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ELEPHANT MOVEMENT AND RESOURCE UTILISATION IN A FENCED ENVIRONMENT

by
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A dissertation submitted in partial fulfilment of the requirements for the degree of M.Res. Wildlife Conservation.

As the nominated University supervisor of this M.Res. project by Lokuliyanage Surendranie Judith Cabral, I confirm that I have had the opportunity to comment on earlier drafts of the report prior to submission of the dissertation for consideration of the award of M.Res. Wildlife Conservation.

Signed..

UoS Supervisor's name: Prof. C. Patrick Doncaster

As the nominated Marwell Wildlife Supervisor of this M.Res. project by Lokuliyanage Surendranie Judith Cabral, I confirm that I have had the opportunity to comment on earlier drafts of the report prior to submission of the dissertation for consideration of the award of M.Res. Wildlife Conservation.

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Abstract

Anthropogenic activities are increasingly threatening wildlife. To separate wildlife from its threats fences are being commonly used. Lewa Wildlife Conservancy (LWC) is a fenced protected area dedicated for the conservation of black rhinoceros. LWC is now experiencing high elephant numbers and perceive it to be a result of increasing hostile events in surrounding areas. This has become a concern because elephants seem to heavily degrade the vegetation that is available for rhinos even within the exclusion zones that are fenced to prevent entry of elephants. This study showed that inward and outward movement of elephants from LWC, is evidently influenced by rainfall and hostile events that occur within and outside LWC. Elephants travel with increased speed outside LWC particularly at night, which suggests that potential threats may be affecting their movement behaviour. Change in green biomass from 2012 to 2014 depict a decrease in the entire conservancy. This should be given attention and further investigated in the immediate future. Elephants cause more damage to plants with height greater than 2 m and diameter at breast height (DBH) greater than 10 cm. Elephants also cause severe damage to some exclusion zones and targeting certain species in particular. However, it is also observed that rhinos select plants with shorter height and smaller DBH. Thus, vegetation utilisation by elephants and rhinos seem complementary. During this study it was also noted that there is secondary damage caused to some plants by insects and lack of seedlings in the sampled population. This require further investigation in order to manage and protect vegetation for rhinos. Elephants use different tactics to break fences and also quickly learn to overcome increased resistance created by modified fences. By further investigation of these methods more successful fences could be developed for exclusion zones. Current efforts by LWC to reduce pressure on vegetation caused by elephants, addresses only the symptom, but it is important to tackle the human caused disturbances in the surrounding areas and facilitate dispersal to manage elephant populations within LWC.

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csv	comma separated values
GIS	Geographic Information System
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
KWS	Kenya Wildlife Service |
LWC	Lewa Wildlife Conservancy
STE	Save the Elephants
UNESCO	United Nations Educational, Scientific and Cultural Organization

1 Introduction

1.1 Background

Threats to biodiversity are increasing daily and rapid growth of the human population is a key factor that impacts Earth's biodiversity (Kerr & Currie 1995; McKee et al. 2004). Anthropogenic activities such as urbanisation and agricultural expansion (Mckinney 2002; Rouget et al. 2003) resulting in habitat loss, habitat alteration, increased pollution (Fitzherbert et al. 2008) and diseases (Daszak et al. 2001; Bradley & Altizer 2007) are threatening wildlife and driving species towards extinction. It has been a great challenge to accommodate human needs and conserve biodiversity at the same time and various conservation efforts are being carried out by scientists and conservation practitioners to achieve this.

Human wildlife coexistence (Madden 2004; Gadd 2005) and land sparing vs. land sharing (Fischer et al. 2008; Phalan et al. 2011; Grau et al. 2013) are widely discussed concepts today. Keeping animals away from humans or humans away from animals is what is commonly practiced to reduce conflict (Osborn & Parker 2003; Packer et al. 2013), where conservation fences have become an important tool. There are many instances of conservation projects resulting in unintentional outcomes, which are quite common in reintroduction programmes (Walker et al. 2008). Fencing for conservation is another instance that has resulted in unintentional impacts on wildlife (Jaeger & Fahrig 2004; Mbaiwa & Mbaiwa 2006; Hayward & Kerley 2009). In addition to controlling human wildlife conflict electric fences are also built to reduce the impact of introduced predators or control diseases (Taylor & Martin 1987; Hayward & Kerley 2009). These are costly to build but allows a defined unit for managers with the goal of separating biodiversity from its threats. However, fences may also result in isolated populations and inbreeding, reducing potential for evolution (Hayward & Kerley 2009) and they may also cause resistance to movement and access to resources, especially for migratory mega-herbivores like elephants (Loarie et al. 2009b). This study investigates such an instance where a fenced protected area is facing problems in conserving their target species due to intolerable levels of elephants inhabiting the land.

1.2 Elephants and electric fences

With resources patchily distributed both spatially and temporally, elephants need to travel long distances in search of food and water at specific times (Cushman et al. 2005). Thus, fences may restrict elephant movement and reduce seasonal differences in elephant movement (Loarie et al. 2009b). This in turn has adverse effects on habitats due to high intensity browsing and degradation of vegetation (Ben-Shahar 1993; Lombard et al. 2001).

Fences, have proven to be ineffective as elephants have learnt to break these fences (Thouless & Sakwa 1995). Moreover, increase in human population in the boundary of the fenced areas lead to an amplification in human elephant conflict (Sitati et al. 2005; Lee & Graham 2006). Thouless & Sakwa (1995) revealed that voltage or the design of the fence did not determine the effectiveness of the fences. They reported that elephants should perceive fenced areas as unsuitable areas rather than physical barriers, and fear of being shot seemed to be a more proximal and effective deterrent.

1.3 Conservation status of African savannah elephants

In 1970's and 1980's the decline of African savannah elephant (*Loxodonta africana*) population due to poaching and illegal trade in ivory was a major issue in conservation (Douglas-Hamilton 1987). The recovery of elephant populations in protected areas in Kenya and Southern African countries after the worldwide ban for ivory trade in 1989 is heralded as the greatest conservation success of recent times (Huxham 2002; Skarpe et al. 2004; Blanc et al. 2005; Cushman et al. 2010). Despite the recovery of the population numbers with more than 10,000 mature individuals inhabiting a large geographical range (IUCN 2012), the African elephant is considered vulnerable because more than 80% of their range is in unprotected areas (Blanc et al. 2005; Blanc et al. 2007) and are still threatened by habitat loss and fragmentation due to human population expansion, and poaching (Blanc 2008). Their populations can grow to large numbers where protected, but they risk extirpation from unprotected areas (Blake & Hedges 2004; Van Aarde & Jackson 2007; Loarie et al. 2009a). Human interventions such as supplementation of water, creation of fences and fragmentation of the landscape that prevent natural dispersal are the main reasons for high abundance of elephants in certain areas (Chamaillé-Jammes et al. 2007; Van Aarde & Jackson 2007). Therefore proper management of elephant populations is important for their conservation.

