Impact of climate variability over large carnivore predation on livestock in the Amboseli Ecosystem, Kenya

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Conservation is a state of harmony
between men and land.

Aldo Leopold

This report is the result of six-month at the Metapopulation Research Centre, in the Department of Biosciences of the University of Helsinki, in Finland, under the supervision of Dr. Mar Cabeza.

This work corresponds to my bachelor's final year project. My bachelor degree was conducted at Facultat de Ciències i Tecnologia of the Universitat de Vic (UVIC), in Spain, where this report has been also supervised by Dr. Josep Bau.

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Main acronyms and abbreviations

AE	Amboseli Ecosystem
ANP	Amboseli National Park
BLF	Big Life Foundation
CRU	Climatic Research Unit
GLMM	Generalized Linear Mixed Models
IPCC	Intergovernmental Panel on Climate Change
MGR	Mbirikani Group Ranch
OGR	Olgulului Group Ranch
PAs	Protected Areas
PCF	Predator Compensation Found
TS	Time-Series

Summary

Title: Impact of climate variability over large carnivore predation on livestock in the Amboseli Ecosystem, Kenya

Key words: Amboseli, ecosystem, habitat fragmentation, connectivity, climate variability, rainfall, wildlife conservation, Maasai, livestock, predation, carnivore

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The increase of human population has accelerated the loss of habitat for many wildlife species and brings humans and wildlife to live in increasingly close proximity to one another, which may exacerbate human-wildlife conflicts. In Amboseli Ecosystem, Kenya, large carnivores populations have declined and their geographic ranges have contracted because Maasai pastoralists kill them in retaliation for livestock predation. Using detailed livestock predation data in two Amboseli group ranches (Olgulului and Mbirikani), I investigated the relative importance of each predator in livestock attacks and the livestock type preference for each predator. Moreover, I determined the period (wet or dry season) where more livestock attacks occur and I examined how climate variability influences the number of livestock attacks. Predator species have different behaviours and use different strategies to attack livestock. Some of them tend to kill more livestock during each attack and others less. Hyena (*Crocuta crocuta*) is the predator who kills more number of livestock during each attack, followed by lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*) and jackal (*Canis mesomelas*). The absolute number of each type of livestock killed by predators varied among years over the 7-year study period, although shoats were always the livestock attacked the most (highest number of kills in both ranches) followed by cows and donkeys in much lower proportion. There is a negative relationship between rainfall and the number of livestock killed per attack and during the drought period more livestock are killed per attack than during the wet period. Furthermore, my results show that climate patterns are changing in Amboseli Ecosystem, decreasing rainfalls and increasing drought periods year after year.

Resum

Títol: Impacte de la variació climàtica en la depredació al bestiar per part dels grans carnívors a l'ecosistema d'Amboseli, Kènia

Paraules clau: Amboseli, ecosistema, fragmentació d'hàbitat, connectivitat, variació climàtica, precipitació, conservació de la fauna, Massai, bestiar, depredació, carnívor

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L'augment de la població humana ha accelerat la pèrdua d'hàbitat de moltes espècies, de manera que éssers humans i fauna han hagut de viure cada vegada més a prop, fet que ha agreujat el conflicte entre humans i vida salvatge. A l'ecosistema d'Amboseli, Kènia, les poblacions de grans carnívors han disminuït i la distribució geogràfica d'aquestes han quedat reduïdes. Una de les causes principals és la mort per venjança que els pastors Massai apliquen als depredadors del seu bestiar. Utilitzant dades detallades de depredació en el bestiar en dos poblats d'Amboseli (Olgulului i Mbirikani) he investigat la importància relativa de cada depredador en atacs al bestiar i la preferència dels diferents tipus de bestiar per a cada depredador. D'altra banda, he determinat el període (estació humida o seca) en què es produeixen més atacs al bestiar i he examinat com la variació climàtica influeix en el nombre d'atacs al bestiar. Els depredadors tenen comportaments diferents i utilitzen diferents estratègies per a atacar el bestiar. Alguns d'ells tendeixen a matar-ne més quantitat durant cada atac i altres, menys. La hiena (*Crocuta crocuta*) és el depredador que mata més nombre d'animals per atac, seguit del lleó (*Panthera leo*), el lleopard (*Panthera pardus*), el guepard (*Acinonyx jubatus*) i el xacal (*Canis mesomelas*). El nombre absolut de cada tipus de bestiar mort pels depredadors varia al llarg dels anys –en un període d'estudi de 7 anys–, tot i que les ovelles i les cabres han estat sempre el bestiar més atacat (nombre més alt de morts en els dos poblats), seguit de vaques i ases, aquests darrers en proporció molt menor. Hi ha una relació negativa entre la pluja i el nombre d'animals morts per atac; durant el període de sequera mor més bestiar per atac que durant el període humit. Així doncs, els patrons climàtics estan canviant a l'ecosistema d'Amboseli amb una disminució de les precipitacions i un augment dels períodes de sequera.

1. INTRODUCTION

In the last century, increased human population has created a high demand for land as well as exerting an incredible amount of pressure and threat to wildlife and other biodiversity types around the world (Mwale, 2000; Woodroffe, 2000). Conversion of natural habitats to agricultural lands (for crop and livestock production) is one of the most important human-induced land-use changes currently affecting the planet (Kameri, 2002; Holmern et al., 2007).

In Africa, wildlife population levels have declined and their geographic ranges have contracted (Woodroffe, 2000). Habitat conversion outside of protected areas (PAs) has led to increasingly fragmented wildlife populations and less connectivity between habitats, which threatens wildlife movement, particularly for migratory species and those characterized by large home ranges, such as large carnivores (Ogutu et al., 2011; Dolrenry et al., 2014). Although most carnivores occur within PAs (Woodroffe and Frank, 2005) they also migrate beyond park boundaries at different times of the year in search of prey. Once outside PAs, carnivores come into contact with human populations. Moreover, people and wildlife are living in increasingly close proximity to one another, which may exacerbate human-wildlife conflicts (Treves and Karanth, 2003; Yihune et al., 2009).

Human-Carnivore conflicts illustrate the challenge of the coexistence between humans and wildlife. Large carnivores are declining throughout Africa primarily due to retaliatory persecution by humans (Hazzah et al., 2009; Dickman, 2010; Ogutu et al., 2011) and overexploitation due to poor management of trophy hunting (Packer et al., 2011). Resident populations of cheetahs (*Acinonyx jubatus*) are thought to remain in only 7% of their original range (IUCN, 2007). Even the iconic lion (*Panthera leo*) is thought to have declined by 30% to 50% during the past two decades (IUCN, 2006), and many other large carnivores have experienced similar dramatic declines.

Rates of livestock depredation by large carnivores can be influenced by local environmental conditions such as abundance of natural prey (Meriggi and

Lovari, 1996; Stoddart et al., 2001; Polisar et al., 2003) and rainfall (Patterson, 2004; Woodroffe and Frank, 2005), as well as by socio-ecological factors including livestock husbandry practices (Meriggi and Lovari, 1996; Stahl et al., 2001; Ogada et al., 2003) and characteristics of attacked farms, villages, and livestock enclosures (Mech et al., 2000; Ogada et al., 2003).

Kenya is an example of African country where all these tensions have become increasingly evident in the last few decades. In this study I focus on one of Kenya's iconic PAs and its surroundings, the Amboseli Ecosystem as a case study.

Amboseli Ecosystem (AE) covers approximately an area of 5700 km^2, which includes the protected areas of Amboseli National Park (ANP) in the centre, stretching between Chyulu Hills and Tsavo West National Parks in the west and Mt. Kilimanjaro in Tanzania in the south (Tuqa et al., 2014) (see Figure 1). This area has a large concentration of wild large mammals, but also supports an expanding human population dominated by the Maasai people (Okello, 2012). Group ranches are important dispersal areas and corridors for wide-ranging wildlife species (Okello and D'amour, 2008). Despite human population has rapidly grown (approximately an increase of 60,000) and the large number of livestock heads (approximately an increase of 150,000) with a period of twenty years (KNBS, 2009; Kenana et. al., 2013), there is more wildlife on the group ranches than inside the PAs (Western et al., 2009). However it is noted that in this ecosystem, large carnivores face the threat of habitat loss as a result of increased human population and habitat fragmentation. There is, as well, a threat from increasing human-wildlife conflicts, which occasionally results in injuries and deaths of both livestock and large carnivores (Thirgood et al., 2005).

For hundreds of years, numerous generations of Maasai pastoralists have grazed their livestock alongside the wildlife of Amboseli (Western et al., 2003). The nomadic pastoralist communities moved with their herds seasonally following the rainfalls to secure forage for their livestock (Marshall, 1990). Most rangelands showed low human densities but, recently, these land uses have changed, due to rapid population growth. Many Maasai people have moved from nomadic lifestyles to permanent human settlements. As a result of land privatization and subdivision, dramatic loss of tree and shrub cover, and development of infrastructure throughout AE, the dispersal areas of wildlife have been substantially reduced, limiting the free movement of animals (Western, 1973; Altmann, 1998; Okello et al., 2009; Moss et al., 2011). These changes have restricted access to important habitats for large carnivores (Ogutu et al., 2005), including dense cover and riparian areas, which are important for stalking predators such as lions (Spong, 2002; Mosser et al., 2009). Moreover, some of AE’s PAs are relatively small to independently support viable wildlife populations (Schuette, 2012). Therefore, most animals rely on surrounding areas for obtaining forage and water resources, breeding grounds, and mating opportunities (Newmark et al., 1993; Wishitemi and Okello, 2003). In AE, over 80% of large mammals circulate from the national parks to neighbouring Maasai group ranches during the wet season and livestock predation can cause significant economic losses among pastoralists. For example, Patterson et al. (2004) estimated livestock predation to represent 2.6% of the herd’s economic value in a Kenyan ranch, which incurred a loss of $8749 per annum.

In addition, many agro-pastoralist landscapes have livestock densities and grazing intensities that can competitively displace native ungulate species (Groom and Harris, 2010), leading a situation where large carnivores are forced to attack the Maasai’s livestock to survive, due to the lack of natural prey species in the ecosystem (Kolowski and Holekamp, 2006). As a consequence, Maasai have recurrently poisoned and speared large carnivores in retaliation, which has resulted in a substantial decline in the AE's large carnivores populations (Hazzah et al., 2014). Conserving large carnivores is a pressing issue because of the striking declines in the geographic ranges and population sizes of these species, and also because of their arguable capacity as umbrella species for wider biodiversity (Dickman et al., 2011).

An increasing concern in the region is climate change. Mt. Kilimanjaro snow and forest cover on the slopes have visibly decreased over these last years and recent research also documents dramatic decreases in the size of the glaciers on the mountain (Thompson, 2001; Schüler et al., 2012). All these changes may have a direct effect of the animal distributions. For instance, substantial changes in the home-ranges of lions in the area have been attributed to severe droughts (Tuqa et al., 2014), with changes in the ranges of lions in the area being attributed to climate change, yet the effects of climate on human-wildlife conflict remain poorly studied.

