additionally, sub-set datasets further based on trends revealed in the exploratory data analysis.

I used Akaike's Information Criterion (AICc), corrected for small sample sizes, to select the most parsimonious model per analyzed dataset (Burnham and Anderson 1998). As less meaningful variables were removed in turn, I assessed the change in AICc, choosing the model with the smallest value. Additionally, correlation coefficients were assessed when selecting final model inputs in order to avoid coefficient bias due to multicollinearity. When correlated variables appeared relevant in candidate models, I selected the most appropriate variable based on AICc values, p-values, and personal knowledge.

8. Results

8.1 Village Landcover Analysis

The landcover analysis of 2009 Landsat TM5 imagery reveals that 67.3% of Loibor Siret's lands are covered by woody savannah. While an accuracy assessment proved the object-based classification superior to the pixel-based classification, in line with a similar assessment by Oruc et al. (2004), I concluded an overall accuracy of 62.0% was not satisfactory (see Appendix for confusion matrices). The low classification accuracy was due to confusion between agricultural landcover and wooded savannahs. I therefore digitized all agriculture in the region and re-classified using the object-based classification approach. This resulted in a landcover layer with an overall accuracy of 78.0% for five different land cover classes (Table 4, Figure 5).

Table 4: Landcover across the village of Loibor Siret

Landcover	Area (km^2)	% of Village
Agriculture	35.8	6.5%
Dense Thickets	67.7	12.3%
Open Savannah	36.4	6.6%
Woody Savannah	370.4	67.3%
Swamp	40.0	7.3%
Total Area	550.2	100%

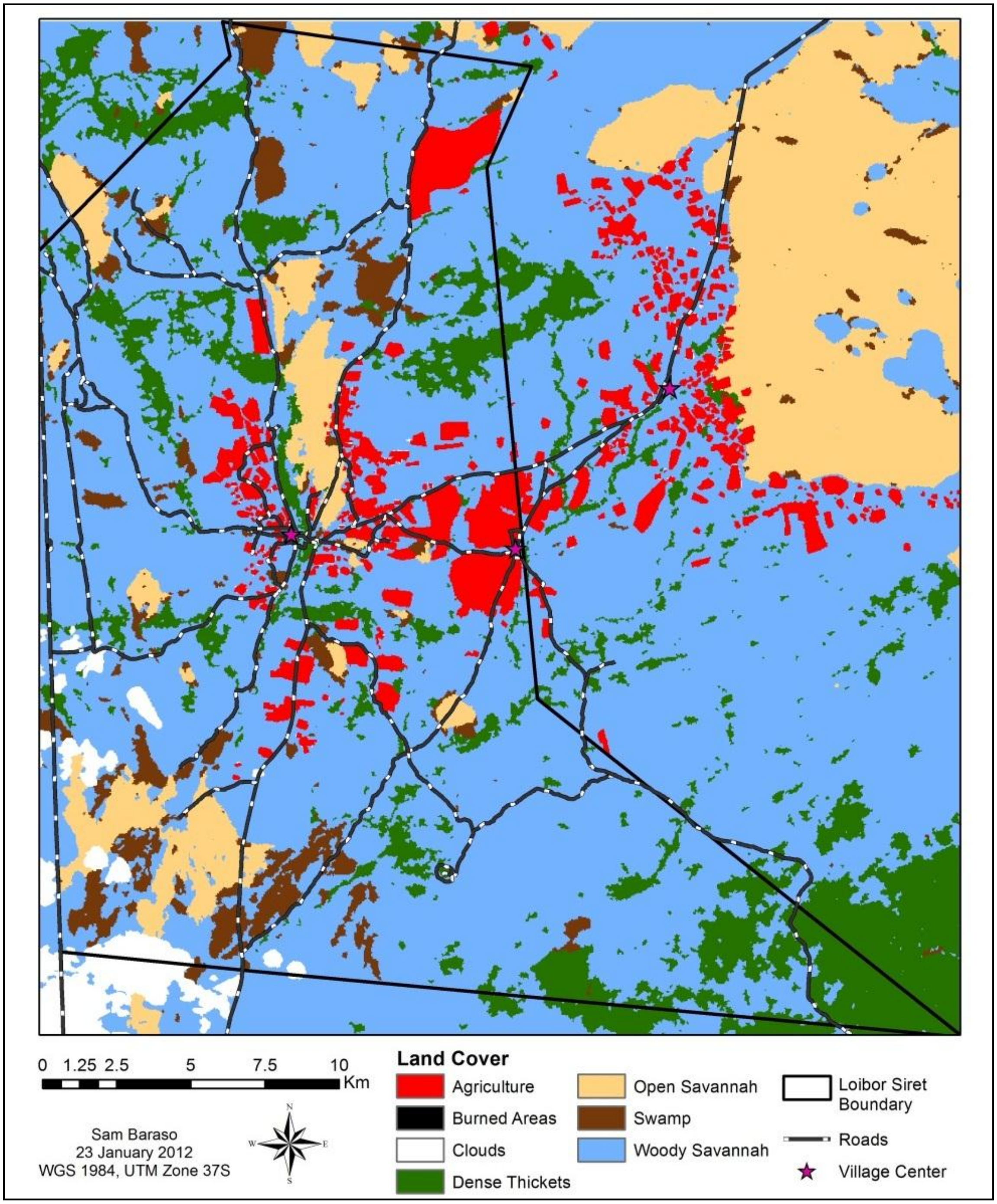


Figure 5: Landcover classification from Landsat TM5 Imagery taken November 4, 2009

8.2 Seasonal pattern of all predation incidences

The histograms in Figure 6 show the number of predation incidences by season (rainy/dry), predator, and area (boma/pasture). In ‘06/’07 the rainy season lasted for 5 months, 5 months in ‘07/’08, 7 months in ‘08/’09, 6 months in ‘09/’10, and 5 months in ‘10/’11.

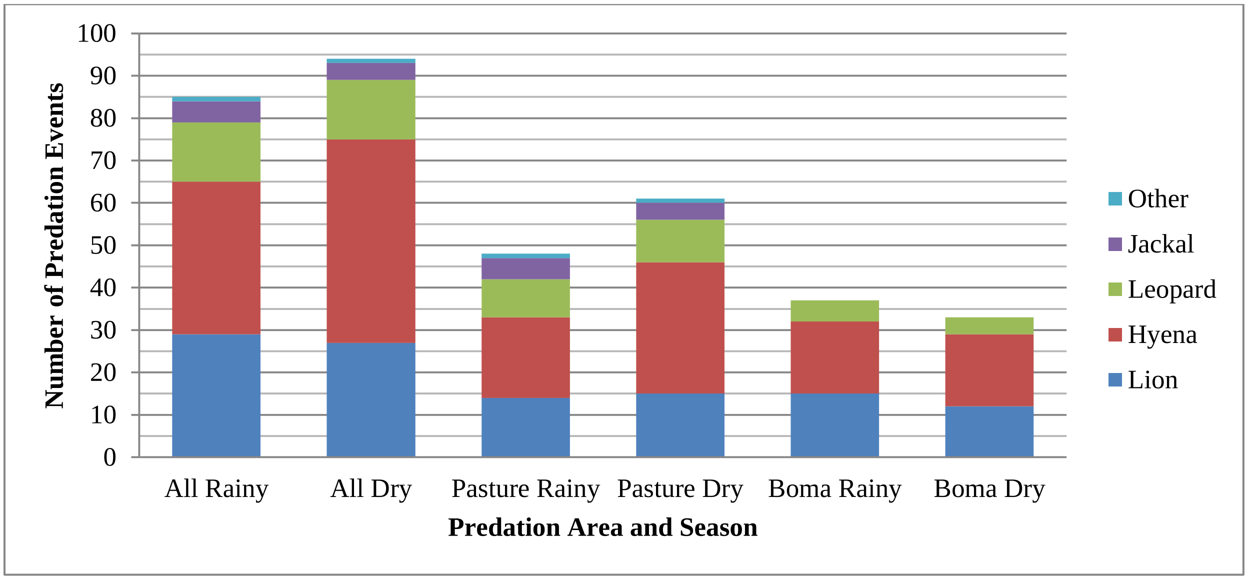


Figure 6: Predations incidences by season, predator, and area.

The plot of predation incidences across seasons indicates that seasonality has little impact in the temporal distribution of predation incidences. Further, correlation tests between precipitation and livestock lost per month revealed no significant relationship when assessing both log monthly rainfall and log 2-month trailing rainfall ($r_p = 0.11$, $p = 0.46$ and $r_p = 0.10$, $p = 0.50$, respectively) (Figure 7).

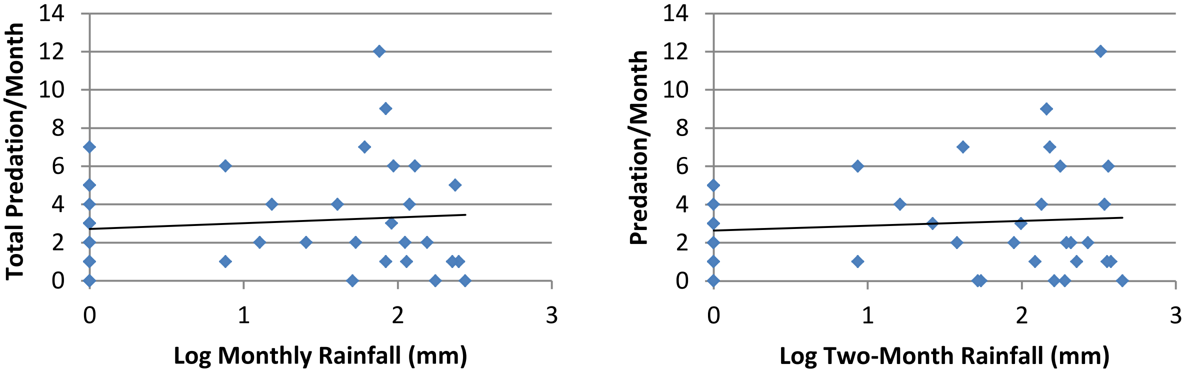


Figure 7: Monthly (logged) and 2-month rainfall (logged) vs. monthly predation incidences. Black line represents ordinary least squares fit. Neither linear nor non-linear relationships fit this this data.