1.4 Status of elephants in Kenya

Kenya is a stronghold of the elephant range where the population size is about 37 000 (KWS 2013). The elephant population in savannah habitats seems to be an increasing or stable population. However, not much is known of the elephants in the forests of Kenya. Poaching has increased in the past decade in some of the key elephant populations in Kenya such as Tsavo, Laikipia–Samburu and Marsabit areas. Habitat encroachment by humans, habitat and population fragmentation, cutting off historical elephant corridors are some of the other main threats affecting elephant populations in Kenya (Thouless et al. 2008).

In northern Kenya lie isolated protected areas distributed among pastoral lands, mainly in the Samburu-Laikipia ranges. This ecosystem supports approximately 7415 elephants, which is the second largest population in Kenya (Litoroh et al. 2010) which increased from 5447 elephants counted in 2002 (Omondi et al. 2002). There seems to be an influx of elephants from arid areas to parts of northern Kenya (Thouless 1994). Among these fragmented protected areas in Laikipia- Samburu range is Lewa Wildlife Conservancy, which is a fenced protected area with purposely built elephant gaps linking the neighbouring lands (Douglas-Hamilton et al. 2005).

1.5 The Lewa paradigm

Lewa Wildlife Conservancy is a UNESCO world heritage site inscribed to the Mount Kenya World Heritage site in 2013 (LWC 2015b). It was first established as Ngare Sergoi Rhino Sanctuary in 1983 with the focus of conserving the endangered black rhinoceros (*Diceros bicornis*). It was later re-established under the name Lewa Wildlife Conservancy (hereafter LWC) in 1995 (LWC 2015a). It has now reached its sustainable level of 70 individuals of black rhinos and about 20 in excess have been translocated to restock previously inhabited or new suitable habitats in northern Kenya (Taylor 2013; LWC 2015a). By 1994, the entire conservancy was enclosed by a 2.5 m high electric fence, creating a 250 km^2 rhino sanctuary which is now home to 10% of Kenya's black rhino population (LWC 2015a). LWC's fence has been established mainly to control rhino poaching and maintain populations at sustainable levels. These fences also prevent animals, roaming outside the conservancy and into human settlements, and so are important in reducing human wildlife conflict.

During the 1950's there were no or very few elephants in LWC and almost the entire land was forested (S. Brown. pers. comm). In contrast to this today there are more open landscapes and holds elephant numbers above tolerable levels specified by the management. It is home to about 200 elephants, and is a very popular habitat during the dry season with close to 400 immigrating to take advantage of permanent water sources and good foraging biomass (Mutinda & Chege 2013). Thouless (1993) also reported that there were almost no elephants in the Laikipia district which borders LWC from west, during early 20th century and elephants started moving south in the late 1960's due to high intensity of poaching that took place in Samburu.

At present elephant movement in LWC is facilitated by several fence gaps. Despite the establishment of gaps to alleviate the resistance to movement and improve access to resources, the increased elephant population is resulting in irreversible damage to vegetation due to over browsing. This is raising concerns that elephant damage to plants will affect the availability of rhino browse (Chege et al. 2006).

With the intention of protecting vegetation for rhinos, LWC has created exclusion zones separated by electric fences which is set up about 2 m above ground allowing smaller herbivores to pass beneath them but preventing elephants utilizing and degrading these areas (Chege et al. 2006). However, elephants have now developed various methods of breaking fences. They break fences by pushing the posts with their legs or by moving them using their tusks, so that the live wire gets displaced and short circuit on the earth wire (Thouless & Sakwa 1995; Mutinda et al. 2014). Apart from breaking fences elephants have also learnt to creep under the fences of these exclusion zones (Fig. 1.1). Now there is a report of a fence breaking at an exclusion zone almost every day (LWC unpublished data). However, it can be seen that some exclusion zones fences are being broken more than the others and hence may be experiencing more vegetation damage than the others.

Damages are mainly caused by bull elephants and to a lesser extent by female family groups (Mutinda et al. 2014). LWC has translocated 4 such bull elephants causing problems to Meru National Park (Mutinda & Chege 2013) and one of them have managed to find their way back to the conservancy (LWC 2015c). Elephants are being detusked to prevent them from causing future damages to fences with tusks, which are good insulators and are used frequently to displace wires. However, detusking is not so effective as elephants soon learn to use their tusk stumps to break fences (Thouless & Sakwa 1995; Mutinda et al. 2014).

Fig. 1.1 Elephant crawling under a recently modified exclusion zone fence

(Photographed by Kimeli Maripet)

Thus LWC is facing problems with elephants transforming the landscape and causing economical loss by damage to fences. LWC management has the perception that insecurity incidents such as poaching, road banditry, livestock theft, tribal conflict etc. occurring in the surrounding communities could be driving elephants to Lewa. With the very high level of armed security maintained in Lewa, poaching pressure and other hostile events are lower compared to surrounding conservancies (LWC unpublished data). Previous studies have shown that elephants may change their range and distribution in response to human disturbance (Hoare & Du Toit 1999; Buij et al. 2007). Elephants travel faster through unprotected areas compared to protected ones as well (Blake 2002; Huxham 2002; Douglas-Hamilton et al. 2005; Graham et al. 2009). Behaviour of wildlife are found to be influenced by noise (Bowles 1995). Buij et al. (2007) reported sounds of vehicles to disturb elephants. Elephants communicate through infrasound (Poole et al. 1988). It has been shown that elephants vacate areas of culling operations and it is suspected that the injured elephants emit an infrasound signal that may disturb other elephants (Whyte 1993). Taking these in to considerations it is important to address the issue of high number of elephants in LWC by finding its causal factors and determine the effectiveness of the current management efforts for the better management of elephant populations.