Maasai communities have different livestock species such as shoats (as Maasai refer to goats and sheep together), cows and donkeys. For the Maasai, cattle provide almost everything they need for survive. Furthermore the main carnivores species responsible for most repeated livestock predation are lion (*Panthera leo*), spotted hyena (*Crocuta crocuta*), jackal (*Canis mesomelas*), cheetah (*Acinonyx jubatus*) and leopard (*Panthera pardus*). Most studies in the area are address to lion, but only few studies address the combination of predators and prey. Yet it is well known that numbers and actions of one predator affect the others, at least in other ecosystems (Patterson et al., 2004).

Therefore, it is essential for the long-term conservation of AE to keep the correct habitat management and give wildlife the security needed to continue living in this ecosystem (Pratt and Gwynne, 1977; Holmern et al., 2007; Kent, 2011; Lyamuya et al., 2014). As a first step to mitigate human-carnivore conflicts in AE, it is important to understand how climate and habitat management in different areas (PAs, game ranches, etc) influence livestock attacks by the five main species of large carnivores present in my study area.

2. AIMS OF THE STUDY

This study has four objectives:

- To identify the relative importance of each predator in livestock attacks.
- To characterize the livestock type preference for each predator.
- To determine the period (wet or dry season) where more livestock attacks occur.
- To examine how climate variability influences the number of livestock attacks.

3. MATERIALS AND METHODS

3.1 Study area

Amboseli Ecosystem is situated in the southwest of Kenya, bordering Tanzania. It covers an approximate area of 5700 km^2 between Chyulu Hills and Tsavo National Parks on the west and Mt. Kilimanjaro in Tanzania on the south, in the eastern Kaijado County of Kenya's Rift Valley Province (Tuqa et al., 2014) (Figure 1). I divided the study area into 9 cells of 50km^2 each, in order to study in more detail the geographic variability of AE. Administratively, AE is divided between ANP (392 km^2), a number of wildlife sanctuaries (such as Kimana Community Wildlife Sanctuary) and up to eight group ranches (such as Olgulului Group Ranch, OGR, and Mbirikani Group Ranch, MGR) that are

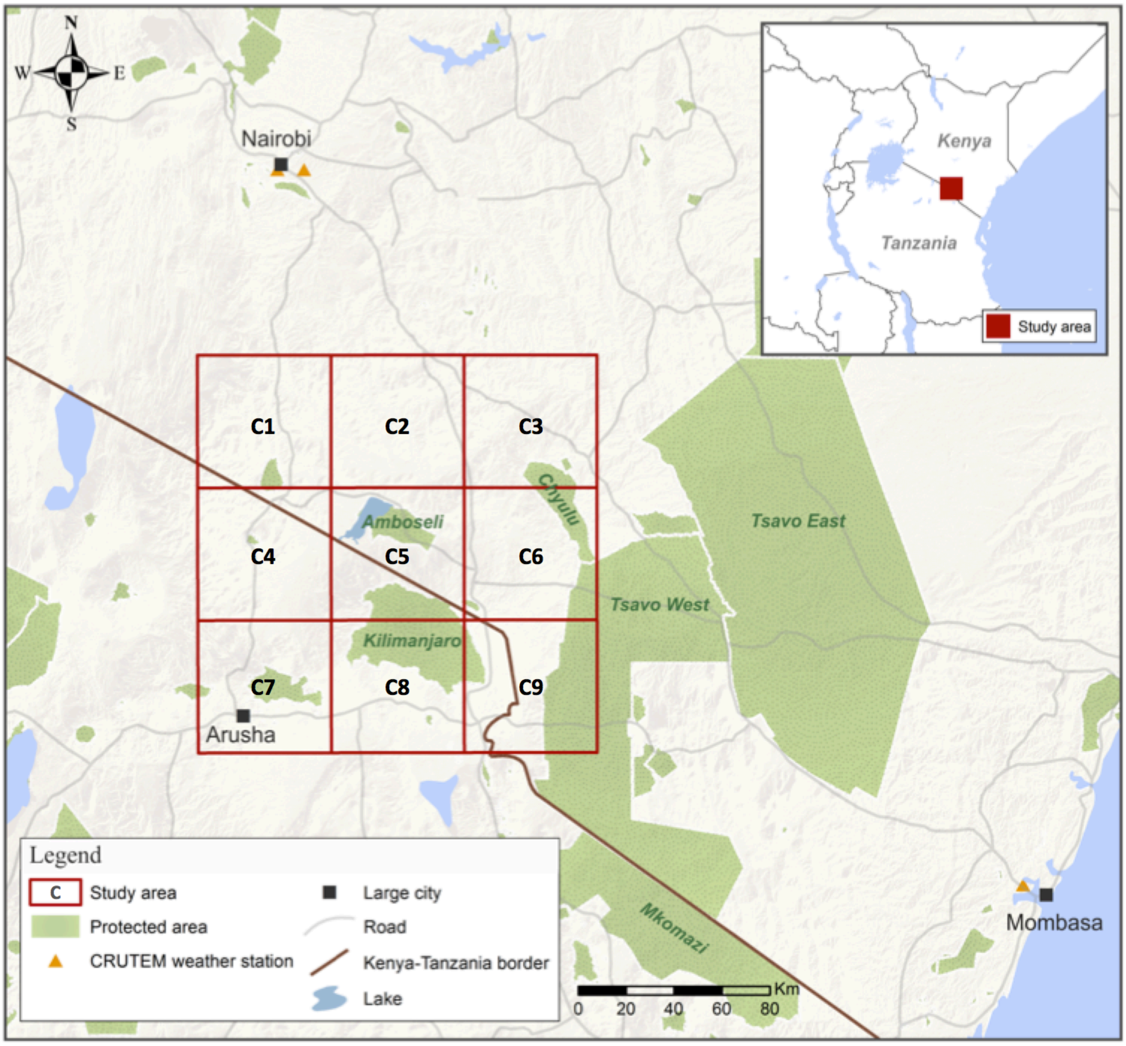

Figure 1: Location map of study area in Amboseli Ecosystem, situated in the southwest of Kenya bordering Tanzania.

communally owned by Maasai pastoralists belonging to the Ilkisongo section (5063 km^2).

At the heart of the study area is ANP, where lies the Amboseli Basin, a semiarid Pleistocene lakebed that covers an area of about 400km^2. The basin is bordered on the north by hills of Precambrian metamorphic rock and on the south by Mt. Kilimanjaro, which consists largely of alkaline lavas, principally olivine basalts. Mt. Kilimanjaro is the major source of water, which flows into the basin as streams and groundwater (Hay and Stoessell, 1984). Amboseli Basin attracts high concentrations of migratory animals during the dry season. Large mammal species move freely in an area communally owned by Maasai moving in and out of ANP seasonally (Wishitemi and Okello, 2003; Tuqa et al., 2014). ANP is a dry season grazing area for wildlife that disperses widely to the adjacent group ranches during the wet season, when water and forage is plentiful (Muthiani and Wandera, 2000; Ntiati, 2002; Groom and Harris, 2010). AE comprises an important area for ecotourism, which provides an important source of foreign revenue for Kenya (Okello, 2005). Amboseli Ecosystem's PAs comprise a large part of the Kenya's wildlife. There are several corridors of land connecting Tsavo, Chyulu, Mt. Kilimanjaro and ANP, all of which serve as a wet season dispersal area for many wildlife populations, making AE a hotspot for the global conservation of predator species.

The traditional Maasai village, or boma, in this region consists of several homesteads, which are in essence small huts made of mud and cow dung. All homesteads encircle a central livestock enclosure, which is typically constructed with thick and thorny bushes occasionally from wooden poles to control the livestock and protect them from predators (Frank, 1998). Boma's walls average 1.5 metres high for 1-1.5 metres thick. Normally livestock is taken out to grazing fields in the morning hours, between 08:00 and 10:00 h, and returned to bomas around 18:00 h (Kissui, 2008). At night, livestock is kept in the thorn stockades or bomas and this is where most predator attacks take place. Human attendants have the job of confront and repel the predators (Patterson, 2004).

Most of AE is classified as a semi-arid environment, with most of it being suitable for pastoralism and wildlife conservation (Pratt and Gwynne, 1977). It has a bi-modal rainfall pattern with long rains coming at the beginning of the year (between March and May) while the short rains occur at the end of the year (end of October and mid-December) (Western, 1975; Okello and D'Amour, 2008). An average of 350-600mm rainfall per annum is expected, while droughts are common when rainfall falls below average. Thus, rainfall is the key determinant of land use practices in the entire region (Ntiati, 2002; Okello, 2005). Surface water availability is sparse and the hydrology is mostly influenced by Mt. Kilimanjaro. Regarding temperature, as expected for this arid tropical environment, the variability across months in average daily temperature is between 19 and 24ºC (Moss et al., 2011).

3.2 Study species

In this study I examined predator and livestock species. I studied five different predators: lion (*Panthera leo*), spotted hyena (*Crocuta crocuta*), jackal (*Canis mesomelas*), cheetah (*Acinonyx jubatus*) and leopard (*Panthera pardus*). All these carnivore species are sympatric in AE's landscape and are responsible for most repeated livestock predation (Table 1).

Table 1: Ecological traits of the five predator species included in this study. Information extracted from African Wildlife Foundation.

Predator species	Habitat preference	Population trend	Diet	Predators
Lion	Grassy plains and open woodlands	Decreasing	Carnivorous	Humans
Cheetah	Open plains	Decreasing	Carnivorous	Humans, lions and hyenas
Hyena	Savannahs, grasslands, woodlands, forest edges, sub-deserts and mountains	Increasing	Carnivorous	Humans and lions
Jackal	Open and wooded savannahs	Decreasing	Omnivorous	Humans, hyenas and leopards
Leopard	Bush and riverine forest	Decreasing	Carnivorous	Humans

Regarding livestock type, I studied three species: shoats (as Maasai refer to goats and sheep together), cows and donkeys that are the most important livestock species for Maasai communities. For the Maasai, cattle provide almost everything they need for survive. Maasai people have an average of 16 head of cattle per person. A typical family (8-10 people) owns 125-140 head, of which the most part are shoats and cows. Maasai people principally eat milk on which the family depends for daily subsistence. Shoats are easier to keep than cows, because cows have more value and the cost for maintain them is higher. However, donkeys are used more for transport, for cultivation and for bring water to Maasai families and to other livestock types (Huho et al., 2011).

3.3 Data

3.3.1 Climate data

The climatic data used to explore annual and monthly trends in a series of climate parameters over the 1980-2014 period and to investigate the effect of rainfalls and temperature on the livestock predation patterns over 2008-2014 period was obtained from Climatic Research Unit (CRU). Rainfall data and temperature data was extracted from the Time-Series (TS) 3.22 gridded climate dataset (0.5º x 0.5º) available from CRU, one of the most used databases in IPCC assessment reports and numerous scientific studies (Harris et al., 2009). These variables included the monthly mean rainfall based on daily values as well the monthly mean temperature based on daily values. Moreover, I divided dry season in seven months (January, February, June, July, August, September and October). However, wet season was divided in five months (November, December, March, April and May). This classification was based in the mean rainfall of each month. The available data are interpolated from local weather station records and undergo several corrections. The dataset used might not have enough accuracy in some small or isolated areas due its coarse resolution. Data was gathered for 1980-2014, a period long enough to determine accurately climate trends. Some analyses have been use with the default resolution to analyse variability and trends of temperature and rainfall in the region, but when climate data is compared with livestock attack data, as I have two ranches data, I used only two grid cells. I related OGR data with the climatic data in cell 5 of my study area and MGR data with climatic data in cell 6 (see Figure 1).