8.3 Data Subset Characteristics

Kissui (2008), Patterson et al. (2004), and Ikanda and Packer (2008) among others have suggested that factors such as seasonality and time of day play a role in the nature of predation on livestock. Further, APW has treated approximately 100 bomas with Living Walls in the village of Loibor Siret, so we consider difference before and after treatment to explore whether boma fortification is impacting predation at the pasture. I therefore explore subsets of each species' predation incidences at the pasture to determine whether spatial predation characteristics differ along seasonality, night vs. day, and pre-LW vs. post-LW treatment. In addition to modeling the spatial distribution of lion, hyena, and leopard attacks, these differences guide the decision to model specific datasets per species. Figures 8 and 9 show a sample of boxplots that influenced the choice of lion and hyena dataset modeling, respectively.

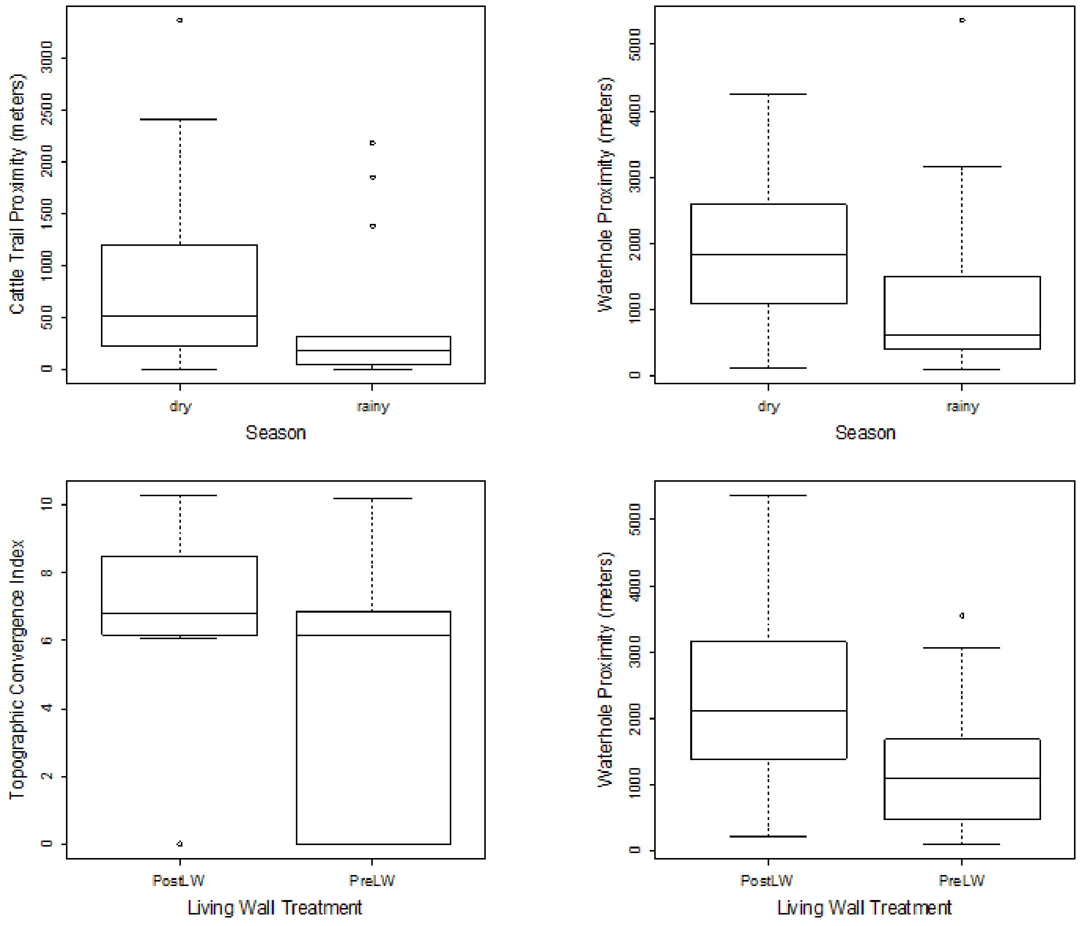


Figure 8: Lion predation variation observed in landscape features across seasons and Living Wall treatment led to separate modeling of each dataset.

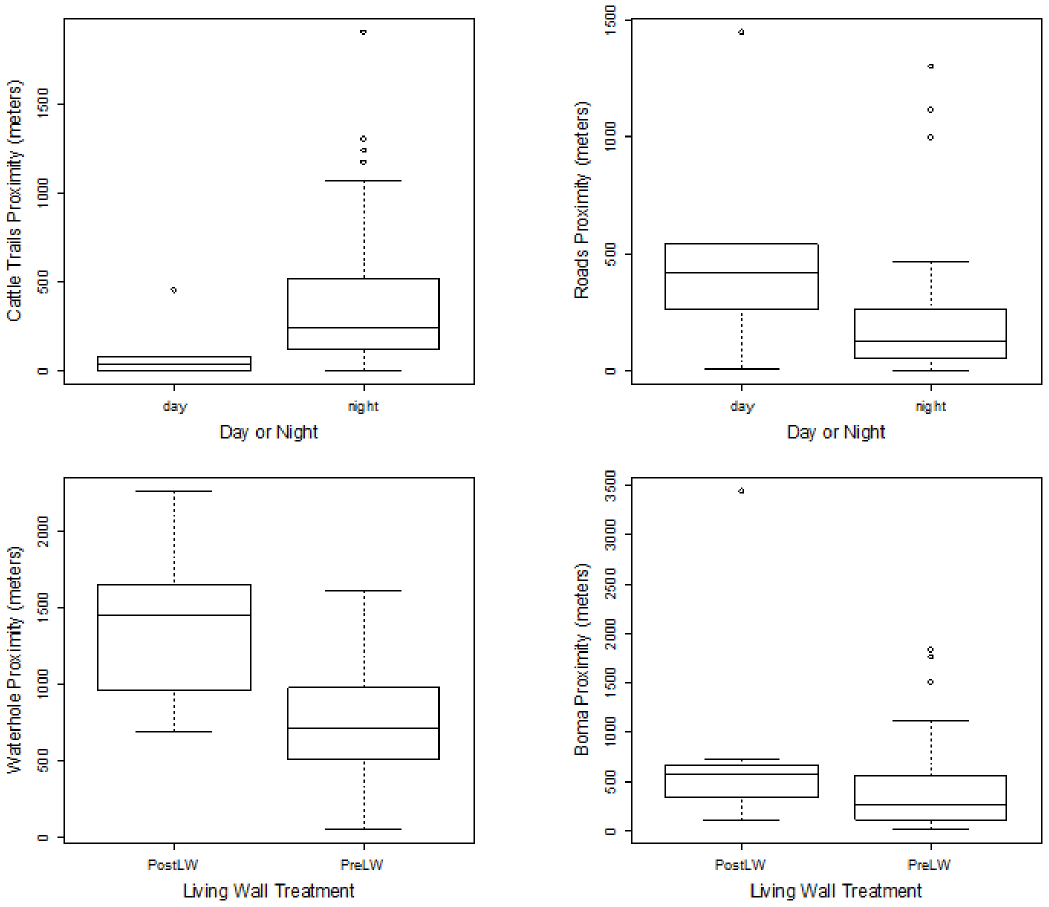


Figure 9: Hyena predation variation observed in landscape features across day/night and Living Wall treatment led to separate modeling of each dataset.

Both lion and hyena datasets revealed differences in the spatial distribution of predation incidences at pasture between the time period pre-LW treatment (pre-2009) and post-LW treatment (post-2009). As a result, these subsets of the data are modeled separately. There were also differences observed in lion predation events during the rainy vs. dry seasons. This does not correspond with predation frequency, but relates to predation location. As hyena predation events that occurred at night vs. day showed clear differences in spatial distribution, this is also assessed. The leopard dataset did not show any marked differences in spatial distribution along these factors.

Figure 10 show mapped landscape variables assessed in the analysis.