1.6 Objectives

The main objectives of this study were

1. To determine influence of insecurity events on high elephant numbers immigrating to LWC by studying their movement
2. To determine the damage to vegetation in LWC, and effectiveness of exclusion zones
3. To assess methods of fence breakages

The goal of this research was to derive best practice guidelines for the use of fences in conservation through understanding elephant movement and maximising their dispersal.

2 Material and methods

2.1 Study area

2.1.1 Location

LWC (0°11'36.03"N, 37°27'4.22"E) is located in Isiolo district in north-central Kenya. It covers an areas of 250 km^2 (Chege et al. 2006) including the Ngare Ndare forest in the south. From the north it is bordered by Il Ngwesi Wildlife Conservancy and Leparua Community Conservancy and from the west by Borana Conservancy (Fig. 2.1). From the south and east it is bordered by several villages.

2.1.2 Climate and vegetation

LWC has a long term mean rainfall of 545 mm and has a semi-desert climate. Rainfall follows a bimodal distribution pattern with long rains received from March to May and short rains received from October to December (Chege et al. 2006). LWC extends from steep lower slopes of Mount Kenya to the flatter grassland to the North. It is located within the migration routes of African elephants of the Mount Kenya and the Somali/Massai Ecosystem (IUCN 2013).

LWC lies between the ecological zones of montane forest ecosystem and semi-arid savannah grasslands. *Acacia seyal* and *A. drepanolobium* are the abundant plant species at higher altitudes and *Acacia mellifera, A. tortilis, A. nilotica* and *Commiphora spp* are abundant in lower altitudes. *Acacia xanthophloea* is abundant near wetland areas (IUCN 2013). Community livestock grazing is allowed in some parts of the conservancy, where otherwise would be subjected to prescribed burning. This is done to control *Pennisetum stramineun* and *P. mezianum* dominated blocks and improve diversity of grasslands for wildlife (Chege et al. 2006).

2.1.3 Gaps, fences and exclusion zones

LWC is connected to Borana Conservancy, to the west through the Western gap, to the communal pastoral lands by the Northern gap and to Mount Kenya through the southern border by the more recently established Mount Kenya underpass (beneath the National A2 highway). See Fig. 2.1 for the location of fence gaps.

Currently there are 18 exclusion zones covering about 27.6 km^2 (Fig. 2.1) which is approximately 11% of the total area demarcated by the main boundary. The main boundary fence is a twelve strand fence. Some strips of the fence have a net from ground till the ninth wire and are called predator fences. The exclusion zone fences are mainly of two strands. There are some private properties within the conservancy with two to three strand fences and one exclusion zone (Lewa Safari Camp) with a short fence, 0.5 m high with long wire stingers (0.75 m long) facing outwards. In a single exclusion zone, different sections may have different configurations such as with stingers or without stingers. There is a predator fence installed surrounding the Manyangalo village that is located within the conservancy, hence the sections of exclusion zones that border Manyangalo have predator fences. Some exclusion zones are currently being modified to a more complex two strand fence with stingers facing outwards.