3.3.2 Livestock Predation data

Livestock predation data were gathered by Big Life Foundation (BLF) at two group ranches, OGR and MGR. In 2003 BLF introduced new guidelines for compensating households for damage caused by predators to their livestock, called Mbirikani Predator Compensation Found (MPCF), aiming to reduce incidences of retaliatory killing of predators after livestock attacks. Furthermore, MCPF collected long term monitoring data on human-wildlife conflicts. The protected predators include lions, cheetahs, leopards, hyenas, jackals and smaller cats. Maasai livestock species protected by MPCF are cows, shoats and donkeys, among others. Depending on the predator, the compensation from MPCF covers different percentage of the livestock value (Okello et al., 2014) (Table 2).

Table 2: Payment amounts for carnivore predation by the compensation scheme and how payment amounts have changed over the years. The units are in Kenyan Shillings. Information extracted from Okello et al., 2014.

Year	Livestock type	No penalties		Lost in the bush		Inadequate boma construction	
		Lion, Cheetah, Leopard	Hyena, Jackal	Lion, Cheetah, Leopard	Hyena, Jackal	Lion, Cheetah, Leopard	Hyena, Jackal
2003-2008	Shoat	2,000	2,000	1,000	1,000	600	600
	Cow	13,500	6,750	6,750	3,375	4,050	2,025
	Donkey	6,000	3,000	3,000	1,500	1,800	900
2008-2010	Shoat	2,500	2,500	1,250	1,250	750	750
	Cow	14,500	7,250	7,250	3,625	4,350	2,175
	Donkey	6,000	3,000	3,000	1,500	1,800	900
2010-2014	Shoat	3,000	3,000	1,500	1,500	900	900
	Cow	20,000	10,000	10,000	5,000	6,000	3,000
	Donkey	7,000	3,500	3,500	1,750	2,100	1,050

Data from BLF used in this study span from January 2008 to December 2014 and included: (a) date of the incident; (b) predator type; (c) number of livestock killed; (d) livestock type killed; and (e) ranch name.

These data only include incidents that were reported to BLF, although it likely corresponds with the majority of incidents. The data does not include attacks of animals injured that did not die, or claims that were only later approved by the committee. Both represent a comparatively small number of incidents.

In addition, it is important to note that during 2010 there are gaps in OGR livestock kills data, in all cases that is either because the program was temporarily suspended or unfortunately because the original credit note was lost, but of course this does not mean that there were not any predation events during those periods.

3.4 Statistical analysis

Climatic data was analysed with a Spearman's rank correlation coefficient, which was used to assess the association between variables. The climatic variable (temperature or precipitation) was treated as a dependent variable, and time as independent variable. Using *cor* function from the *stats* R package we examined the relationship between time (month or years) and climate.

To investigate how climate affects livestock attacks I built Poisson Generalized Linear Mixed Models (GLMM) using *glmer* function from the *lme4*, *nlme* and *MCMCglmm* packages. Year was treated as random effect. On the one hand, I built two GLMM with 'number livestock killed' as the response variable, and various combinations of explanatory variables (temperature, precipitation, predator species, ranch and period (drought or wet). I also built separated GLMMs for each livestock type (shoat, cow and donkey) as response variables.

4. RESULTS

4.1 Climate patterns in Amboseli Ecosystem

Based on available climate coarse-resolution data from CRU, climatic trends for AE between 1980 and 2014 show extended spatial variation. Six out of the 9 cells show decreasing trends in the mean annual rainfall and there are also some pronounced temporal changes in mean annual rainfall between years (Figure 2). Noticeable spatial variation in rainfall is present in the study area. There is a north-south pattern with less rainfall in north cells and with more rainfall in south cells; in other words, total annual rainfall is higher in the

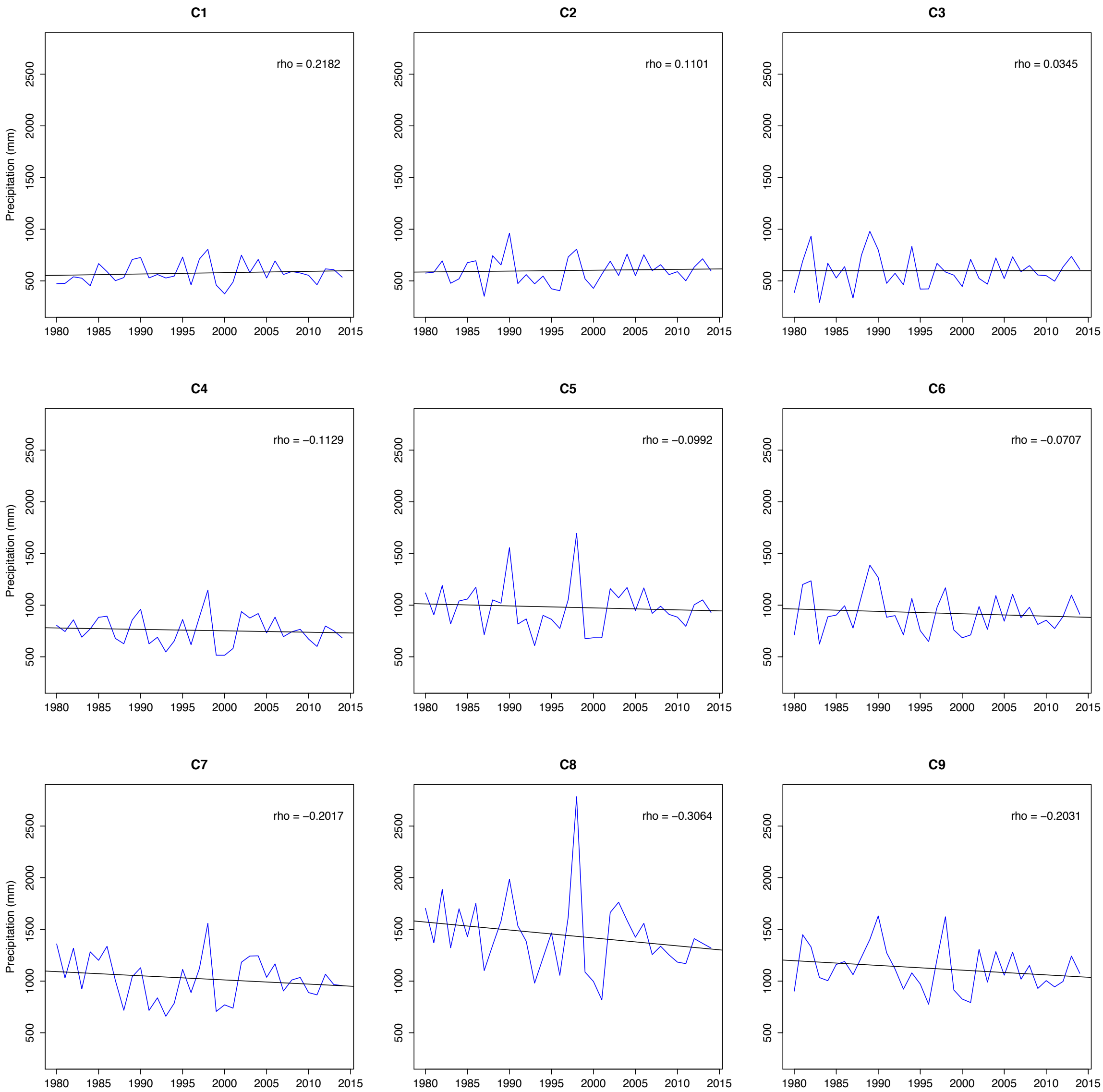

Figure 2: Total annual rainfall in Amboseli Ecosystem, 1980-2014, by calendar year.

northern parts of the study area than in the southernmost parts. Cell number 8 (C8) has the highest rainfall in all AE study area because of Mt. Kilimanjaro, which also covers a small part of cell 6 (C6) and cell 9 (C9) thus explaining the higher level of rainfall in these cells. Moreover, rainfall is slowly increasing in the north and decreasing in the south over the 34 year period (Figure 3).

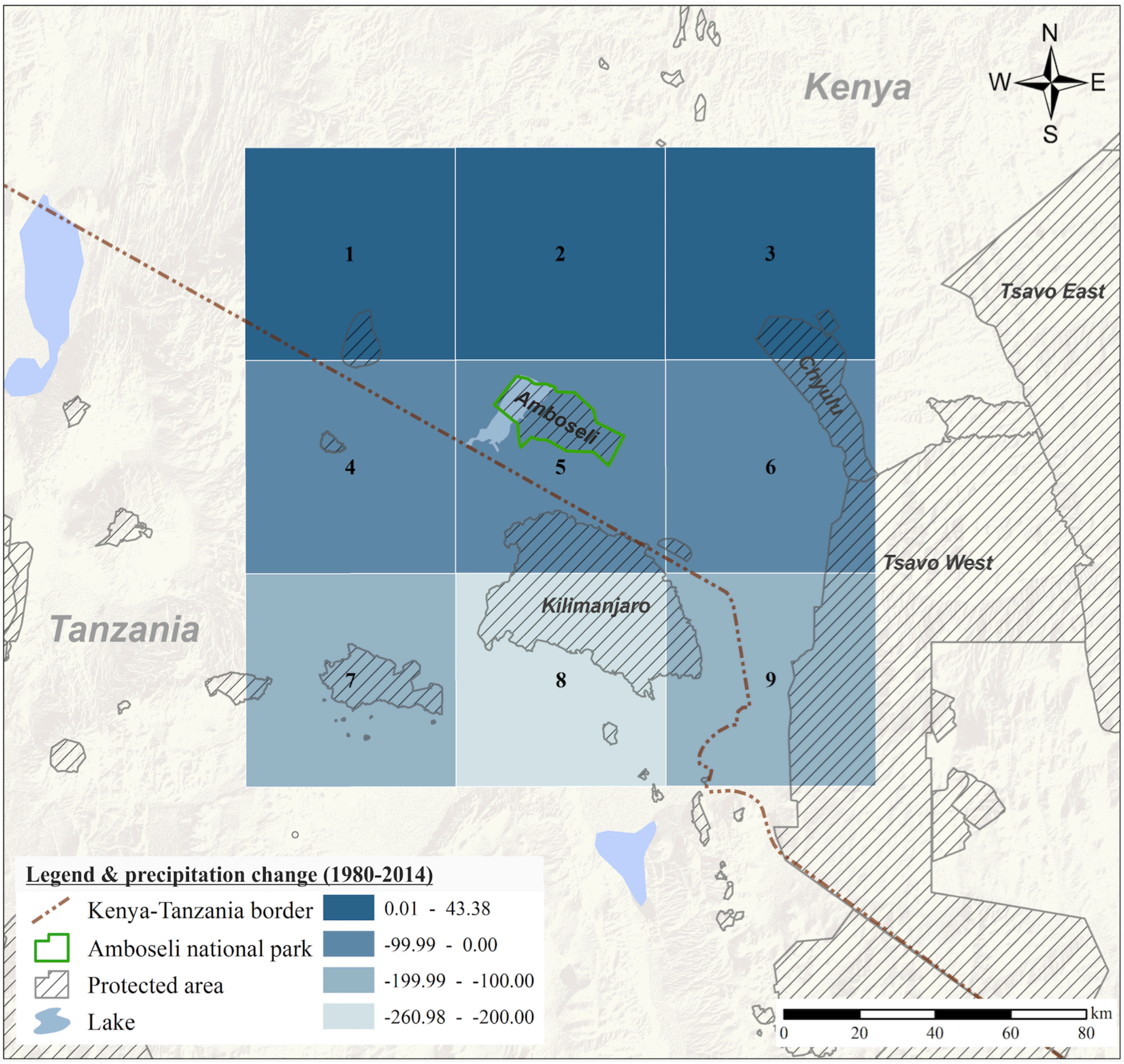

Figure 3: Rainfall trends in Amboseli Ecosystem, 1980-2014. Note: Positive values indicate increasing trends and negative values indicate decreasing trends. Gradient from dark blue to light blue, means changes from wetter conditions, towards drier conditions.