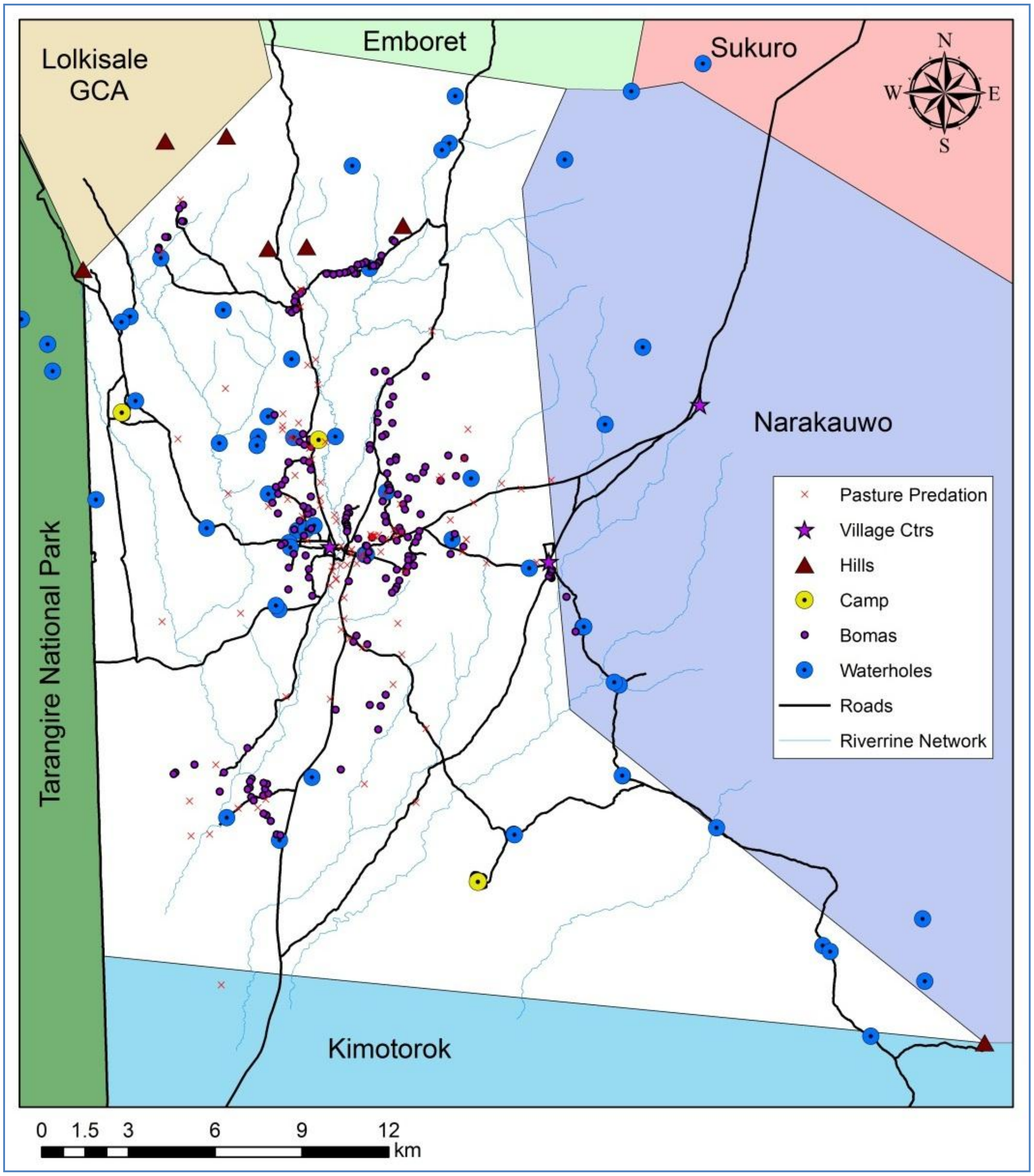


Figure 10: Landscape variables assessed in the analysis.

8.4 Landscape Features Influencing Pasture Predation

In the five years of data collection between 2006 and 2011, lions were responsible for 29 attacks at the pasture, while hyenas and leopards were responsible for 50 and 19 predation events, respectively at the pasture (Table 5).

The following sections discuss landscape variables that were relevant in predicting livestock predation at the pasture. Models are presented for each species as a whole, as well as relevant subsets per species. Variables boma, cattle trail, and road proximity were moderately correlated across all models. As stated in the methods, when more than one of these variables (boma, cattle trail, road proximity) appeared relevant in candidate models, I selected the most appropriate based on AICc values, p-values, and personal knowledge (Table 5).

8.4.1 Lion Pasture Predation

Of multiple candidate models, the most parsimonious model for predicting lion pasture predation across the entire time period was a single variable model of boma proximity ($p = 0.002$; Table 6). Cattle trail, road, and waterhole proximity are also individually significant ($p < 0.05$) in various data subsets modeled (rainy season, pre/post LW). Of note, cattle trail proximity is significant ($p < 0.05$) in the rainy season, whereas this relationship does not appear in the dry season model. Overall, lion predation events tend to occur closer to bomas, cattle trails and roads than in other areas of the landscape. Details of the most relevant models of lion predation are shown in Tables 5 and 6.

8.4.2 Hyena Pasture Predation

The most parsimonious model for hyena pasture predation includes variables boma and waterhole proximity (both $p < 0.01$). Competing models repeatedly identified that hyena attacks tend to occur closer to bomas, waterholes, and often in areas with low percentages of woody savannah (Table 5; Table 6).

8.4.3 Leopard Pasture Predation

Due to the limited sample of leopard predation incidences over the 5 year period ($n = 19$), I was only able to create one relevant model for leopard pasture predation. Boma proximity was the sole predictor for leopard predation ($p < 0.05$) (Table 5;Table 6).

Table 5: Results of logistic regression models for predicting livestock predation by species

			Landscape Variable											
Species	Data Subset	Sample Size (n)	Waterhole Proximity	Gulley (Korongo) Proximity	Woody Savannah Cover	Boma Proximity	Cattle Trail Proximity	Road Proximity	Village Center Proximity	Slope	AICc	Pseudo R^2	χ^2 p-value
Lion	All	29	+	—	—	—**	—	—		—	47.6	0.24	**0.015**
					—	—	—				40.3	0.22	**0.001**
						—***					38.0	0.19	**0.001**
	Rainy Season	14	—	+	—	—	—*	—		—	29.0	0.32	0.128
			—	+	—		—*				23.1	0.30	**0.038**
					—		—**				19.0	0.28	**0.013**
	Dry Season	15	—	+	—	—*	—	—		—	30.9	0.30	0.139
			+	—	—	—*					25.4	0.26	**0.054**
						—*					19.7	0.24	**0.020**
	Pre Living Wall	20	—		—	—	—	—		+	31.5	0.38	**0.004**
			—**					—**			23.8	0.31	**0.001**
	Post Living Wall	9				—*			+		15.9	0.19	0.184
Hyena	All	50	—**		—	—*	—*	—			41.5	0.54	**0.000**
			—***			—***					39.5	0.48	**0.000**
	Nighttime	45	—**		—*	—*	—	—			34.7	0.57	**0.000**
			—***		—*	—***					31.8	0.54	**0.000**
	Pre Living Wall	41	—**		—*	—*	—	—			29.4	0.64	**0.000**
			—***		—**	—**					24.5	0.62	**0.000**
	Post Living Wall	9	—			—	—	—			15.1	0.52	**0.024**
								—*			10.6	0.39	**0.008**
Leopard	All	19				—**					26.0	0.15	**0.022**

Note: Negative and positive signs indicate the variable occurred in the model and the sign of the variable coefficient; chi-square p-values < 0.1 shown in bold.
The last model per data subset is the optimal model based on AICc value.
*significant at 10%, **significant at 5%, ***significant at 1%

Table 6 provides details associated with the most relevant models. While most models were significant with overall chi-square p-values < 0.05, I did not present details for post-Living Wall models as there were small sample sizes (owing to the fewer predation incidences). Additionally, I did not present details associated with pre-Living wall models due to limited relevance today. Maps of probability of conflict (greater than expected by chance; value > 0.5) for the three species are presented in Figure 11. Notice that the map for hyena predation at the pasture has more concentrated hotspots likely for predation, compared to models for other predators.

Table 6: Logistic model outputs –Most relevant models

	Lion				**Hyena**				**Leopard**	
All, relevant subset	All		Rainy		All		Night-time		All	
Boma prox. (m)	-0.00093	***	--		-0.00117	***	-0.00180	***	-0.00084	**
Waterhole prox. (m)	--		--		-0.00168	****	-0.00149	***	--	
Woody savannah (%)	--		-2.95230		--		-2.79900	*	--	
Cattle trail prox (m)	--		-0.00148	**	--		--		--	
Constant	1.21854	***	3.06306	**	3.56819	****	5.39155	****	1.26567	**
Model p-value	0.001		0.013		0.000		0.000		0.022	
Pseudo R^2	0.19		0.28		0.48		0.54		0.15	
Observations	29		14		50		45		19	

Note: *significant at 10%, **significant at 5%, ***significant at 1%, ****significant at 0.1%,