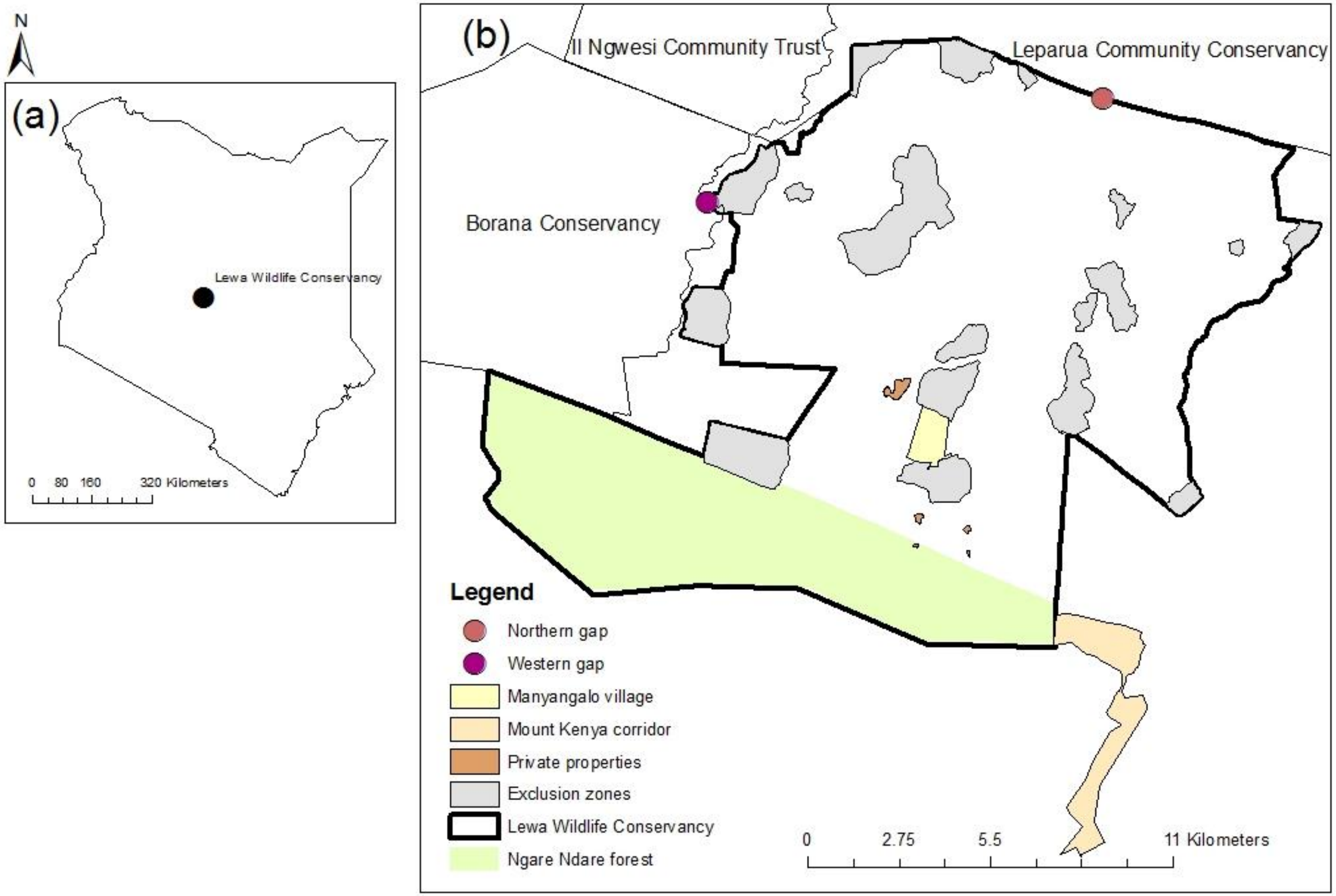

Fig. 2.1 Map of Lewa Wildlife Conservancy

(a) Location of LWC in Kenya (b) Enlarged map of LWC

2.2 Data collection

2.2.1 Data from existing databases maintained by LWC

Elephant movement through main border fence gaps

Camera traps have been set up at three fence gaps. The photo data were retrieved weekly by the LWC research team and wildlife moving inward and outward were counted. Before 2013 data collection was not consistent due to logistical issues. Hence for this study elephant movement from January 2013 to December 2014 have been used.

Insecurity events

Daily records of insecurity events occurring within LWC and surrounding conservancies are recorded by the LWC Operations room. These insecurity events include events such as poaching, livestock theft, road banditry, arrests, gun shots heard, armed men sighted and arrests. For details please see appendix A. From the descriptions in the database each incident was categorised according to the classification in Table 2.1.

Table 2.1 Classification of insecurity incidents

Category	Classification
Distance	Inside LWC, Within 25 km from LWC boundary (0 -25 km) Between 25 km -50 km Beyond 50 km
Gunfire	Gunfire events (gunfire heard or exchanged) Other events (gunfire not recorded)
Insecurity type	Poaching Road banditry and theft Other hostile events

Fence breaking

Main boundary and exclusion zone fences are being monitored daily by fence patrols (each exclusion zone and sections of the main boundary are allocated to a particular fence man) and any fence breaking events are reported to the LWC radio room which coordinates with the head of fence office and elephant monitoring officer to take necessary actions. The elephant monitoring officer would then visit the location and collect details such as Global Positioning System (GPS) location of breakage, date and time of damage, type of fence, type of damage (wires snapped, crawled under or stepped over the wire) and where possible identify the animal/s responsible for the incident. These data are entered in to a database. This problem elephant database maintained by LWC was obtained and modified for further analysis.

Rainfall

Daily rainfall data are being collected at 12 stations around LWC and daily average was calculated from the data recorded in 2013 and 2014.

2.2.2 Remote sensing data and GIS layers

Geographical Information Systems (GIS) shape files

Shape files of LWC boundary, exclusion zones, bordering community conservancies were obtained from the LWC research team. In addition shape files for conservancies, ranches, forests and sanctuaries surrounding LWC were obtained from the Northern Rangeland Trust. Some private properties, exclusion zones and fence along the government road that runs inside LWC for which shape files were not available were mapped by walking along the electric fences with a GPS unit (Garmin GPSMAP 64). The objective of mapping all possible fences was for creation of maps and the use in a future analysis

GPS collar data

GPS collars have been fitted to many elephants across Kenya, in a long term monitoring study conducted by the Save the Elephants (STE) organisation. A memorandum of understanding was signed between STE and Marwell Wildlife to share location data of collared elephants who had intersected with LWC. Out of this, elephant collar data from January 2013 to May 2015 were used for the analysis.

Normalised Difference Vegetation Index

Normalised Difference Vegetation Index (NDVI) is a metric which is directly related to green biomass. Smoothed, 250 m resolution, 16 day composite, Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI images for the study area from 2000 to May 2015 were downloaded from the freely available data service platform run by University of Natural Resources and Life Sciences, Vienna (Vuolo et al. 2012).

Contours for altitude and slope

Using Google Earth Pro (2015), closely spaced points were created on the surface of the satellite map of the area covered by the selected collared elephants. TCX Converter (2014) was then used to generate altitude data in a comma separated value (csv) file. This csv file was then read to ArcGIS (ESRI 2014) and first converted to a raster and then to polygon contours using the Spatial Analyst tool. Using the slope tool, a raster with slopes was created and reclassified as given in Table 2.2.

Table 2.2 Scale for slope based on natural breaks

Slope (in degrees)	Scale
0-2	1
2-5	2
5-15	3
15-30	4
30-85	5

2.2.3 Vegetation sampling survey in exclusion zones

Woody vegetation structure and utilisation by elephants in exclusion zones were measured in 65 sample plots of 20 m x 20 m (Table 2.3, Fig. 2.2). Selection of sampling plots were done in several steps. First a fish net grid with 20 m x 20 m polygons were created and projected on the polygon of LWC. The polygons for exclusion zones were clipped from the fish net grid using the clip tool. Then selection of sampling plots was done initially by stratified random sampling (using the Sampling Design Tool add in for ArcGIS) where 60 sample units were initially selected (decided based on feasibility with time and resources available). Using this tool random polygons were selected from a clipped grid of polygons in relation to the total area of each exclusion zone. However, this resulted in five small exclusion zones being allocated only one sample quadrat. Due to the variation of plant distribution within an exclusion zone, another sampling quadrat was selected randomly for those exclusion zones so the minimum number of quadrats per exclusion zone was two.

Table 2.3 Number of sample plots for each exclusion zone

Exclusion zone	Number of quadrats
Anna Merz (AM)	10
Ngare Ndare (NN)	6
Head Quarters (HQ)	5
Kariyonga (KA)	5
Konasafi (KO)	5
Mawingu (MW)	5
Sirikoi (SI)	4
Digby's (DI)	4
Leparua (LE)	3
Mlima Mwitia (MM)	2
Willie Roberts (WR)	2
Kifaru (KI)	2
Lewa Safari Camp (LSC)	2
Mama's Place (MA)	2
Matunda (MT)	2
Sambara (SA)	2
Wilderness (WI)	2
Luchimi Meza (LM)	2

The location of quadrats selected using the GIS software sometimes had to be changed on reaching the site because it was not feasible to reach some of these locations by vehicle and walking long distances in the conservancy was not advised for safety. Quadrats were established by marking each plot with string attached to four wooden pegs. The survey was carried out from late April to mid May 2015.