All 9 cells show significant increasing trends in the mean annual temperature (Figure 4) and there are also some pronounced temporal changes in mean annual temperature between years. Cells numbers 5 and 8 (C5 and C8) have the lowest temperature in all AE study area because of Mt. Kilimanjaro.

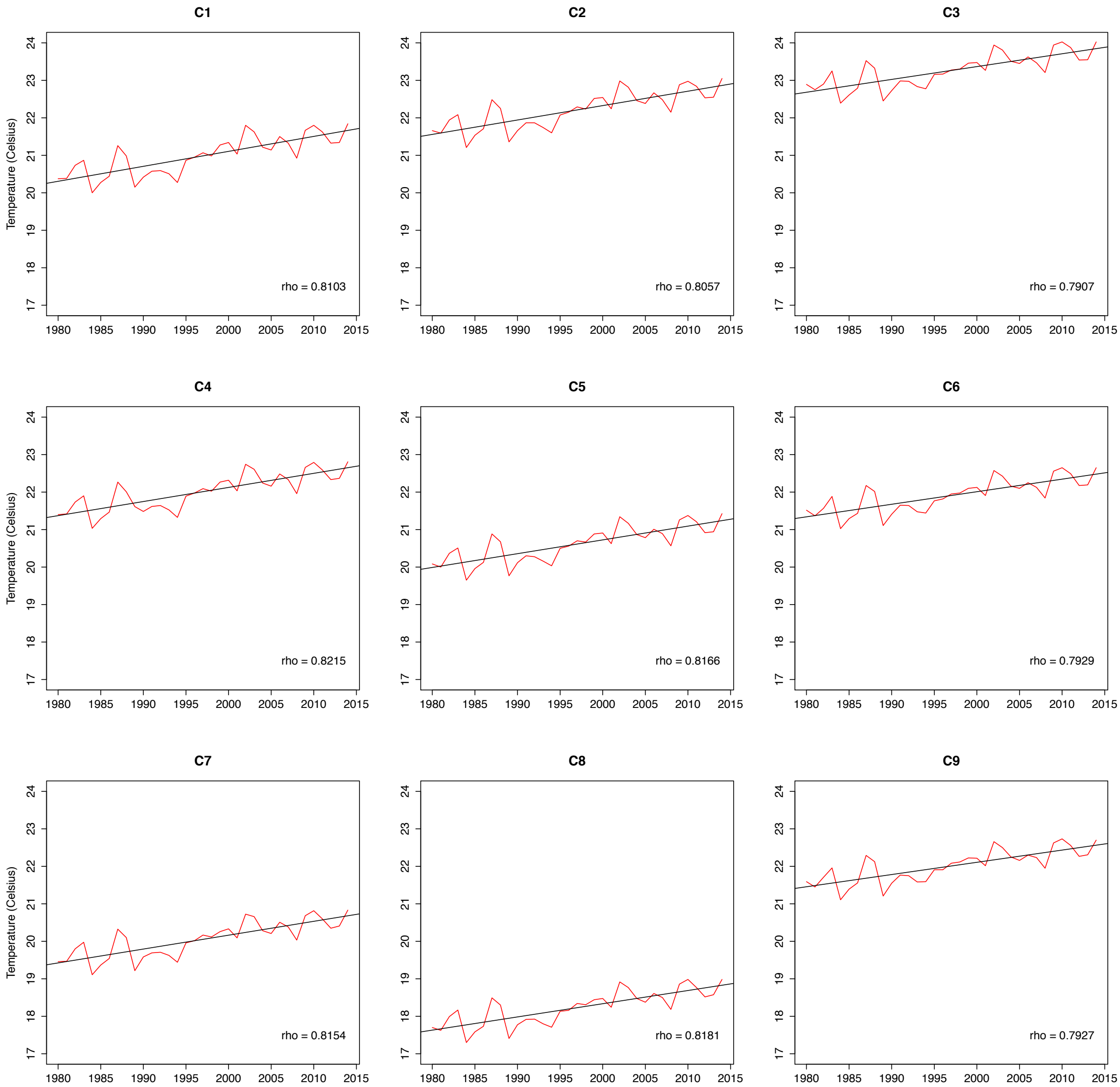

Figure 4: Total annual temperature in Amboseli Ecosystem, 1980-2014, by calendar year.

Moreover, temperature is quickly increasing over the 34 year period. In east temperature is increasing slower because proximity to the ocean. However, in west temperature is increasing faster because of more far away to the ocean (Figure 5). The scale was defined using the TS 3.22 gridded climate dataset (0.5º x 0.5º) available from CRU. See Section 3.3.1 for further details.

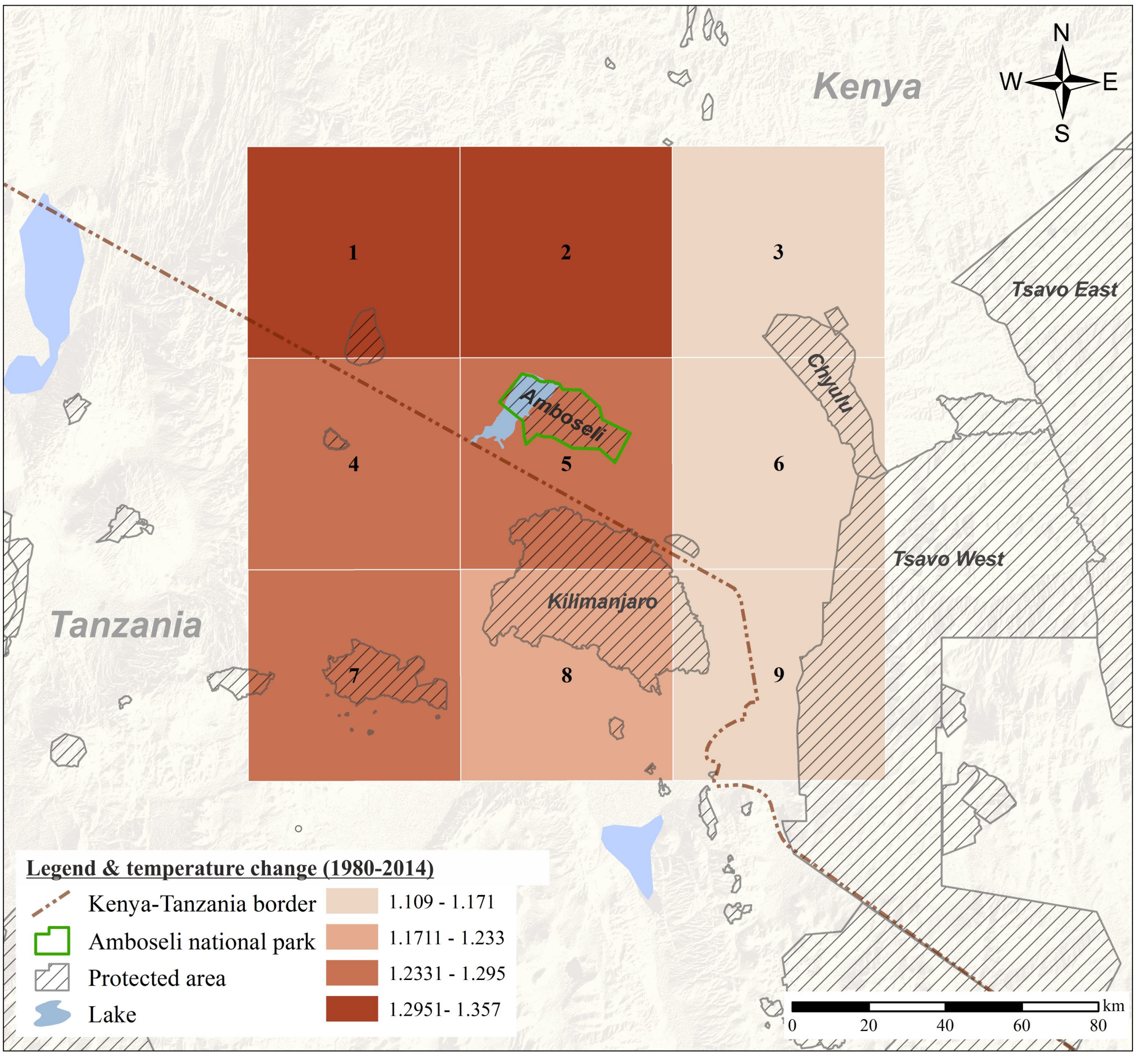

Figure 5: Temperature trends in Amboseli Ecosystem, 1980-2014. Note: Gradient from dark red to light red, means changes from warmer conditions, towards colder conditions.

Rainfall average of all AE subareas (from C1 to C9) showed high rainfall variability and severe recurrent droughts at varying intervals (Figure 6a). The amount of rainfall decreased over the whole study period (rho = -0.1535). Moreover, temperature showed variability at varying intervals (Figure 6b). Furthermore, temperature increased over the whole study period (rho = 0.8185).