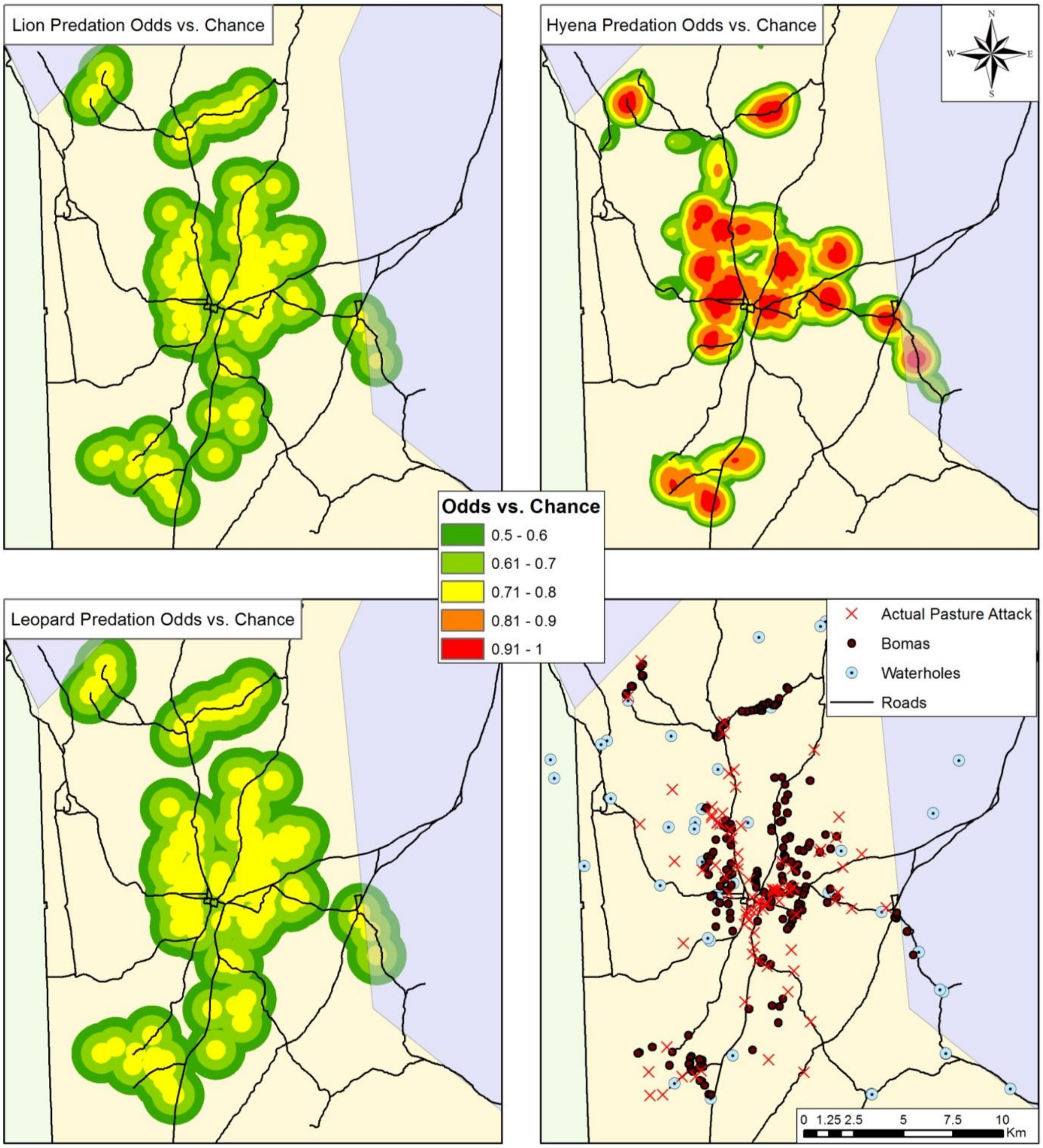


Figure 11: Maps of predation likelihood (Value > 0.5 expected by chance) based on models of all lion (top-left), all hyena (top-right), and all leopard (bottom-left) (boma and waterhole explanatory variables in bottom-right map).

8.5 Predation Trends over Time

The first pilot Living Wall was installed on a boma in October 2008 and the program began systematic installation a year later in October 2009 (Lichtenfeld unpub data).

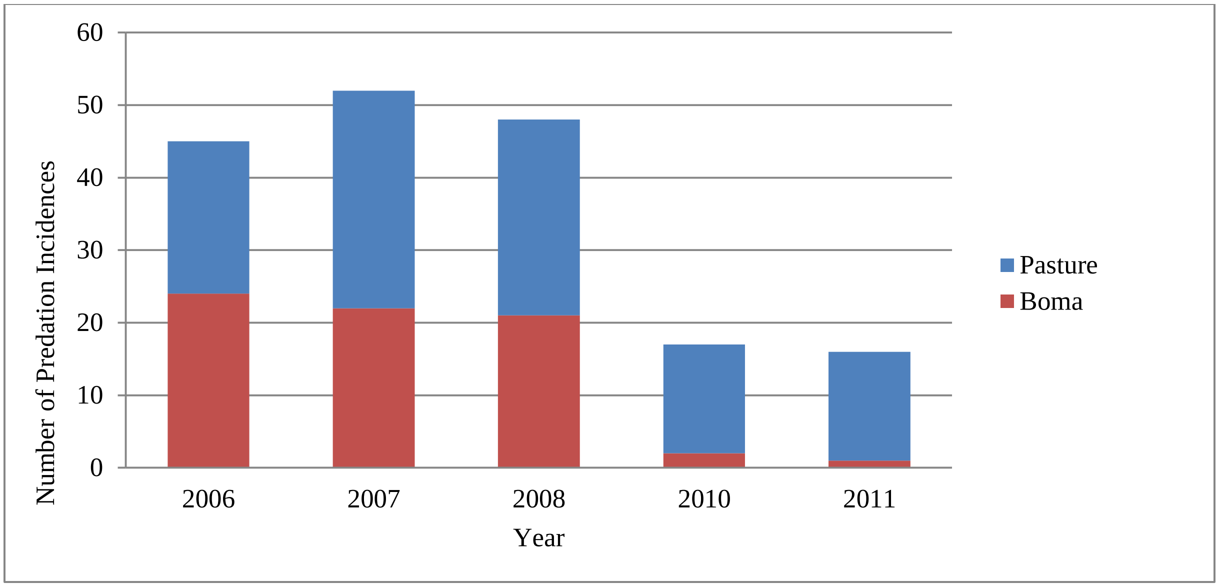


Figure 12: Total predation trends over time, at pasture and boma

Thereafter, attacks in the boma are virtually eliminated (Figure 12). As Living Walls were rolled out gradually, some bomas remained unfortified and there were two attacks in 2010 and one in 2011 in unfortified bomas. Additionally, attacks at the pasture also declined after the initiation of the Living Wall program (Figure 12; Figure 13). Figure 13 below shows a clearer trend in pasture attacks, with percent change in total pasture attacks year-over-year. Note that 2006, 2008, and 2010 represent only 9, 11, and 10 months of depredation data, respectively. As a result, these years are likely to be underestimated accordingly.

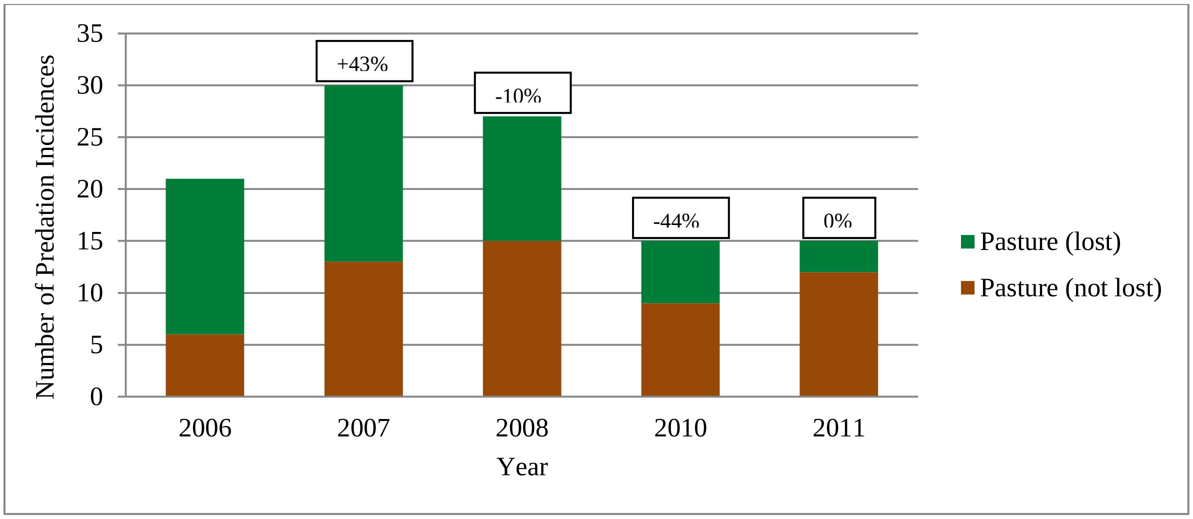


Figure 13: Total predation trends over time, at pasture

A significant portion of predation events at the pasture occurred after the livestock had been lost (Figures 13, Table 7). For the first period of monitoring, these measures were obtained from lengthy depredation narratives. As a result, it is likely that figures for 2006, 2007, and 2008 are accurate. However, data collection in the second monitoring period neither explicitly sought to characterize whether livestock had been lost prior to predation, nor had lengthy narratives. As a result, this measure for years 2010 and 2011 was ascertained from simple one-sentence event commentaries. Therefore, lost predation events were likely underestimated for 2010 and 2011.

Table 7: Pasture predation events on lost livestock

	2006	2007	2008	2010	2011
Predated at pasture after lost	15	17	12	6	3
Pasture predation total	21	30	27	15	15
Percent lost at pasture	71.4%	56.7%	44.4%	40.0%	20.0%

A regression on lost livestock predated at the pasture indicates that boma proximity is a significant predictor (p = 0.000) (Table 8). Given the portion of predation events within each species dataset associated with the "lost status", it is not surprising that boma proximity was found relevant in this context and vice versa. While understanding the environment affecting lost vs. non-lost predations is critical, limited sample sizes preclude analysis of non-lost predations per predator species.

Table 8: Logistic regression model outputs - likelihood of livestock predation on lost livestock

	Lost at Pasture	
Boma prox. (m)	-0.00159	****
Constant	1.79217	****
Chi-sqaure p-value	0.000	
Pseudo R^2	0.33	
Observations	53	

Note: ****significant at 0.1%,

9. Discussion

9.1 Seasonality

While several studies including a 2006 study by Kolowski and Holekamp near the Maasai Mara have noted a significant positive correlation between depredation frequency and rainfall, several others have failed to find a correlation be between precipitation and livestock predation (Patterson et al. 2004; Rudnai 1979). Data in my analysis does not support the existence of a relationship between predation frequency and rainfall. The plausible existence of a relationship between rainfall and depredation is related to the seasonal variation in natural prey availability (Woodroffe and Frank 2005). While wildlife in the Tarangire ecosystem are migratory, there are also many resident populations which may sustain less migratory predators (Kahurananga and Silkiluwasha 1997). Further, Patterson et al. (2004) suggest that predation and rainfall may instead be correlated within temporal scales related to large scale climate patterns. Patterson et al. (2004) were able to ascertain significant relationships between rainfall and predation within the driest year, however, no relationship was observed during El Nino years. As monitoring continues at APW and more data is collected, seasonality and precipitation should be revisited.

Anecdotal stories by several herders indicate that hyenas often attack during nights of heavy rainfall. Unfortunately, I was unable to assess this due to the temporal and spatial resolution of the rainfall data. Future predation event assessments also should explicitly inquire about rainfall surrounding the predation incident.