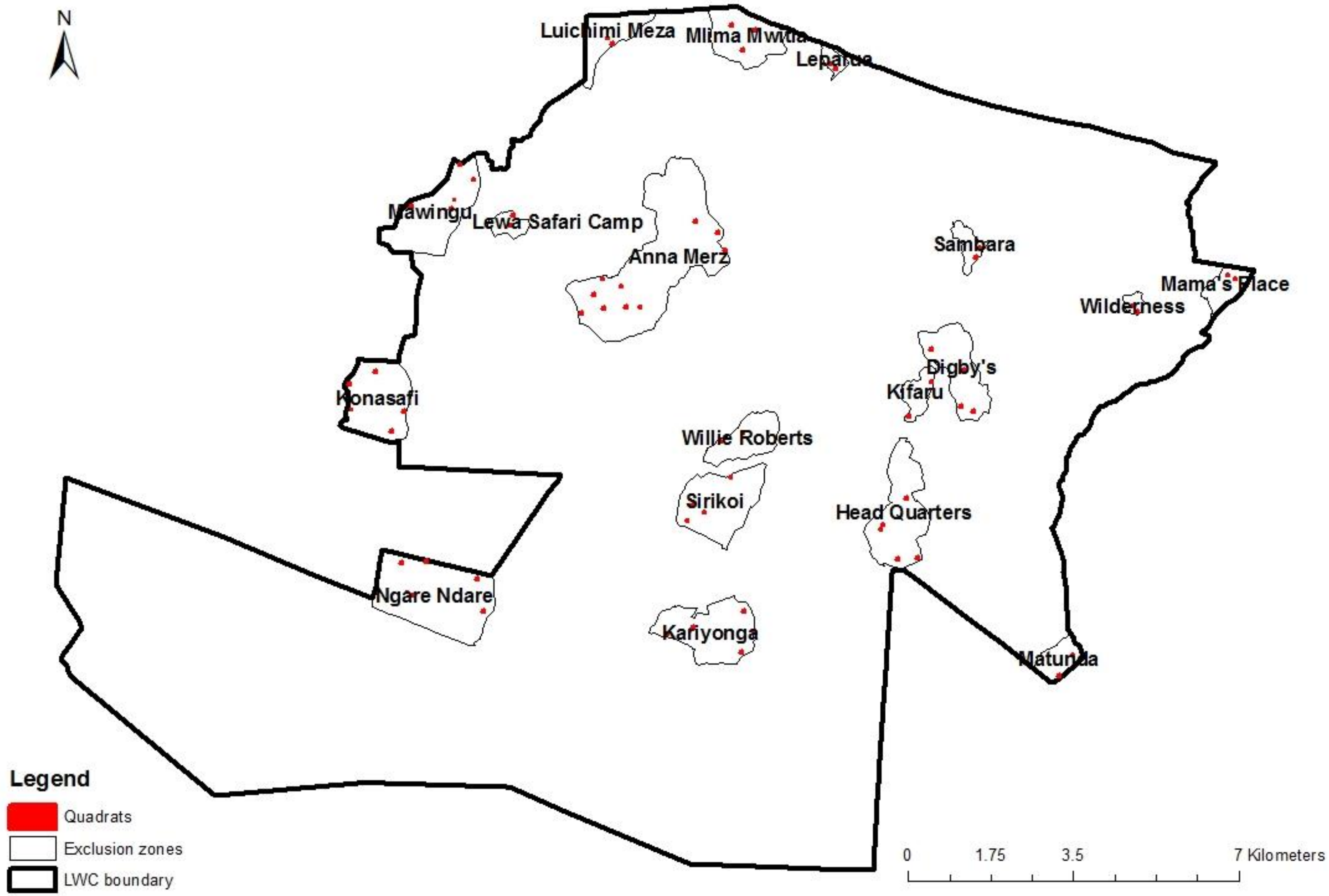

Fig. 2.2 Distribution of sampled quadrats

2.2.3.1 Determination of vegetation structure

Each living and dead woody plant species was recorded and following measurements were obtained (canopy width, even though not used in the analysis was recorded for possible future use). Plant species identification was achieved mainly by recording the local names (in Massai) with the assistance of the LWC field assistants or photographing them and then determining the scientific name with the help of taxonomic experts or by using the plant field guides (Beentje 1994; Giesen et al. 2007).

1. Height

Height of felled trees were measured using a measuring tape. The height of standing trees <7 m were measured using a telescoping measuring stick and height of trees >7 m were calculated using the sine method (Larjavaara & Muller-Landau 2013) and required measurements were taken using the laser range finder (Leica Rangemaster 1600B). Height was classified using the classification used in Baxter & Getz (2005) as given in Table 2.4.

2. Stem girth at breast height

Girth at breast height (GBH) was measured, at 1.3 m for stems ≥ 2.6 m tall. For stems ≤ 2.6 m tall were measured at half their height as suggested by Batcheler (1985). Where more than one stem occurred at the GBH measurement point, each stem was measured and the mean size girth was used to calculate the mean diameter at breast height (DBH). Following Banda et al. (2006) DBH were classified as given in Table 2.5.

3. Canopy width

Each tree was viewed from all sides to determine where the canopy is widest and narrowest. Two poles were then erected to mark the edges of each and the distance was measured using a measuring tape. The canopy width was calculated by averaging the widest and narrowest measurements.

Table 2.4 Height classification based on Baxter & Getz (2005)

Meta class	Sub-class	Height range (m)
Seedling	1	<0.15
Saplings	2	0.15-0.3
	3	0.3-0.5
	4	0.5-0.75
	5	0.75-1.0
Shrubs	6	1.0-2.0
	7	2.0-3.0
Trees	8	3.0-5.0
	9	>5.0 (beyond browsing height)

Table 2.5 Classification of DBH based on Banda et al. (2006)

DBH class	DBH range (cm)
A	<2
B	2-10
C	10-20
D	20-30
E	30-40
F	40-50
G	>50

2.2.3.2 Measuring damage to woody vegetation by elephants

The condition of each tree sampled with relation to damage caused by elephants and other factors were recorded as follows.

a) Time of damage - old or new
b) Agents of damage - elephant, rhino, other damage (other herbivore, human, wind, bush fire)
c) Damage category - damage caused by each agent was classified based on Jacobs & Biggs (2002) as in Table 2.6.

Agents causing damage and time of damage was classified based on Ben-Shahar (1993). See Appendix B for details of each category.