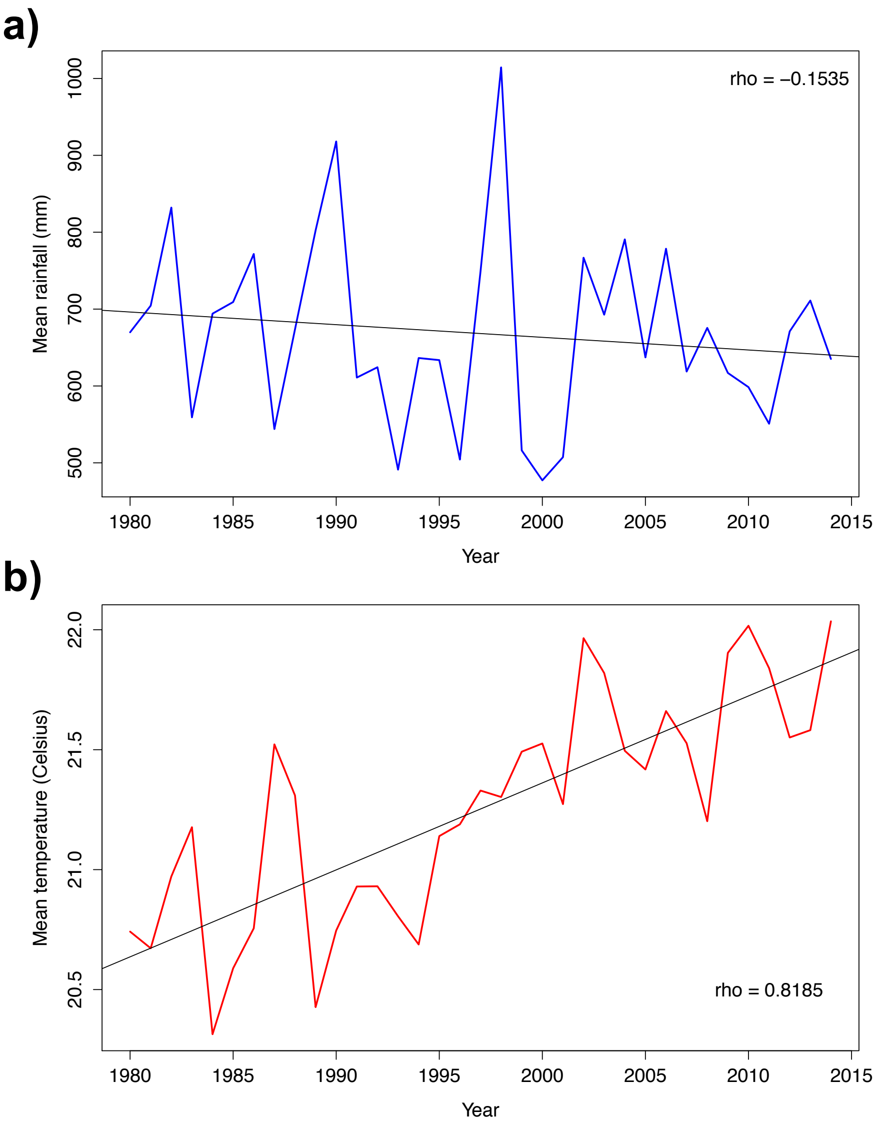

Figure 6: Changes in (a) mean annual rainfall (b) mean annual temperature in Amboseli Ecosystem, 1980-2014.

Period ranging from June till the end of October is referred to as long dry season, and was consistently a rainless period; January and February corresponds to the period referred to as the short dry season. Furthermore, one rainy season comes at the end of October until mid December and a second, and longer one comes between March and May. However, often the long dry season was preceded by the failure of one or both of the previous rainy seasons (Figure 7a). Sometimes, significant amounts of rain fell not only during the two usual seasons but also to varying degrees in January and February (Figure 7b).

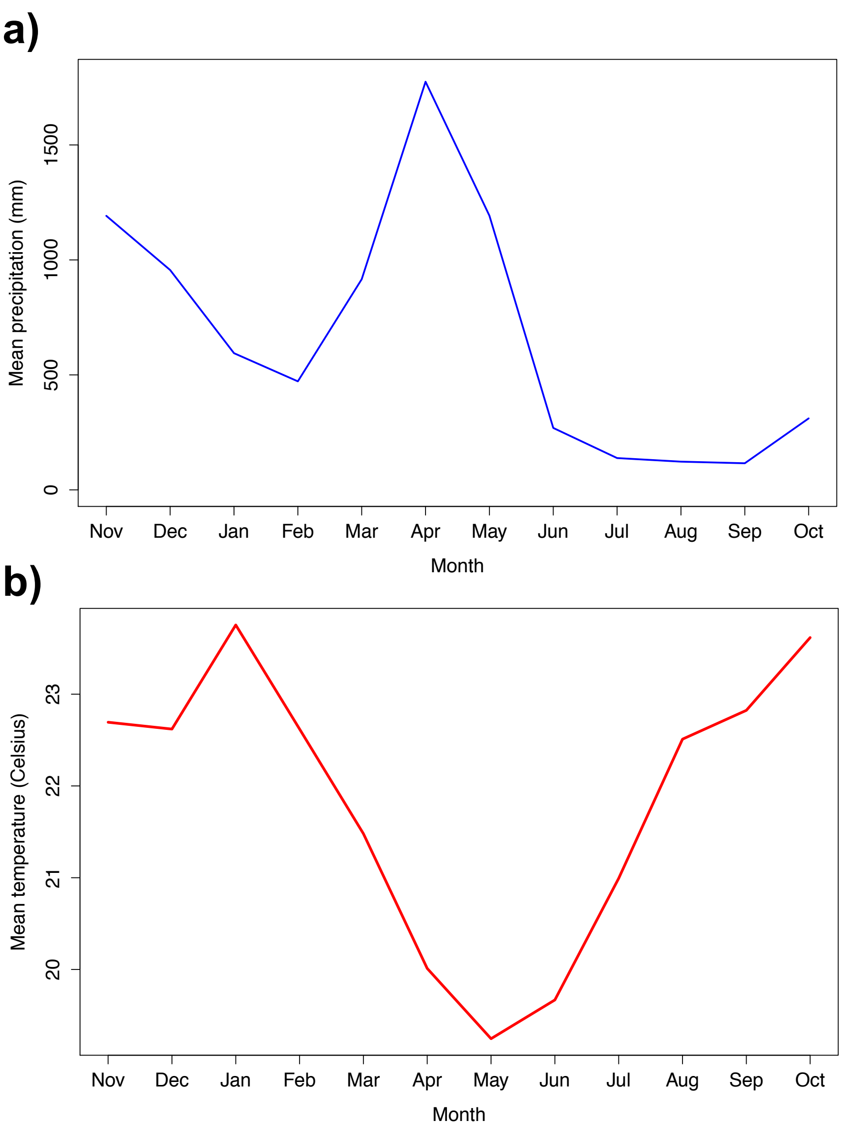

Figure 7: Changes in (a) mean monthly rainfall (b) mean monthly temperature in Amboseli Ecosystem, 1980-2014.

4.2 Which are the most notable predators and the most notable victims?

Over the seven-years study period, in OGR there was an average of 1548.57 heads of livestock killed by predators per year. In contrast, in MGR an average of 1296.63 heads of livestock per year were killed by predators (Figure 8). During 2009, there was a fast increase in the number of livestock killed in both group ranches. After 2009, there is a sharp decrease in number of livestock killed until 2011, that is when starts to increase again. The number of livestock killed in OGR is significantly higher than MGR (Table 3). See Appendix 8.1 for further details.

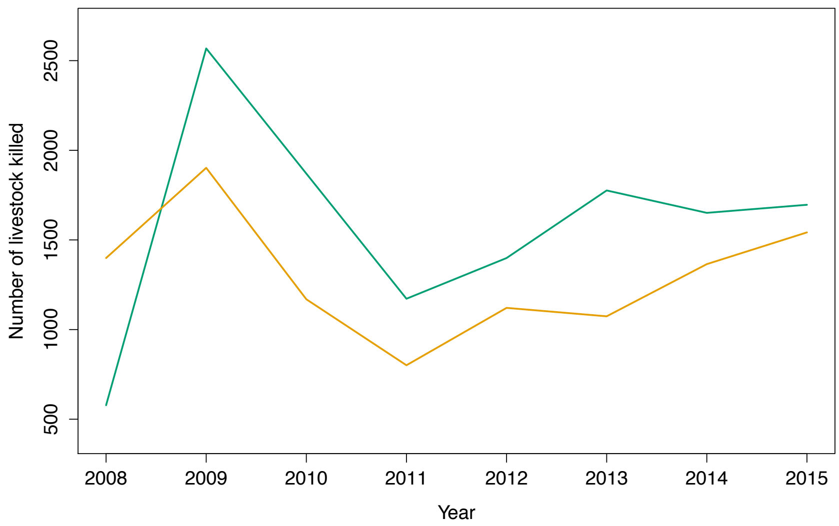

Figure 8: Total number of livestock killed in OGR (green) and MGR (orange).

Different predator species are involved in livestock predation in both OGR and MGR. Hyena is the predator who kills more number of livestock, followed by cheetah, jackal, lion and leopard. There is a trend for hyena to kill more livestock than other predators (Figure 9).

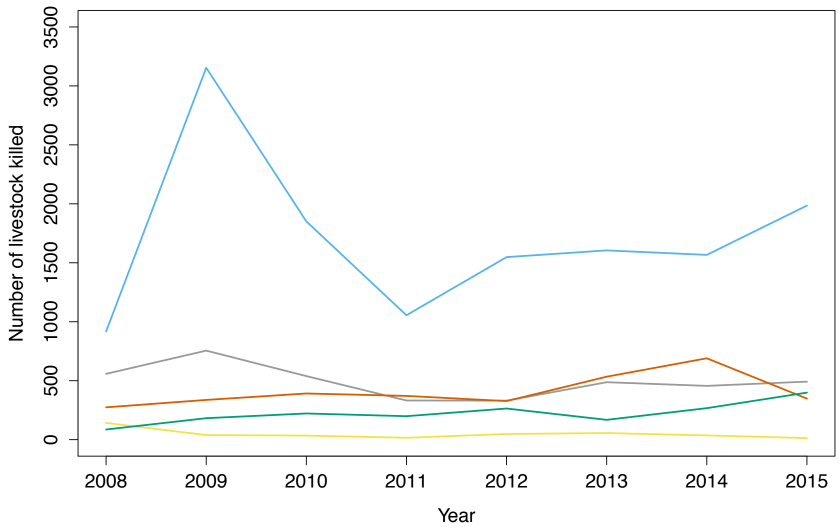

Figure 9: Total number of livestock killed in OGR and MGR by predator over year. Different solid and colour lines mean: hyena (blue), cheetah (grey), jackal (red), lion (green) and leopard (yellow).

Predator species have different behaviours and use different strategies to attack livestock. Some of them prefer to kill more livestock during each attack and others less (Figure 10). Hyena is the predator who kills more number of livestock during each attack, followed by lion, leopard, cheetah and jackal (Table 3).

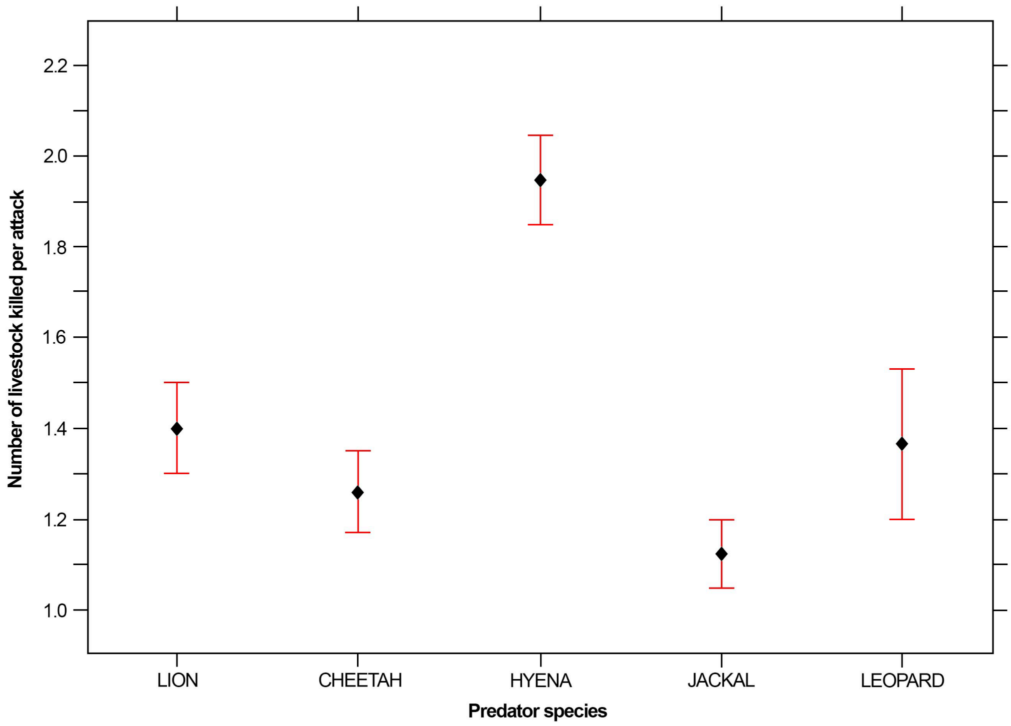

Figure 10: Predicted values (±SE) of total number of livestock killed per attack in relation to predator type.