9.2 Landscape Feature Related to Predation

9.2.1 Lions

Results indicate that lion predation is best predicted by boma proximity, whereas rainy season predation by lions is best predicted by proximity to cattle trails and lower woody savannah cover. Unfortunately, most of these features are unavoidable since livestock must return to bomas daily for protection at night. Should they avoid the protection afforded by bomas, predation incidences will assuredly increase. What is noteworthy, however, is the significance of cattle trails in the rainy season, which do not play a role in explaining predation in the dry season. It may be the case that denser vegetation in the rainy season affords suitable cover allowing lions to stalk closer without being detected (Smuts 1978). Cattle trails would be more prone vs. roads, which are also used by livestock, as they are usually surrounded by more vegetation. Additionally, cattle trails often allow for greater dispersion of livestock, whereas roads concentrate livestock on paths of least resistance, allowing herders to more easily keep visual contact (personal observation). The coefficient on woody savannah cover indicates that lion predation in the rainy season was more likely to occur in dense thickets or agricultural plots, however the coefficient was not significant ($p = 0.13$).

Figure 11 showed that the model for lion predation did not predict a value in the highest probability class (0.9-1) anywhere in the village, indicating that the model is leaving quite a bit unexplained. Additionally, areas with lower probabilities align with areas most commonly occupied by livestock. As a result, it is not possible to discern whether lions are preferentially occupying areas near bomas to prey on livestock or opportunistically attacking livestock. Based on optimal foraging theory, it is more likely that lions simply attack livestock when they are encountered, when perceived threats are lower (i.e. herder not in plain view) (Pyke et al. 1977; Packer 2009).

9.2.2 Hyenas

Hyena predation was most closely linked with boma and waterhole proximity, as well as percent woody savannah cover in modeled subsets of the data. Similar to lion predation incidences, the explanatory variables relate equally well to livestock presence. As a result, it is difficult to parse out whether hyenas are preferentially predating on livestock in certain areas vs. random chance. However, comparison of hyena predation likelihood models (and maps) with that of the lion indicate that the two species have different spatial patterns of attack. Hyena models are able to predict probabilities closer to 1indicating that the models predict predation with greater likelihood. This is particularly relevant given the significance of boma proximity. Consistent with our model, Kolowski and Holekamp (2006) observed hyenas at ease within 50 m of humans and sleeping for extended periods within 150 m of bomas.

While woody savannah cover was a significant explanatory variable (negative coefficient), there is likely weak omitted variable bias due to its correlation with agricultural cover ($r_p = -0.34$) and dense thicket cover ($r_p = -0.20$). This would be consistent with Boydston et al. (2003) and Pangle and Holekamp (2010) who found hyenas closer to dense vegetation in areas of higher human activity.

9.2.3 Leopards

Although the small sample size associated with leopards was small (n= 19), boma proximity was a significant explanatory variable was with a p-value = 0.018. Similar to the lion models, predation incidences for the leopard appear random after factoring the spatial distribution of cattle.

9.2.4 Study Limitations

Coundon and Gegout (2007) concluded that at least 50 observations of species occurrence are needed for accurate species predication with logistic regression. However, several others have suggested methods requiring as few as 30 observations to produce acceptable results (Elith et al., 2006; Kremen et al. 2008, Wisz et al. 2008). Despite violating even the lower sample bound in several models, I believe results are robust as one to three variables are used to model predation likelihood, limiting degrees of freedom. Further, coefficients in most models were significant at 5%. Additionally, extra caution was taken to limit bias associated with uneven contribution associated with absence points (via weighing; see Statistical Analysis), while sampling adequately to represent the landscape (Mattson and Merrill 2004; Keating and Cherry 2005).

Predators attack livestock when natural prey is unavailable (Petterson et al. 2004). Unfortunately, prey information was not available for this study. Additionally, I did not have temporal distribution of livestock nor spatial distribution of livestock with sufficient resolution. These two pieces of data would have improved modeling of predation likelihood by parsing out the attacks expected solely due to livestock presence.

9.2.5 Lost Animals

As noted in the results, a large portion of animals predated at the pasture were lost prior to predation. While this data is incomplete, it has implications that point beyond landscape features influencing predation. Kissui (2008) also reports lost livestock as a predation context, yet, excluded the data for analysis due to small sample size. Conversely, my sample size for lost pasture predations was large enough to model. Boma proximity played a significant role in predicting pasture predation on lost animals. Further, of the 57 (out of 108) pasture predation events occurring at night, 72% (n = 41) of animals were lost. Hyenas were responsible for 33 of these 41 lost predations at night. On the other hand, only 24% of animals were lost in pasture predation events during the day. As a result, it appears that most livestock are lost when returning to the boma in the evening. Based on anecdotal evidence, one can suppose the following story:

Livestock, like many other animals, develop an understanding of home. Livestock herds are usually led by a lead animal, likely cattle, and Maasai herders, whom keep them together (Lichtenfeld pers. comm). As herds return home, often the lead animal picks up pace (as opposed to when the animal goes out to pasture) (personal observation). In the village of Loibor Siret, this implies 60,000 livestock moving at a faster pace, mostly in the same direction -- recall from the maps that the bomas are spatially concentrated along the main riverine (gulley) running through the center of the village. As herds collide in their rush to get home, they swell in size and thousands of cattle compete for limited space. With this picture, it may be easy to understand how one loses a single animal.

We know that 65% of lion predation events at pasture occur during the day, vs. 10% hyena predation during the day. As a result, lions are more prone to retaliatory killings. This is consistent with Kissui (2008). However, ~50% (53/108) of pasture predation events occur after an animal is lost. In contrast to other studies, this may be associated with the habitat in Loibor Siret, which varies significantly from its neighboring villages. Mixed with dense thickets and woody savannah, it is easier to lose animals here than in the open plains to the south in Kimotorok.

We also see the proportion of lost animal predated at pasture decline from 71% in 2006 to 20% in 2011. There are a host of reasons that may explain this. As mentioned earlier, underreporting in the second monitoring period may be to blame. On the other hand, Living Walls may be facilitating better sleep at night and therefore better vigilance during the day (Lichtenfeld pers. comm.). Given the proportion of pasture predation on lost animals, understanding the context surrounding “lost animals” is a critical area that necessitates greater inquiry. Conflict officers should begin explicitly asking whether animals were lost or not prior to pasture predation.

9.3 Herder Age/Numbers

While herder age and count associated with predation incidences was recorded in the second monitoring period, wide age classes and limited data restricted analysis. Age classes were classified as:

- Male/female 11-15 years, male/female 16-25 years, male/female 25+ years

Of the 30 pasture predation events in the second monitoring period, only one had a record of a boy (11-15 yrs) without a male herder over 15 years old. However, ten incidences had no records of any herders or ages. As it is improbable that a herd would be completely unattended, this represents unreported data precluding analysis. Ikanda and Packer (2008), however, noted significant differences in herds managed by children vs. herds managed by Moranis, older Maasai members of the warrior class. In the study, herds tended by children suffered greater predation events. Future monitoring and assessments should pay particular attention to herder ages and numbers.

9.4 Living Walls

Living Walls show a clear impact on predation at the boma. In the first year of the program, it appears that Living Walls reduce predation at the boma >90% (Lichtenfeld unpub data). Further, it appears Living Walls are impacting predation at the pasture. While the causal mechanism remains unclear, this would have profound impacts for Living Walls, livestock, and predators. With 25,000 head of livestock protected by 100 Living Walls as of 2011, Living Walls should expand to other permanent bomas across the Maasai Steppe to protect the approximately one million head of cattle and numerous other livestock (Lichtenfeld unpub data; Sachedina 2006).

There remain other plausible explanations, however. The installation of Living Walls may be allowing herders to sleep better at night. This could result in more vigilant herding during the day (Lichtenfeld pers. comm.). There is also the possibility that prey numbers in the village have increased resulting in reduced predation pressure on livestock (Petterson et al. 2004; Smuts 1978). Conversely, predator numbers could have declined. While a decline in predators is unlikely to show the drastic drop in predation observed at the boma, it may be responsible for the resulting drop in predation at the pasture. In order to test these hypotheses, as well as the effectiveness of Living Walls, both prey and predator numbers must be assessed across the village. APW is currently conducting long-term monitoring of both predator and prey populations. Once numbers are compiled and assessed, we will have a better picture regarding the causal mechanism of Living Walls and pasture predation.

9.5 Alternative Mitigation Strategies

Fortified corrals, audio deterrents, visual deterrents, dogs, donkeys, herder education, compensation schemes, and many other mitigation strategies have been suggested by numerous lion experts to minimize livestock predation. However, few empirical studies have been conducted assessing the effectiveness of proposed strategies (Chardonnet et al. 2010). Of the few studies that address some of these strategies (Ikana and Packs 2008; Kolowski and Holekamp 2006; Ogada et al. 2003; Kissui 2008), none have yet to prove one of these strategies effective with the exception of fortified corrals (Lichtenfeld unpub data; Packer 2009). At a cost of $300-$600 USD per boma, one Living Wall roughly equates to the cost of one adult bull (est. 2011 prices). Given the losses some households have sustained at the boma, the financial argument is clear.

With fewer strategies proposed for attacks at the pasture, improvement of herder knowledge and behavior is an obvious first step. It is likely that the mere presence of APW within the village of Loibor Siret has shifted attitudes and reactions to predators. By leveraging such relationships, education will play a key role in minimizing conflict and sustaining lion populations.

9.6 Water Availability and Climate Change

East African savannahs are water-limited ecosystems due to seasonal variation in rainfall. As a result, they are most vulnerable to climate change (Sankaran et al. 2005). Further, human and livestock populations in Loibor Siret have increased rapidly as has human-wildlife conflict. With decreased water availability predicted in the future, there will inevitably be closer interactions between humans, livestock and wildlife as they vie for a shared, critical resource. Such tensions are likely to result in greater amounts of retaliatory killing (Kissui 2008). It is therefore critical to mitigate the root causes of livestock depredation. Mitigating conflict both at the boma and pasture should promote more sustainable coexistence despite increased droughts.