Table 2.6 Classification of damage category based on Jacobs & Biggs (2002)

Tree type	Damage category
Living tree	No damage (ND)
	Light (L)
	Moderate (M)
	Heavy (H)
	Extreme (EX)
Dead tree	Standing (DS)
	Uprooted (DU)
	Felled (DF)

2.2.4 Camera trapping at fences of exclusion zones

Camera traps were set up around exclusion zones to capture fence breaking incidents. Due to the large size of exclusion zones and many potential points of elephants breaking in, careful placing of camera traps was important. We set up 15 camera traps (Bushnell trophy cam-model 119636) in locations that were broken frequently (see Fig. C.1 in Appendix C) in Karionga, Sirikoi, Head Quarters and Digby's. The total trap nights were 630 (six weeks). In the first week seven camera traps were set on video mode, however was later changed to photo mode for ease of data retrieval and analysis during the limited time available. The photo data were retrieved each week to find if any fence breaking incidents were captured. Each camera trap was moved after 3 weeks to another location.

Each camera trap was set up facing the fence from inside or outside the exclusion zone or on a fence post, depending on the availability of substrate to attach. When a suitable substrate was not available a wooden post was used to attach the camera trap. Care was taken not to attach the camera to a post near a wire frequently broken or a tree with a high chance of being pushed over. Metal boxes with padlocks and chains were used in some exclusion zones to prevent from being stolen.

2.3 Data Analysis

Except where indicated all analysis were conducted using R statistical software (R Core Team 2014) and ArcGIS 10.2 (ESRI 2014). The confidence interval considered for all analyses was 95%, thus p value < 0.05 were considered to be significant.

2.3.1 Effect of insecurity events on elephant movement across gaps

Spearman correlation test was carried out to find the correlation between inward and outward movement of elephants in 2013 and 2014. The first difference was calculated by subtracting inward and outward movement on each day from the number moved inwards and outwards on the next day respectively. This was done to detrend the data and show only absolute changes in response variable. Since the time of events were not considered and most incidents occurred in the evening or at night, it was important to use first differences which allowed to see change in movement in relation to the previous day.

This was then analysed with occurrence of daily insecurity events. The number of insecurity events occurring each day ranged from 1-2. Therefore for the analysis, occurrence of each event category was recorded as “Yes” or “No”.

Elephants are known to respond to disturbances very far away from their location (Hoare & Du Toit 1999; Buij et al. 2007). Elephants communicate with conspecifics from several kilometres away (Poole et al. 1988; Langbauer et al. 1991) and flee away in response to warning calls by others (O’Connell-Rodwell et al. 2000). It has been found that a call can be heard from more than 10 km away and may cover an area between 15 – 300 km^2 (Garstang 2004). Therefore it was assumed that elephants may respond to events with gunfire occurring even further away. Elephants have shown linear displacement of 58 km in two days (Blake 2002). For this analysis, events beyond 50 km were not utilised as it was assumed that these events will not affect elephants moving into or out of LWC the very next day.

Buffer strips of 25 km and 50 km were drawn using the buffer tool on a map of LWC with the neighbouring areas to identify locations within each distant category. Data were analysed using a generalised linear model (GLM) with a Gaussian distribution to identify factors affecting elephant movement. The analysis was conducted only for days in which an insecurity event was recorded. In each model daily rainfall was also included as an explanatory variable as rainfall is a key determinant of elephant movement (Whyte 1993; Chamaillé-Jammes et al. 2008). The minimum adequate model for each initial model was obtained through model simplification by removal of insignificant terms.

2.3.1.1 Impact of gunfire events

To test the impact of occurrence of events with gunfire, the first difference was analysed with the following explanatory variables (Table 2.7)

Table 2.7 Explanatory variables tested in the GLM Model for effect of gunfire events

Variable type	Explanatory variable in the model*
Individual variables	Gunfire events (inside LWC)
	Gunfire events (0 to 25 km)
	Gunfire events (25 to 50 km)
	Other events (inside LWC)
	Other events (0 to 25 km)
	Other events (25 to 50 km)
Interaction terms	Gunfire events (inside LWC) : Other events (inside LWC)
	Gunfire events (0 to 25 km) : Other events (0 to 25 km)
	Gunfire events (25 to 50 km) : Other events (25 to 50 km)
	Gunfire events (0 to 25 km) : Gunfire (25 to 50 km)
	Other events (0 to25 km) : Other events (25 to 50 km)

*All terms were tested for detectable interactions with rainfall

2.3.1.2 Impact of insecurity types

To test the effect of different insecurity types on elephant movement, the first difference was analysed with the following explanatory variables (Table 2.8)

Table 2.8 Explanatory variable tested in the GLM model for the effect of insecurity types

Variable type	Explanatory variable in the model*
Individual variables	Poaching events (inside LWC)
	Road banditry and theft (inside LWC)
	Other hostile events (inside LWC)
	Poaching events (0 to 25 km)
	Road banditry and theft (0 to 25 km)
	Other hostile events (0 to 25 km)
	Poaching events (25 to 50 km)
	Road banditry and theft (25 to 50 km)
	Other hostile events (25 to 50km)
Interaction terms	Poaching events (0 to 25km) : Poaching events (25 to 50 km)
	Road banditry and theft (0 to 25 km) : Road banditry and theft (25 to 50 km)
	Other hostile events (0 to 25 km) : Other hostile events (25 to 50 km)

*All terms were tested for detectable interactions with rainfall

2.3.2 Speed of elephant movement with location

GPS collar locations from January 2013 to May 2015, which included two females and five males were selected. Using the "movement.pathmetrics" command in Geospatial Modelling Environment (Beyer 2012), time interval and step length (distance between two consecutive points) were calculated for each individual. The records with time difference of one hour ± 15 minutes (3600 s ± 900 s) were selected for further analysis. The hourly distances were calculated for those with time fixes ± 900 s.

Each location was then categorised according to location as "Lewa" (points within LWC), "Corridor" (points within the elephant corridor) and "Outside" (points falling outside LWC and corridor). Corridor was considered as a separate category as it is a strip of fenced area outside LWC, which is used as a travel route. Thus the factors affecting speed of movement within this strip could be very different from the rest of the areas. Records were also categorised according to time of day, with fixes between 0600 h and 1859 h as "Day" (light hours) and fixes between 1900 h to 0559 h as "Night" (dark hours).

Each point was also allocated the NDVI value for the particular day based on 16 day composite MODIS NDVI images by extracting values from raster to points. Each location was also allocated the altitude and slope by joining attributes based on spatial location.