Table 3: Parameters estimates for the GLMM, describing how variations in the number of livestock attacks were explained by four explanatory variables (precipitation, temperature, predator species and ranch). 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables	Parameter Estimate ± SE	Z	p	
(Intercept)	0.25 ± 0.12	2.07	**<0.05**	*
Precipitation	-0.00 ± 0.00	-5.72	**<0.001**	***
Temperature	0.00 ± 0.01	0.91	0.36	
Predator Cheetah	-0.11 ± 0.03	-3.22	**<0.01**	**
Predator Hyena	0.33 ± 0.03	10.94	**<0.001**	***
Predator Jackal	-0.21 ± 0.03	-6.04	**<0.001**	***
Predator Leopard	-0.03 ± 0.01	-0.46	0.64	
Ranch OGR	0.04 ± 0.02	2.34	**<0.05**	*

The absolute number of each type of livestock killed by predators varied between years over the 7-year study period, although shoats are always the livestock attacked the most (highest number of kills in both ranches) followed by cows and donkeys in much lower proportion (Figure 11).

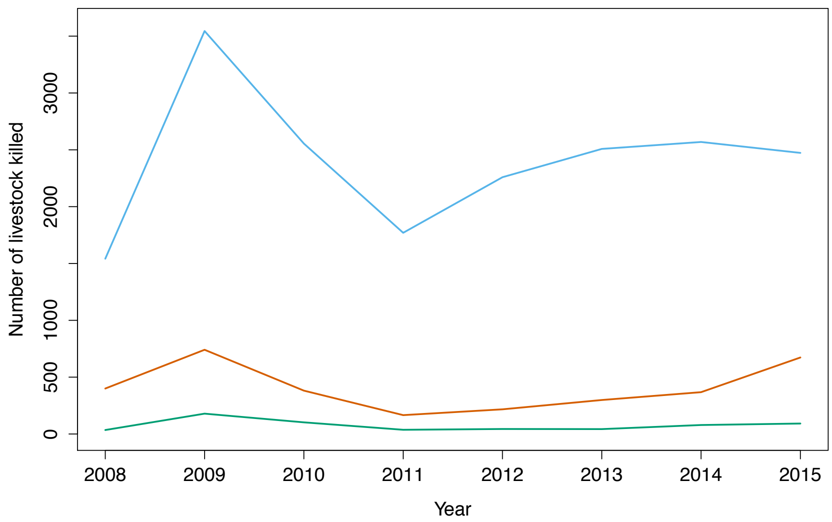

Figure 11: Total numbers of different livestock types killed in OGR and MGR by predators over year. Different solid and colour lines mean: shoat (blue), cow (red) and donkey (green).

Hyena is the predator killing the highest number of shoat, followed by lion, leopard, cheetah and jackal (Figure 12). The number of shoat killed by hyena was significantly higher than the number of shoat killed by lion, but lion killed significantly more shoat than cheetah and jackal. There is no significant difference between lion and leopard regarding shoat attacks. The number of shoat attacks is significantly higher in OGR than in MGR (Table 4). Hyenas killed as well more cows than any other predator species followed closely by lions, leopards, cheetahs and jackals, respectively. There was no significant difference between the number of cows killed by lions and hyenas, but lion killed significantly more cows than cheetahs, jackals and leopards. In addition, in OGR there was significantly less cow predation than in MGR (Table 5). Regarding the number of donkeys killed, jackals killed less number of donkeys than lions, but there is not significant differences between the others predator species. Furthermore, in OGR there is significantly less donkey attacks than in MGR (Table 6).

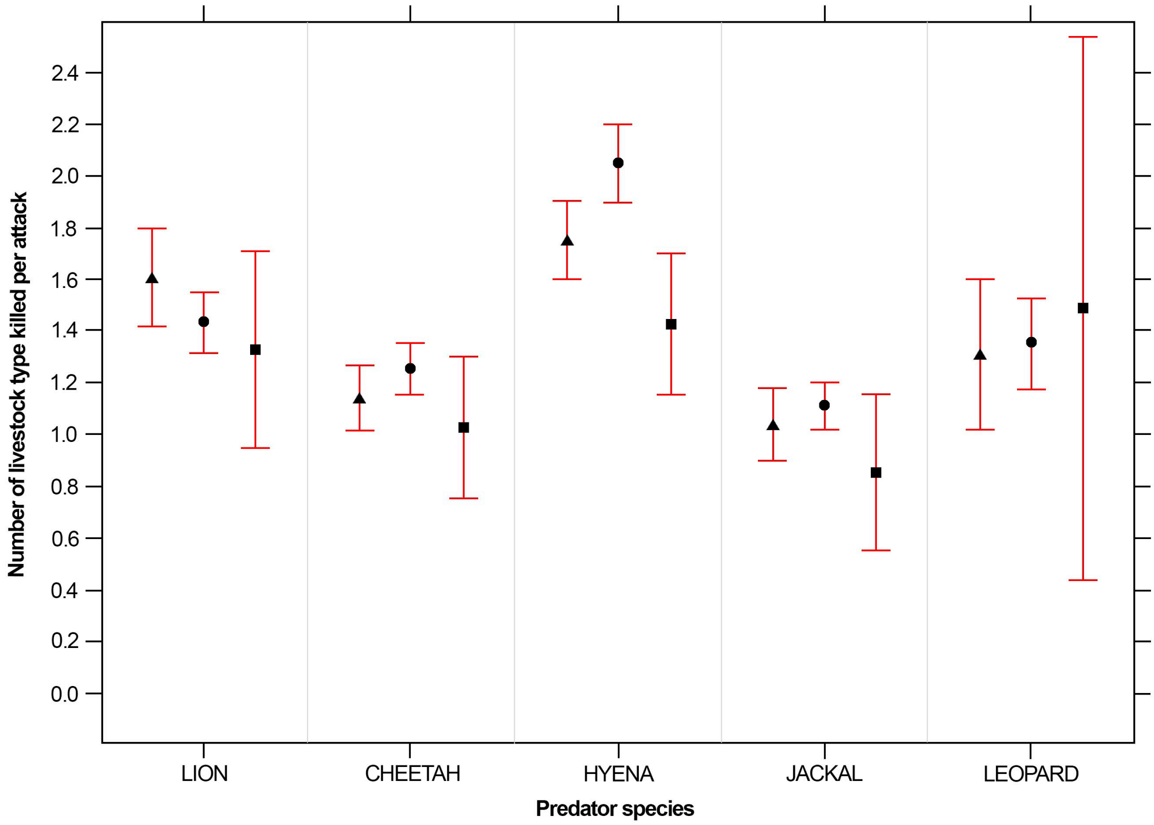

Figure 12: Predicted values (±SE) of total number of shoats (●), cows (▲) and donkeys (■) killed per attack in relation to predator type.

Table 4: Parameters estimates of the GLMM, describing the factors (precipitation, predator species and ranch) that influence variations in the number of shoats killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Shoat	Parameter Estimate ± SE	Z	p	
(Intercept)	0.17 ± 0.14	1.25	0.21	
Precipitation	-0.00 ± 0.00	-4.29	**<0.001**	***
Temperature	0.01 ± 0.01	1.12	0.27	
Predator Cheetah	-0.13 ± 0.04	-3.34	**<0.001**	***
Predator Hyena	0.36 ± 0.04	9.81	**<0.001**	***
Predator Jackal	-0.24 ± 0.04	-5.9	**<0.001**	***
Predator Leopard	-0.07 ± 0.07	-0.93	0.35	
Ranch OGR	0.16 ± 0.02	8.11	**<0.001**	***

Table 5: Parameters estimates of the GLMM, describing the factors (precipitation, predator species and ranch) that influence variations in the number of cows killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Cow	Parameter Estimate ± SE	Z	p	
(Intercept)	0.59 ± 0.30	2	**<0,05**	*
Precipitation	-0.00 ± 0.00	-3.16	**<0.01**	**
Temperature	0.01± 0.01	0.39	0.61	
Predator Cheetah	-0.35 ± 0.07	-4.91	**<0.001**	***
Predator Hyena	0.08 ± 0.06	1.39	0.16	
Predator Jackal	-0.45 ± 0.08	-5.48	**<0.001**	***
Predator Leopard	-0.23 ± 0.12	-1.86	<0.1	.
Ranch OGR	-0.42 ± 0.05	-9.19	**<0.001**	***

Table 6: Parameters estimates of the GLMM, describing the factors (precipitation, predator species and ranch) that influence variations in the number of donkeys killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Donkey	Parameter Estimate ± SE	Z	p	
(Intercept)	1.04 ± 0.70	1.49	0.14	
Precipitation	-0.00 ± 0.00	-0.59	0.56	
Temperature	-0.02 ± 0.03	-0.78	0.44	
Predator Cheetah	-0.27 ± 0.19	-1.46	0.15	
Predator Hyena	0.07 ± 0.14	0.49	0.62	
Predator Jackal	-0.50 ± 0.22	-2.23	**<0,05**	*
Predator Leopard	-0.00 ± 0.36	-0.01	0.99	
Ranch OGR	-0.38 ± 0.12	-3.24	**<0,01**	**

4.3 Does climate explain differences in livestock kills?

In all combination of explanatory variables tried, temperature did not have a significant contribution. Rainfall and period (drought/wet) did have an effect in different models. There is a negative relationship between rainfall and the number of livestock killed per attack (Figure 13). The period of the year also shows an association with the number of livestock killed per attack (Figure 14). This figure shows that during the drought period more livestock are killed per attack than during the wet period (Table 7).