9.7 Implications

In the village of Loibor Siret, livestock are taken from the bomas to pasture daily. In addition, they are taken to various waterholes at least once every two days (Lichtenfeld pers. comm). As a result, features associated with predation for all three predators cannot be avoided. However, herders should take greater vigilance near both waterholes and bomas. It is clear that predation at the boma can be eliminated. Attacks at the pasture have also declined. These trends argue well for livestock, lions, leopards, hyenas, and the Maasai. Whether due to Living Walls, APW, or mere chance, the outlook for lions in Loibor Siret is improving pending an update on their numbers and distribution.

With large carnivores sharing territory with pastoralists, livestock predation at some level is inevitable, as is some retaliation. Tanzania is home to almost half the population of lions (Riggio et al. unpub data). This is not likely mere coincidence. Pastoral communities like the Maasai are therefore critical towards to survival of lions outside of protected parks. With effective strategies, lions can survive, as will the Maasai and their cattle.

Literature Cited

Bailey, T. N. (1993). The African Leopard: Ecology and Behavior. New York: Columbia University Press.

Bauer, H. Nowell, K., and Packer, C. (2008). Panthera leo. IUCN Red List of Threatened Species. Version 2011.2.

Boydston, E. E., Kapheim, K. M., Watts, H. E., Szykman, M., and Holekamp, K. E. (2003). Altered behaviour in spotted hyena associated with increased human activity. Animal Conservation. 6: 207-219.

Burnham, K.P., Anderson, D.R., (1998). Model Selection and Inference: A Practical Information-theoretic Approach. Springer Verlag, New York, NY.

Chardonnet, P., Soto, B., Fritz, H., Crosmary, W., Drouet-Hoguet, N., Mesochina, P., et al. (2010). Managing the Conflict between People and Lion: Review and insights from the literature and field experience. FAO. Wildlife Management Working Paper 13.

Coudun, C. and Gegout, J. C. (2007). Quantitative prediction of the distribution and abundance of Vaccinium myrtillus with climatic and edaphic factors. Journal of Vegetation Science. 18: 517-524.

Elith, J., Graham, C. H., Anderson, R. P. et al. (2006). Novel methods improve prediction of species distributions from occurrence data. Ecography. 29: 129-151.

Elliott, J. P., I. M. Cowan, and C. S. Holling. 1977. Prey capture by the African lion. Canadian Journal of Zoology. 55:1811-1828.

Franklin, J. (2009). Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, UK.

Graham, K., Beckerman, A. P., and Thirgood, S. (2005). Human-predator-prey conflicts: ecological correlates, prey losses and patterns of management. Biological Conservation. 122: 159-171.

Henschel, J. R. and Tilson R. L. (1988). How much does a spotted hyaena eat? Perspective from the Namib Desert. African Journal of Ecology. 26: 247-255.

Holekamp, K. E., Smale, L., Berg, R., and Cooper, S. M. (1997). Hunting rates and hunting success in the spotted hyena (Crocuta crocuta). Journal of Zoology. 242: 1-15.

Ikanda, D.K. and Packer, C. (2008). Ritual vs. retaliatory killing of African lions in the Ngorongoro Conservation Area, Tanzania. End. Spec. Res. 6: 67-74.

Kahurananga, J. and Silkiluwasha, F. (1997). The migration of zebra and wildebeest between Tarangire national park and Simanjiro plains, Northern Tanzania, in 1972 and recent trends. African Journal of Ecology. 35: 179-185.

Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68:774-789.

Kissui, B. M. (2008). Livestock predation by lions, leopards, spotted hyenas, and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. Animal Conservation. 11:1-11.

Kolowski, J. M. and Holekamp, K. E. (2006). Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biological Conservation.128: 529-541.

Kremen, C., Cameron, A., Moilanen, A. et al. (2008). Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. Science. 320: 222-226.

Lichtenfeld, L., L. (2005). Our Shared Kingdom At Risk: Human–Lion Relationships in the 21st Century. Yale University.

Lichtenfeld, L., L. (2012). Untitled. Unpublished.

Maddox, T. (2003). The ecology of cheetahs and other large carnivores in a pastoralist-dominated buffer zone. Unpublished Ph.D. thesis, University of London.

Mattson, D.J., and Merrill, T. (2004). A model-based appraisal of habitat conditions for grizzly bear in the Cabinet-Yaak region of Montana and Idaho. Ursus. 15: 76–89.

McCabe, J.T. (2003). Sustainability and livelihood diversification among the Maasai of northern Tanzania. Human Organization. 62 (2):100-111.

Mésochina, P., Mbangwa, O., Chardonnet, P., Mosha, R., Mtui, B., et al. (2010). Conservation status of the lion (Panthera leo Linnaeus, 1758) in Tanzania. Wildlife Division & IGF Fondation, Paris.

Msoffe, F. U., Said, M., Ogutu, J., Shem, K., Leeuw, J., Gardingen, P., Reid, R. (2011). Spatial correlates of land-use changes in the Maasai-Steppe of Tanzania: Implications for conservation and environmental planning. International Journal of Biodiversity and Conservation. 3: 280-290.

Myers, N. (1975). “The silent savannahs.” International Wildlife. 5 (5): 5-10.

National Bureau of Statistics, Ministry of Planning, Dar es Salaam. (2006) “Tanzania Population and Housing Census 2002.” Volume X,
<http://www.nbs.go.tz/takwimu/references/2002popcensus.pdf>

Norton-Griffiths, M., Herlocker, D. & Pennycuick, L. (1975). The patterns of rainfall in the Serengeti ecosystem, Tanzania. East Afr. Wildl. J., 13, 347–374.

Ogada, M. O., Woodroffe, R., Oguge, N. O., Frank, L. (2003). Limiting Depredation by African Carnivores: the Role of Livestock Husbandry. Conservation Biology. 17: 1521-1530.

Oruc, M., Marangoz, A., M., Buyuksalih, G. (2004). Comparison of Pixel-based and Object-oriented classification approaches using Landsat-7 ETM Spectral Bands. ISPRS. Proceedings of Commission IV. 1118-1122.

Owen-Smith, N. and Mills, M. G. L. (2008). Predator–prey size relationships in an African large-mammal food web. Journal of Animal Ecology. 77: 177-183.

Packer, C. (2009). Managing Human-Lion Conflicts (Session V: Predators and Prey: Integrating Predator and Prey Management to Achieve Conservation Objectives). Transactions of the 72nd North American Wildlife and Natural Resources Conference : 1-12.

Pangle, W. M., Holekamp, K. E. (2010). Lethal and non-lethal anthropogenic effects on spotted hyenas in the Masai Mara National Reserve. Journal of Mammalogy. 91: 154-164.

Patterson, B.D., Kasiki, S.M., Selempo, E., Kays, R.W. (2004). Livestock depredation by lions (Panthera leo) and other carnivores on ranches neighboring Tsavo National Parks, Kenya. Biological Conservation 119, 507–516.

Pyke, G.H., Pulliam, H.R. & Charnov, E.L. (1977). Optimal foraging – selective review of theory and tests. Quarterly Review of Biology. 52: 137–154.

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0,<http://www.R-project.org/>

Rapson, J. A., Bernard, R. T. F. (2007). Interpreting the diet of lions (Panthera leo); a comparison of various methods of analysis. S Afr J Wildl Res 37:179–187.

Riggio, J., Jacobson, A., Dollar, L., Bauer, H., Dickman, A., Funston, P., Henschel, P., de Iongh, H., Lichtenfeld, L., & Pimm, S. (2012).“The size of savannah Africa: a lion’s view.” Unpublished.

Rudnai, J. (1979). Ecology of lions in Nairobi National Park and the adjoining Kitengela Conservation Unit in Kena. African Journal of Ecology. 17: 85–95.

Sachedina, H. (2006). Conservation, land rights and livelihoods in the Tarangire ecosystem of Tanzania: increasing incentives for non-conservation compatible land use change through conservation policy. In Pastoralism and poverty reduction in East Africa: A Policy Research Conference, June 27–28th, 2006. Safari Park Hotel, Nairobi, Kenya: International Livestock Research Institute.

Sankaran, M., N. P. Hanan, R. J. Scholes, J. Ratnam, D. J. Augustine, B. S. Cade, J., et al. (2005). Determinants of woody cover in African savannas. Nature. 438 (7069): 846-849.

Stander, P.E. (1992). Foraging dynamics of lions in a semi-arid environment. Canadian Journal of Zoology, 70, 8–21.

Smuts, G. L. (1978). Interrelations between Predators, Prey, and Their Environment. BioScience. 28 (5): 316-320 .

TANAPA. Tanzania National Parks: The Official Website. <http://www.tanzaniaparks.com/> Accessed 4/22/2012.

Tarboton, D. G., Bras R. L., and Rodriguez-Iturbe, I. (1991). On the extraction of channel networks from digital elevation data. Hydrological Processes. 5: 81-100.