Using the R package lme4 a linear mixed effect model analysis was carried out for log transformed speed (transformed to reduce the skewness and increase the fit of residuals to a normal distribution). Location, time, altitude, slope and NDVI were given as fixed effects and individual animal was given as a random effect. Using the R package MuMIn, a global model was analysed by model averaging method explained in Grueber et al. (2011). The global model tested interaction between time of day with location and interactions between altitude, slope and NDVI.

The primary focus of this analysis was to infer if the hourly speed of movement is affected by location and time of day. However, because previous studies have shown that elephant movement is influenced by slope, altitude and NDVI, they were included in the model to deduce the best fit model.

2.3.3 Change detection maps using NDVI images

Using the cell statistics function in Spatial Analyst, the mean NDVI values for each year (2000 to 2014) were computed from all raster images obtained for each year. The change in mean NDVI values between 2000 and 2014 and then every two years from 2000 to 2014 were computed using the Difference function in the Image analysis tool. Raster maps were created to depict the change.

2.3.4 Effectiveness of exclusion zones and fences

The damage to woody plants by elephants and rhinos were analysed with height class, DBH class, exclusion zone and species of plant using a chi square test. Shannon Wiener diversity index (H); Eq. (2.1) and density (per square meter) were calculated for each exclusion zone. A generalised linear model with a binomial distribution was used to find the relationship of proportion of damaged plants with diversity and square root of density. A linear regression analysis with log transformed number of fence breaking events from January 2013 to March 2015 was used to explore for any relationship with diversity and square root of density of plant species in the exclusion zones. Log transformed number of fence breaking events and square root of density was used to increase normality of residuals. Spearman correlation analysis was also conducted between log fence breaking events and percentage of damaged plants.

Eq. (2.1) $$H = -\sum_{i=}^{s} pi \ln (pi)$$

pi= Number of individuals of species i/ total number of plants

s = number of species

3 Results

3.1 Effect of insecurity on elephant movement across gaps

A total of 719 insecurity events were recorded between 2013 and 2014. Out of this 48, 201 and 186 were recorded inside LWC, within 25 km from LWC and 25 to 50 km from LWC boundary respectively, totalling to 426 events. These insecurity events spanned across 296 days out of the 730 days of the two years.

3.1.1 Inward and outward movements across gaps

There is a moderate positive correlation between inward and outward movements in LWC (Fig. 3.1) with a relatively constant number of elephants in LWC throughout (r_s=0.39, df= 686, $p < 0.01$).

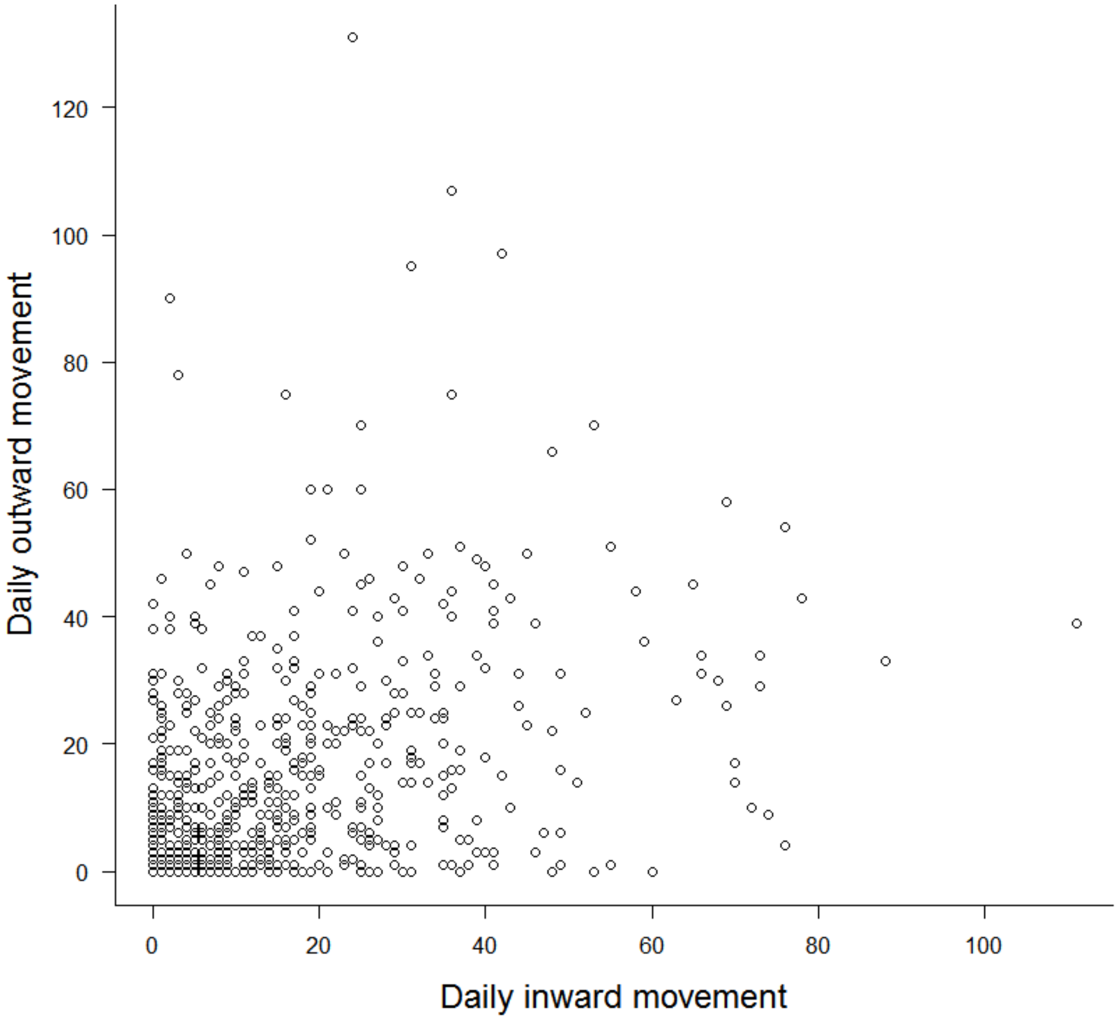

Fig. 3.1 Daily number of elephants entering and leaving LWC

3.1.2 Elephant movement with gunfire events

The first difference of inward movement did not show any detectable response to occurrence gunfire events and events with no gunfire recorded at any distance category. However, with first difference of outward movement the minimum adequate model (Table 3.1) exhibit a detectable relationship with two interaction terms. Effect of gunfire events inside LWC on increasing outward movement was modulated by occurrence of other events inside LWC. Impact of occurrence of other events within 25 km from LWC in decreasing outward movement was modulated by the occurrence of other events within 25 to 50 km from LWC border. These interactions are depicted in Fig. 3.2.