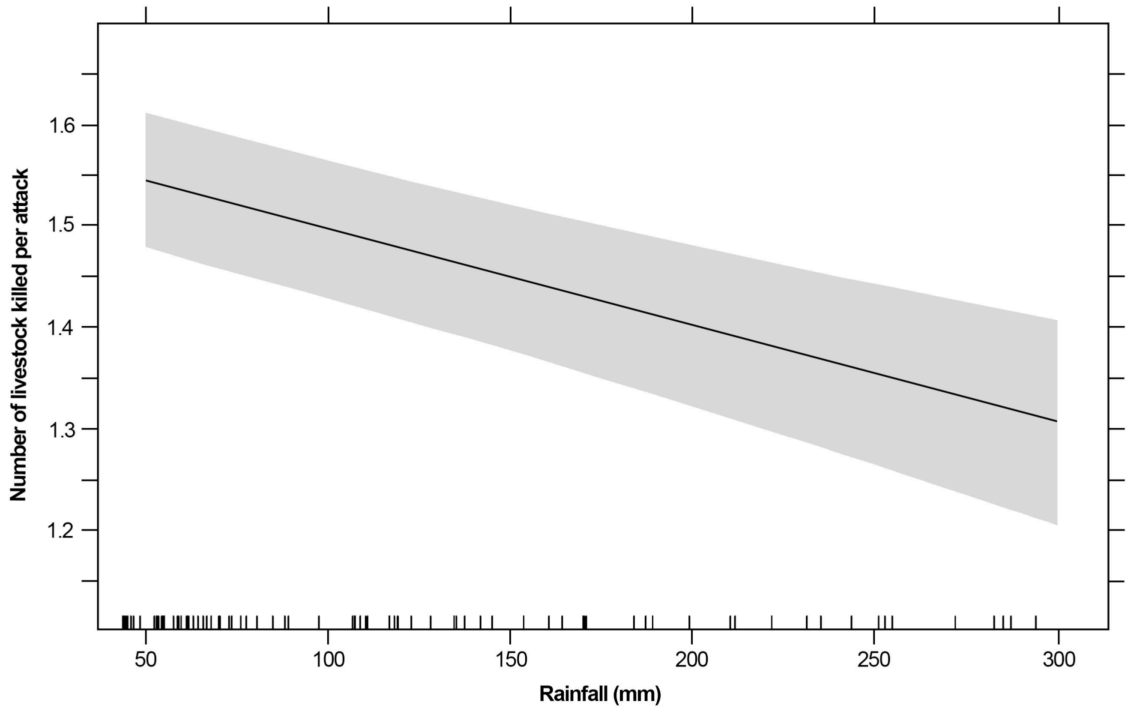

Figure 13: Predicted values (±SE) of the number of livestock killed per attack in relation to rainfall variability.

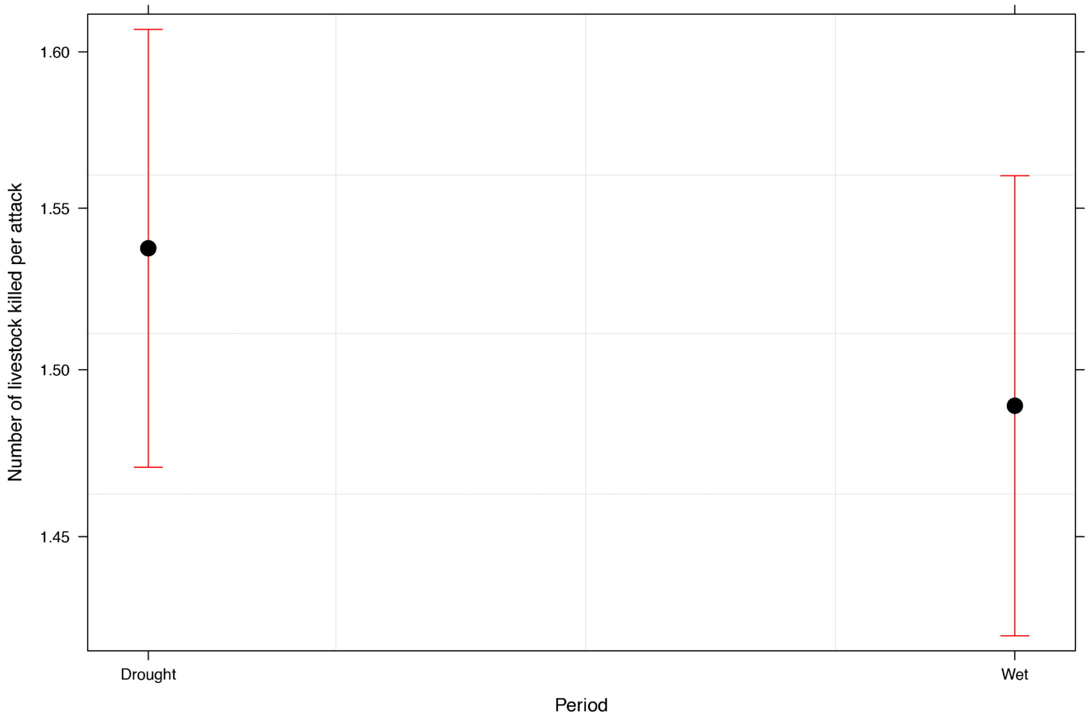

Figure 14: Predicted values (±SE) of the number of livestock killed per attack in relation to period.

Table 7: Parameters estimates for the GLMM, describing how variations in the number of livestock attacks were explained by tree explanatory variables (period, predator species and ranch). 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables	Parameter Estimate ± SE	Z	p	
(Intercept)	0.39 ± 0.03	11.50	**<0.001**	***
Period Wet	-0.03 ± 0.01	-2.22	**<0.05**	*
Predator Cheetah	-0.18 ± 0.03	-5.97	**<0.001**	***
Predator Hyena	0.25 ± 0.03	9.62	**<0.001**	***
Predator Jackal	-0.26 ± 0.03	-8.51	**<0.001**	***
Predator Leopard	-0.10 ± 0.06	-1.64	0.10	
Ranch OGR	0.03 ± 0.01	1.80	<0.1	.

When separated by livestock type I found that both the number of shoat killed and the number of cows killed per attack were negatively associated with rainfall (Figure 15a and Table 4 for shoats; Figure 15b and Table 5 for cows). But the period (wet, drought) did not have an effect in the number of kills per attack. See Tables 8, 9 and 10 in Appendix 8.2. The number of donkeys killed per attack was not associated neither to precipitation, temperature or period (Figure 15c and Table 6 for donkeys).

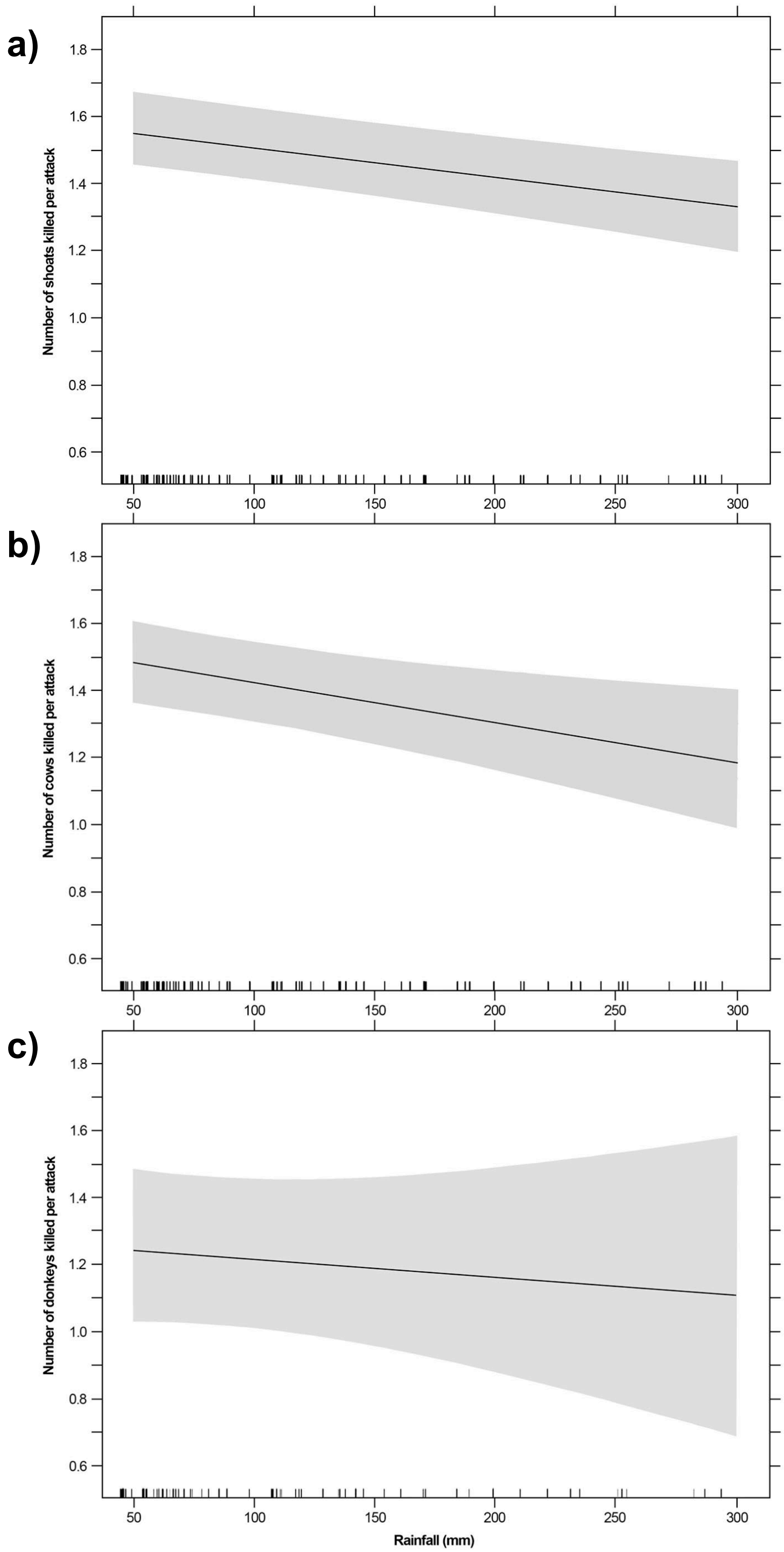

Figure 15: Predicted values (±SE) of the numbers of (a) shoats, (b) cows and (c) donkeys killed by rainfall variability in OGR and MGR.

5. DISCUSSION

I found significant differences in various patterns of the datasets analysed: differences in attacks between the ranches, differences in attacks in different seasons and differences through time that can be explained by differences in rainfall but not in temperature.

Even at coarse scale, and derived from interpolated datasets, I found rainfall variability in the ecosystem. In northern parts there were less rainfall than in southern parts, possibly explained by the presence of Mt. Kilimanjaro. In addition, ANP is located a few kilometres from the northern base of Mt. Kilimanjaro and both its weather and its permanent water levels are highly affected by conditions in neighbouring mountainous areas. Southern parts have experienced a decreasing trend in rainfall. This could result from high level of local deforestation and land-use change (Thompson, 2001), in addition to global climatic change.

Human-carnivore conflict is higher in those communities that are closer to PAs than those which are located further: OGR, which surrounds over 90% of the ANP perimeter, suffered higher frequency and intensity of livestock kills than MGR. A plausible explanation could be that carnivores venture out from the safety of PAs into neighbouring dispersal areas, especially in the dry season where the amount of preys is lower and carnivores should to expand their foraging range for find preys. Furthermore, in the dry season there is less vegetation cover where to hide within the National Parks, attacking then livestock that is grazing there or in poorly protected Maasai homesteads. Typically, an increase in livestock numbers as witnessed presently, results in the degradation of thorny fences. Thus fences become inefficient as a barrier, thereby increasing the probability of successful attacks by predators (Kiringe and Okello, 2004). Apparently, those bomas that were better maintained had lower numbers of carnivore attacks compared with those that were poorly maintained. This accentuates the necessity to adapt boma fencing and to strengthen security measures against livestock predation (Okello et al., 2014). Responsible herding focusing on minimizing the loss of livestock during grazing, tracing straying livestock and enhancing boma preservation, as well as support for construction of predators proof bomas (carried out by different conservation organisations, like BLF, in AE) should complement the compensation scheme (Ogada et al., 2003). Finally, it is important to comment that land uses are changing very fast over most of AE area in the last decades, thereby increasing cultivation and urbanisation coupled with increased human immigration and birth rates and this implies a diminishing space for livestock grazing (Campbell et al., 2000; Woodroffe, 2000). This also involves a confinement of grazing in areas where livestock are more vulnerable to attacks by carnivores, which consequently increases predation rates.