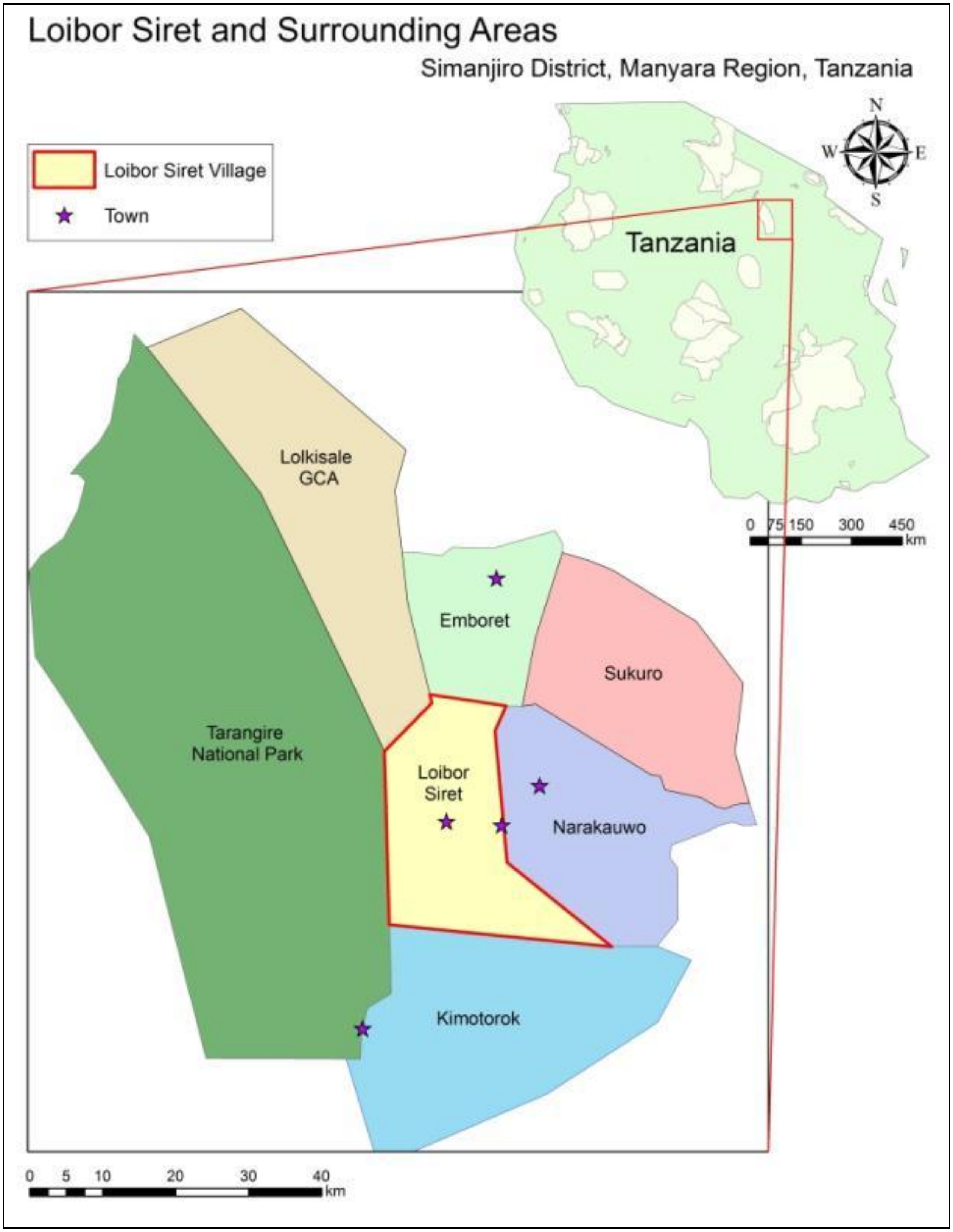
Western, D. (1975). Water availability and its influence on the structure and dynamics of a savannah large mammal community. African Journal of Ecology, 13: 265–286.

Wilson, S. M., Madel, M. J., Mattson, D. J., Graham, J. M., and Merrill, T. (2006). Landscape conditions predisposing grizzly bears to conflicts on private agricultural lands in the western USA. Biological Conservation. 130: 47-59.

Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., & Guisan, A. (2008b). Effect of sample size on the performance of species distribution models. Diversity and Distributions. 14: 763-773.

Woodroffe, R., Frank, L. (2005). Lethal Control of African Lions (Panthera Leo): local and regional population impacts. Animal Conservation. 8: 91-98.

Appendix A – Study Area and surrounding area



Appendix B – Landsat Imagery Classification Confusion Matrices

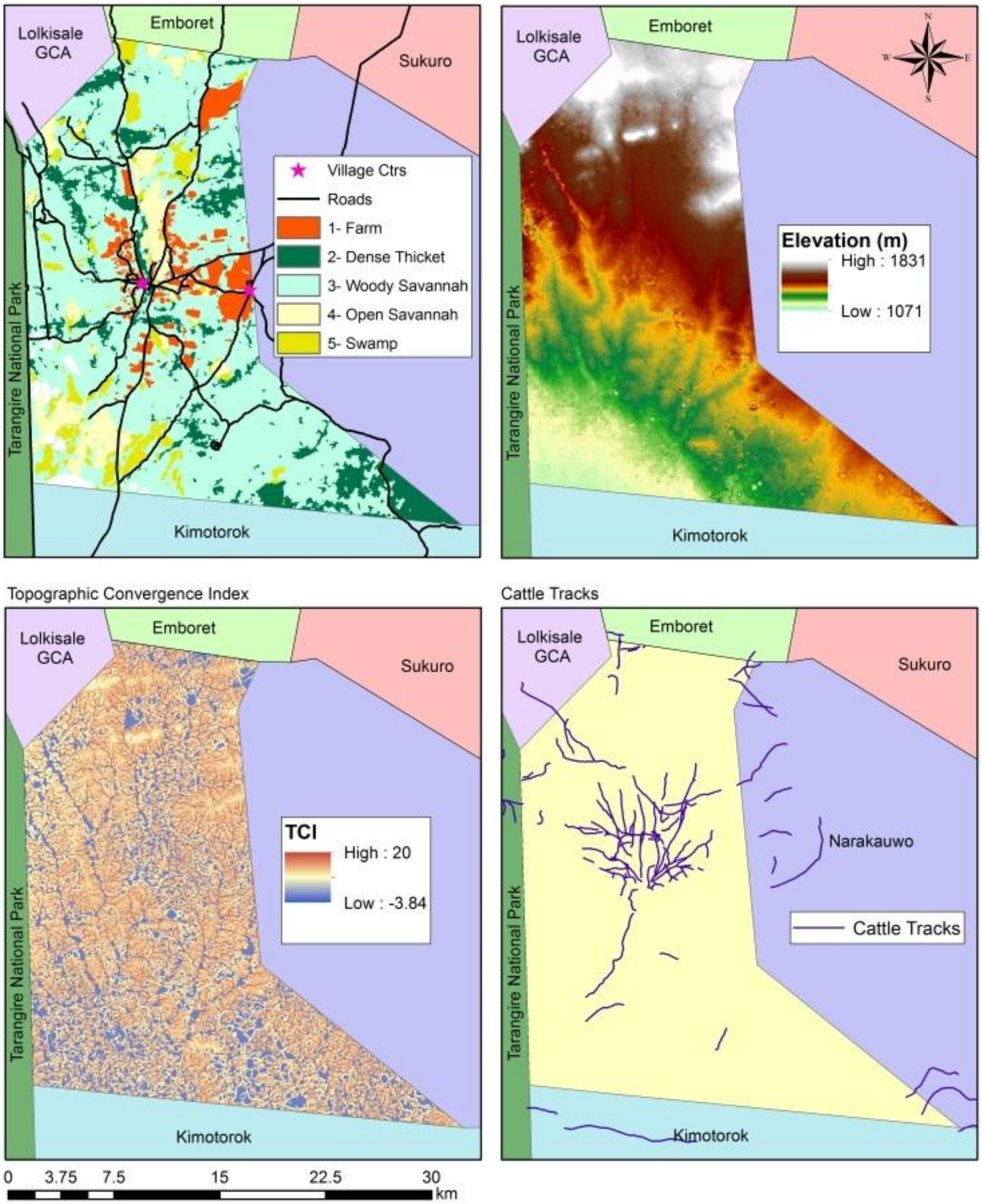
Original Object-based classification accuracy assessment