Moreover, I found that hyena is the predator who kills more livestock in AE (see Figure 9), as well as the predator who kills more livestock in the same attack event (see Figure 10). Our data focused only on predation events occurring in bomas and there could be some differences if we had included predation events registered both in bomas and in the field as well. Yet hyenas are rarely killed or trapped by Maasai. Instead, lions are the most vulnerable predator to retaliatory killing by humans because they usually return to feed on the carcasses after the attack. Besides, lions are the easiest predator to kill using traditional methods, such as spearing, in comparison to other carnivores because hyenas, cheetahs, jackal and leopards are more difficult to track. Furthermore, for Maasai culture, spearing lions have traditionally been an enormous prestige (Hazzah et al., 2009). Compensation payments for livestock kills thus do not reflect the true needs of the Maasai population suffering predator attacks, but instead reflect a need to reduce retaliation against predators such as lions: livestock killed by lion receives much higher compensation than that killed by a hyena (see Table 2).

In terms of the type of livestock killed, shoats are the most affected by predation, followed by cows and donkeys. There could be several explanations for this. First of all, shoats are the most common livestock in terms of total number of individuals, followed by cows and donkeys in the studied group ranches. If the number of large carnivore attacks is correlated to the relative abundance and frequency of encounter of different livestock types, it therefore makes sense that attacks on shoats follow the pattern that my results show (Holmern et al., 2007). Another possible explanation is the large quantity of the carnivore types that AE have and their different hunting strategies. Hyena seems to be the most bountiful carnivore in the ecosystem and because of its collective hunting strategy and its physical strength, it can easily take both small prey, like shoats, and larger prey, like cows and donkeys (Mills, 1998; Kissui, 2008). My results also shows that the fact that hyena is the predator that kills more livestock is driven by the number of shoats kills. Therefore my data seem to support the observation by Holekamp et al. (1997) that attacks by hyena are likely to depend on which livestock type is more readily accessible. In addition all other small predators including jackal, cheetah and leopard prefer smaller sized prey. There is more diversity and abundance of predators close to PAs and large abundance of bomas with shoats in the neighbouring ranch, thus resulting in larger numbers of shoat killed. Lions, on the other hand have non-preference sized prey, but they attack more shoats and cows. These two hypotheses could explain the relatively higher rates of predation on shoats than on cows and donkeys I observed. In addition, lion may optimize their search for food by choosing bigger size livestock prey such as cows or donkeys than smaller sizes like shoats. Surely, lion can kill a cow and a donkey easier than other carnivores (excepting hyenas that have no preference on different livestock types).

Furthermore in MGR there are more cows attacks and this is potentially because of the ranch remoteness from PAs (predators want to optimize their attacks and therefore go for larger sized livestock species). In addition, the number of donkeys killed does not seems to have any relation with rainfalls, but there are still more donkey attacks in MGR maybe also as a result of the ranch remoteness.

I found a significant relationship between livestock predation and rainfall, both throughout the year and across years. There could be several explanations for this. First, high rainfall results in high vegetation productivity and high food abundance for large herds of herbivores dispersing inside and outside PAs. When rainfalls come down, the local abundance of large herds of herbivores decreases (because ungulates migrate to other areas with higher rainfall). When rainfall decreases, AE’s predators are forced to move outside the PAs to try to find more food and this is when human-wildlife conflicts start. In addition, we found that during the drought period there are also more livestock attacks than during the wet period (Hazzah et al., 2013).

The yearly average of rainfall in our 9 study area cells showed a decreasing trend over years. Rainfall levels in AE are decreasing, and this could have a huge and direct effect on wildlife. Furthermore, Mt. Kilimanjaro snow-cap and forest cover on the slopes have been decreasing. Increased conversion of natural habitats to agricultural lands and a dramatic decrease in the glacier extent are proofs that global change is affecting extensively my study area (Altmann et al., 2002). Amboseli Basin is also having an extensive loss of forest cover and associated shrubs that constituted the Acacia woodland component of this savannah habitat.

Although we still do not fully understand all the relationships between climate and livestock attacks, there seem to be clear patterns at least with rainfall. Noteworthy, climatic variables have rarely been addressed to explain variation and trends in such attacks. With the foreseen climatic changes in the area, and the increasing numbers of livestock pointing to a future of increasing human-wildlife conflict, it becomes ever more important to understand this relationship, and perhaps account for it when adapting livestock compensatory programs such as that of BLF.

6. CONCLUSIONS

The results of this study reveal a significant association between climate variability patterns and livestock predation of large carnivores in AE.

1) Climate patterns are changing in AE, i.e. decreasing rainfalls and increasing drought periods.

2) These changes affect directly predator's behaviour due to the decrease of wild prey populations and change in migration patterns. Therefore, large carnivores attack more livestock when rainfalls decrease in AE.

3) Human-carnivore coexistence is incompatible with most current livestock production practices.

4) Different carnivores species have preference in different livestock type. Meanwhile hyenas attack with the same intensity all livestock type, lions prefer large-sized livestock and cheetahs, jackals and leopards smaller size.

5) OGR has more livestock attacks because it is located close to ANP where carnivore density is higher. As well, in MGR, predators prefer to attack large sized livestock because the ranch is more remote and predators can get more food in one attack.

6) To address carnivore conservation and management outside PAs and mitigate ongoing human-carnivore conflicts, particularly in regions where livestock production is a predominant land use strategy, is an absolute priority to stop predator persecution and potentially reverse the decline currently observed in several large African felid species.

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8. APPENDIX

8.1 Figure showing variation in the number of livestock killed per attack and ranches

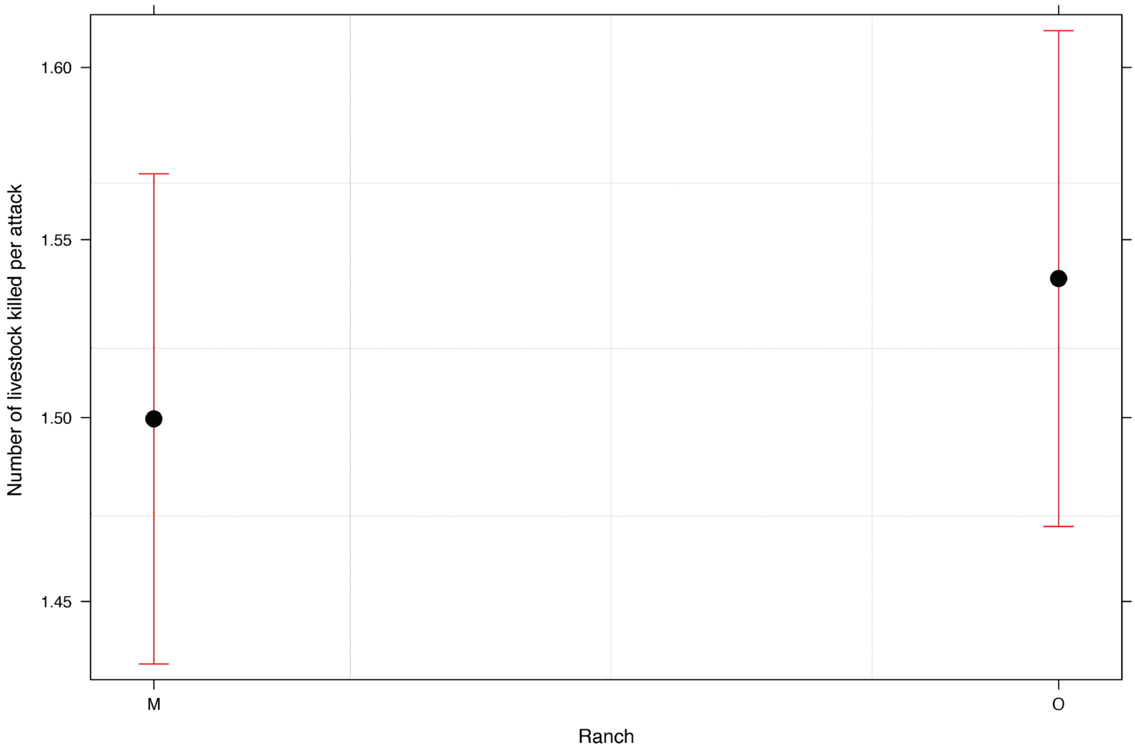

Figure 16: Predicted values (±SE) of total number of livestock killed per attack in relation to ranch.

8.2 Tables showing the relation between the number of livestock killed and rainfall period (dry vs. wet)

Table 8: Parameters estimates of the GLMM, describing the factors (period, predator species and ranch) that influence variations in the number of shoats killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Shoat	Parameter Estimate ± SE	Z	p	
(Intercept)	0.58 ± 0.05	12.49	**<0.001**	***
Period Wet	-0.00 ± 0.02	-0.21	0.83	
Predator Cheetah	-0.39 ± 0.04	-10.11	**<0.001**	***
Predator Hyena	0.20 ± 0.04	5.64	**<0.001**	***
Predator Jackal	-0.47 ± 0.04	-12.14	**<0.001**	***
Predator Leopard	-0.30 ± 0.07	-4.49	**<0.001**	***
Ranch OGR	0.05 ± 0.02	3.11	**<0.01**	**

Table 9: Parameters estimates of the GLMM, describing the factors (period, predator species and ranch) that influence variations in the number of cows killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Cow	Parameter Estimate ± SE	Z	p	
(Intercept)	0.22 ± 0.05	4.79	**<0.001**	***
Period Wet	-0.02 ± 0.04	-0.62	0.54	
Predator Cheetah	-0.09 ± 0.07	-1.30	0.19	
Predator Hyena	-0.05 ± 0.04	-1.03	0.30	
Predator Leopard	-0.07 ± 0.15	-0.47	0.64	
Ranch OGR	0.00 ± 0.04	0.08	0.94	

Table 10: Parameters estimates of the GLMM, describing the factors (period, predator species and ranch) that influence variations in the number of donkeys killed. 'Lion' was set up as the reference for Predator Type in the model. Results are considered significant at p<0.05 (*** p<0.001, ** p<0.01, * p<0,05, . p<0,1).

Variables Donkey	Parameter Estimate ± SE	Z	p
(Intercept)	0.11 ± 0.12	0.95	0.34
Period Wet	-0.00 ± 0.09	-0.03	0.98
Predator Cheetah	-0.12 ± 1.01	-0.12	0.90
Predator Hyena	-0.03 ± 0.11	-0.30	0.77
Predator Leopard	-0.12 ± 1.01	-0.12	0.90
Ranch OGR	0.01 ± 0.11	0.11	0.91