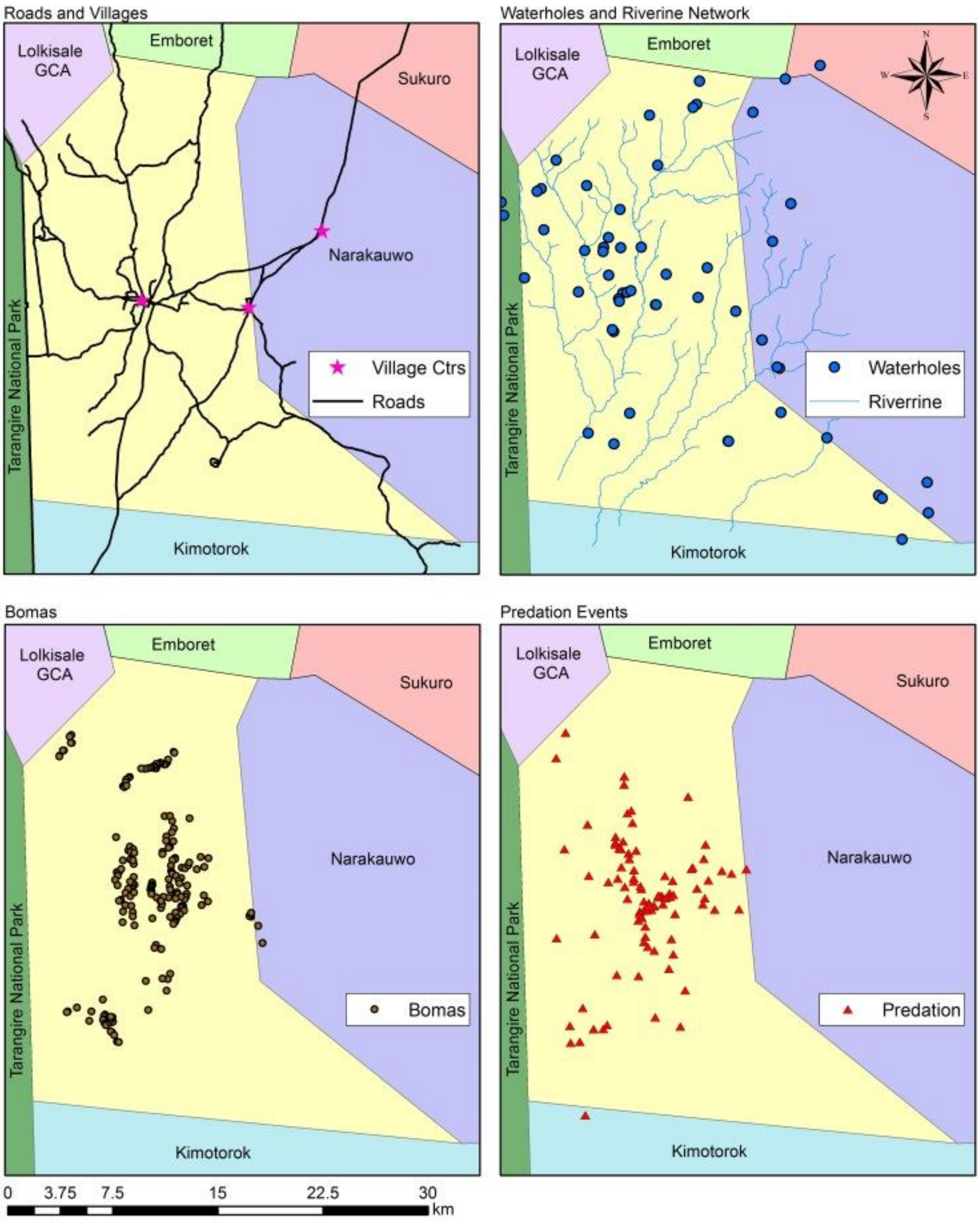
	Google Earth Ground-Truth Points						
Object-based Classification	Active Farms	Fallow Farms	Dense Thickets	Open Savannah	Woody Savannah	Swamp	**Users Accuracy**
Active Farms	**13**	1	1	0	10	0	52.0%
Fallow Farms	0	**7**	0	0	17	0	29.2%
Dense Thickets	0	0	**22**	0	4	0	84.6%
Open Savannah	0	0	0	**23**	2	0	92.0%
Woody Savannah	1	1	0	0	**23**	0	92.0%
Swamp	0	0	1	5	14	**5**	20.0%
Producers Accuracy	92.9%	77.8%	91.7%	82.1%	32.9%	100.0%	
Overall Accuracy	62.0%						
kappa statistic	54.4%						

Modified (agriculture digitized) Object-based classification accuracy assessment

	Google Earth Ground-Truth Points					
Object-based Classification	Agriculture	Dense Thickets	Open Savannah	Woody Savannah	Swamp	**Users Accuracy**
Agriculture	**25**	1	0	4	0	83.3%
Dense Thickets	2	**28**	0	0	0	93.3%
Open Savannah	1	0	**26**	1	2	86.7%
Woody Savannah	5	2	1	**22**	0	73.3%
Swamp	3	0	10	1	**16**	53.3%
Producers Accuracy	69.4%	90.3%	70.3%	78.6%	88.9%	
Overall Accuracy	78.0%					
kappa statistic	72.5%					

Appendix C – Maps of additional variables assessed, including elevation and Topographic convergence index




Roads and Villages
Waterholes and Riverine Network
Bomas
Predation Events
Lolkisale GCA
Emboret
Sukuro
Narakauwo
Tarangire National Park
Kimotorok
N
S
E
W
★ Village Ctrs
Roads
● Waterholes
Riverine
● Bomas
▲ Predation
0
3.75
7.5
15
22.5
30
km

Appendix D – Table of Pearson's Correlation Coefficients between landscape features

	DEM	SLOPE	TCI_MASKED	ALLTRX_DIS	CATTLE_TRA	ALL_ROADS_	MAIN_ROADS	ALLWATER_D	WATERHOLE_
DEM	1	0.063661916	0.25584871	-0.21243121	-0.30475291	-0.02888082	-0.28678918	-0.311212316	-0.31813596
SLOPE	0.06366192	1	-0.03665387	0.18313084	-0.02760568	0.19301884	0.11601636	-0.008144251	-0.01729545
TCI_MASKED	0.25584871	-0.036653871	1	-0.10424691	-0.17833659	-0.04345986	-0.04346739	0.054530066	0.05412966
ALLTRX_DIS	-0.21243121	0.183130842	-0.10424691	1	0.58916785	0.85615445	0.56020702	0.491229756	0.47669505
CATTLE_TRA	-0.30475291	-0.027605678	-0.17833659	0.58916785	1	0.38803468	0.46550541	0.492098112	0.47980492
ALL_ROADS_	-0.02888082	0.193018844	-0.04345986	0.85615445	0.38803468	1	0.53536427	0.505983682	0.49234039
MAIN_ROADS	-0.28678918	0.116016359	-0.04346739	0.56020702	0.46550541	0.53536427	1	0.389015435	0.36943167
ALLWATER_D	-0.31121232	-0.008144251	0.05453007	0.49122976	0.49209811	0.50598368	0.38901543	1	0.99363895
WATERHOLE_	-0.31813596	-0.01729545	0.05412966	0.47669505	0.47980492	0.49234039	0.36943167	0.993638945	1
BOMA_DIST	-0.34023485	0.121538171	-0.12601758	0.55920888	0.55069293	0.52666905	0.45209988	0.666580743	0.65139019
RIVERRINE_	-0.18071922	-0.05601667	-0.14824403	0.09802427	-0.04282542	0.21044081	0.08510154	0.019912856	0.01591084
TARANGIRE_	0.50322852	-0.205707522	0.17093436	-0.23223029	-0.07727162	-0.09426965	-0.5600328	-0.100479075	-0.09360049
VILLAGE_DI	-0.23748093	0.113488108	-0.13252747	0.51231657	0.36519732	0.47783045	0.3270599	0.629223937	0.60912309
LANDCLASS3	-0.10451251	-0.007702449	-0.05231517	0.11819116	0.14649575	0.05318063	0.18847514	0.096765131	0.08298136
MJ_LANDCLA	-0.05838636	-0.01549888	-0.01086113	0.0930792	0.14433059	0.04131965	0.19860766	0.123786206	0.11033956
FARM_RATIO	0.19601544	-0.140768196	-0.06343985	-0.36084782	-0.25805673	-0.29689593	-0.39649621	-0.39664415	-0.39024459
DENSE_THIC	0.16704406	0.141573847	0.0446481	0.03983028	-0.05172879	0.07554882	-0.03607941	0.00618808	0.01018272
WOODY_SAVA	0.1026803	0.058576436	0.20099536	-0.06393867	0.14597146	-0.07178507	0.14632343	0.109863785	0.10811315

	BOMA_DIST	RIVERRINE_	TARANGIRE_	VILLAGE_DI	LANDCLASS3	MJ_LANDCLA	FARM_RATIO	DENSE_THIC	WOODY_SAVA
DEM	-0.34023485	-0.18071922	0.50322852	-0.23748093	-0.104512514	-0.05838636	0.19601544	0.16704406	0.1026803
SLOPE	0.12153817	-0.05601667	-0.20570752	0.11348811	-0.007702449	-0.01549888	-0.1407682	0.14157385	0.05857644
TCI_MASKED	-0.12601758	-0.14824403	0.17093436	-0.13252747	-0.052315165	-0.01086113	-0.06343985	0.0446481	0.20099536
ALLTRX_DIS	0.55920888	0.09802427	-0.23223029	0.51231657	0.118191163	0.0930792	-0.36084782	0.03983028	-0.06393867
CATTLE_TRA	0.55069293	-0.04282542	-0.07727162	0.36519732	0.146495746	0.14433059	-0.25805673	-0.05172879	0.14597146
ALL_ROADS_	0.52666905	0.21044081	-0.09426965	0.47783045	0.05318063	0.04131965	-0.29689593	0.07554882	-0.07178507
MAIN_ROADS	0.45209988	0.08510154	-0.5600328	0.3270599	0.188475136	0.19860766	-0.39649621	-0.03607941	0.14632343
ALLWATER_D	0.66658074	0.01991286	-0.10047907	0.62922394	0.096765131	0.12378621	-0.39664415	0.00618808	0.10986379
WATERHOLE_	0.65139019	0.01591084	-0.09360049	0.60912309	0.082981361	0.11033956	-0.39024459	0.01018272	0.10811315
BOMA_DIST	1	-0.03170862	-0.26095987	0.57940654	0.147727965	0.14687388	-0.43586022	0.02488929	0.12956009
RIVERRINE_	-0.03170862	1	-0.08163219	0.0934926	-0.056764055	-0.06947226	0.32484327	-0.36122284	-0.31882734
TARANGIRE_	-0.26095987	-0.08163219	1	-0.40608088	-0.140744907	-0.1278057	0.40018491	0.02506806	-0.02828335
VILLAGE_DI	0.57940654	0.0934926	-0.40608088	1	0.219739802	0.23028318	-0.48554195	-0.10377378	0.0296926
LANDCLASS3	0.14772797	-0.05676406	-0.14074491	0.2197398	1	0.85504497	-0.41584047	-0.1959043	0.02326738
MJ_LANDCLA	0.14687388	-0.06947226	-0.1278057	0.23028318	0.855044971	1	-0.40938685	-0.26016108	0.10153359
FARM_RATIO	-0.43586022	0.32484327	0.40018491	-0.48554195	-0.415840472	-0.40938685	1	-0.26654688	-0.3538848
DENSE_THIC	0.02488929	-0.36122284	0.02506806	-0.10377378	-0.195904298	-0.26016108	-0.26654688	1	-0.17815785
WOODY_SAVA	0.12956009	-0.31882734	-0.02828335	0.0296926	0.023267382	0.10153359	-0.3538848	-0.17815785	1