Table 3.1 Components of the minimum adequate model with first difference of outward movement

Explanatory variable/ interaction terms	*t* value	df	*p* value
Gunfire events (inside LWC)	-1.81	276	0.07
Other events (inside LWC)	-1.4	276	0.16
Other events (0-25 km)	0.59	276	0.55
Other events (25-50 km)	0.24	276	0.81
Gunfire events (inside LWC) : Other events (inside LWC)	2.54	276	0.01
Other events (0-25 km) : Other events (25-50 km)	-2.11	276	0.03

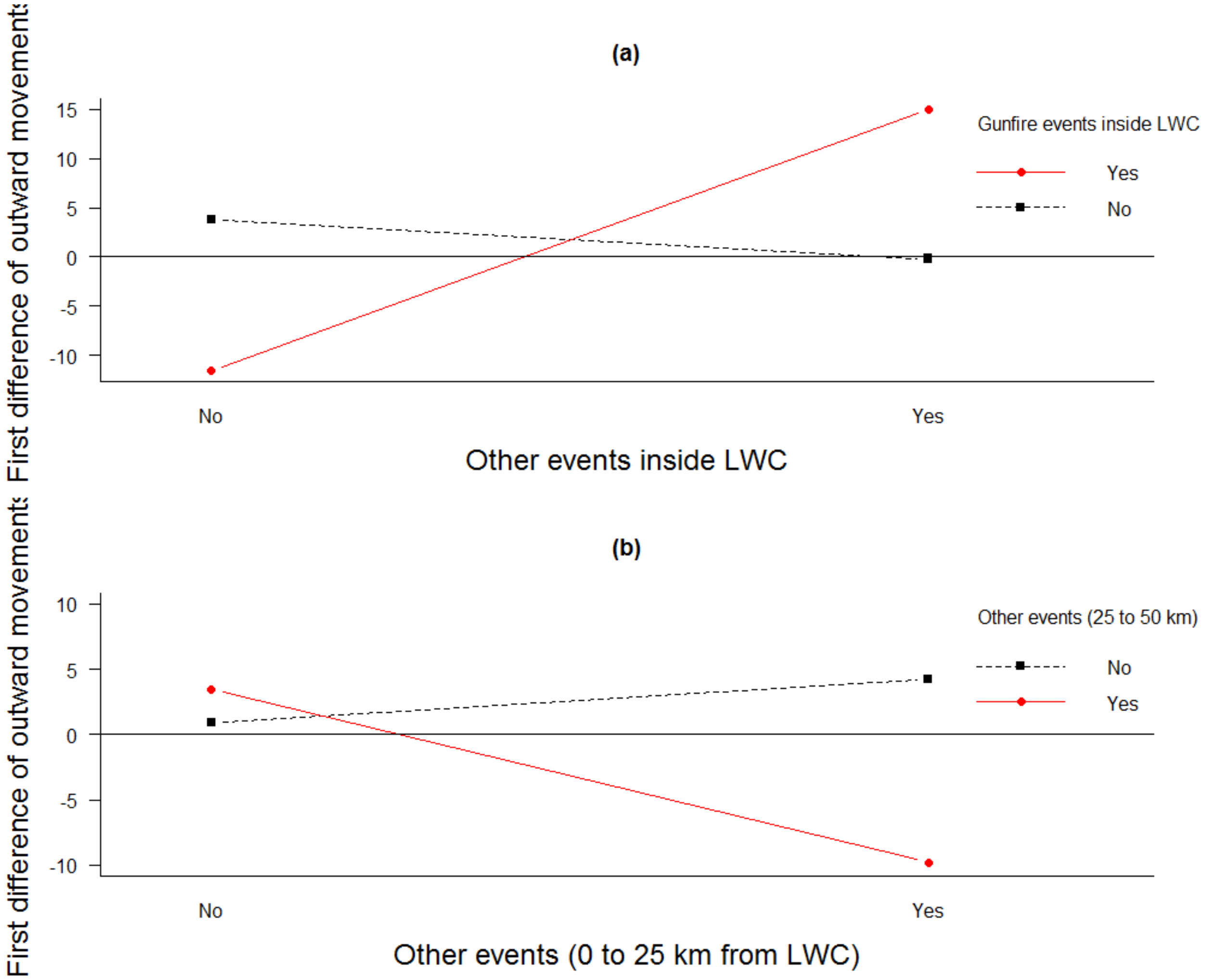

Fig. 3.2 First difference of outward movement of elephants with events with gunfire

(a) occurrence of gunfire events and other events inside LWC, (b) occurrence of other events within 25 km from Lewa and within 25 to 50 km from LWC.

3.1.3 Elephant movement with insecurity type

There are detectable relationships between some of the insecurity types with first differences of both inward and outward movements as shown in Table 3.2Table 3.3. Poaching events inside Lewa negatively influence inward movement of elephants. However, poaching events inside LWC is controlled by rainfall. Effect of occurrence of poaching events within 25 km from LWC boundary in increasing inward movement was dependent on the occurrence of other insecurity events within 25 km from LWC. Analysis of insecurity types with first difference of outward movement revealed that effect of poaching events from 25 to 50 km from LWC, in decreasing outward movement was dependent on rainfall. These detectable relationships are depicted in Fig. 3.3Fig. 3.4.

Table 3.2 Minimum adequate model for first difference of inward movement of elephants with insecurity types

Explanatory variable/ interaction terms	*t* value	df	*p* value
Poaching (inside LWC)	-2.91	276	<0.01
Other hostile events (0 to 25 km)	-0.97	276	0.33
Poaching (0 to 25 km)	-1.38	276	0.16
Rainfall	-0.10	283	0.92
Poaching (inside LWC):Rainfall	2.75	283	<0.01
Other hostile events (0 to 25 km) : Poaching (0 to 25 km)	2.75	283	<0.01

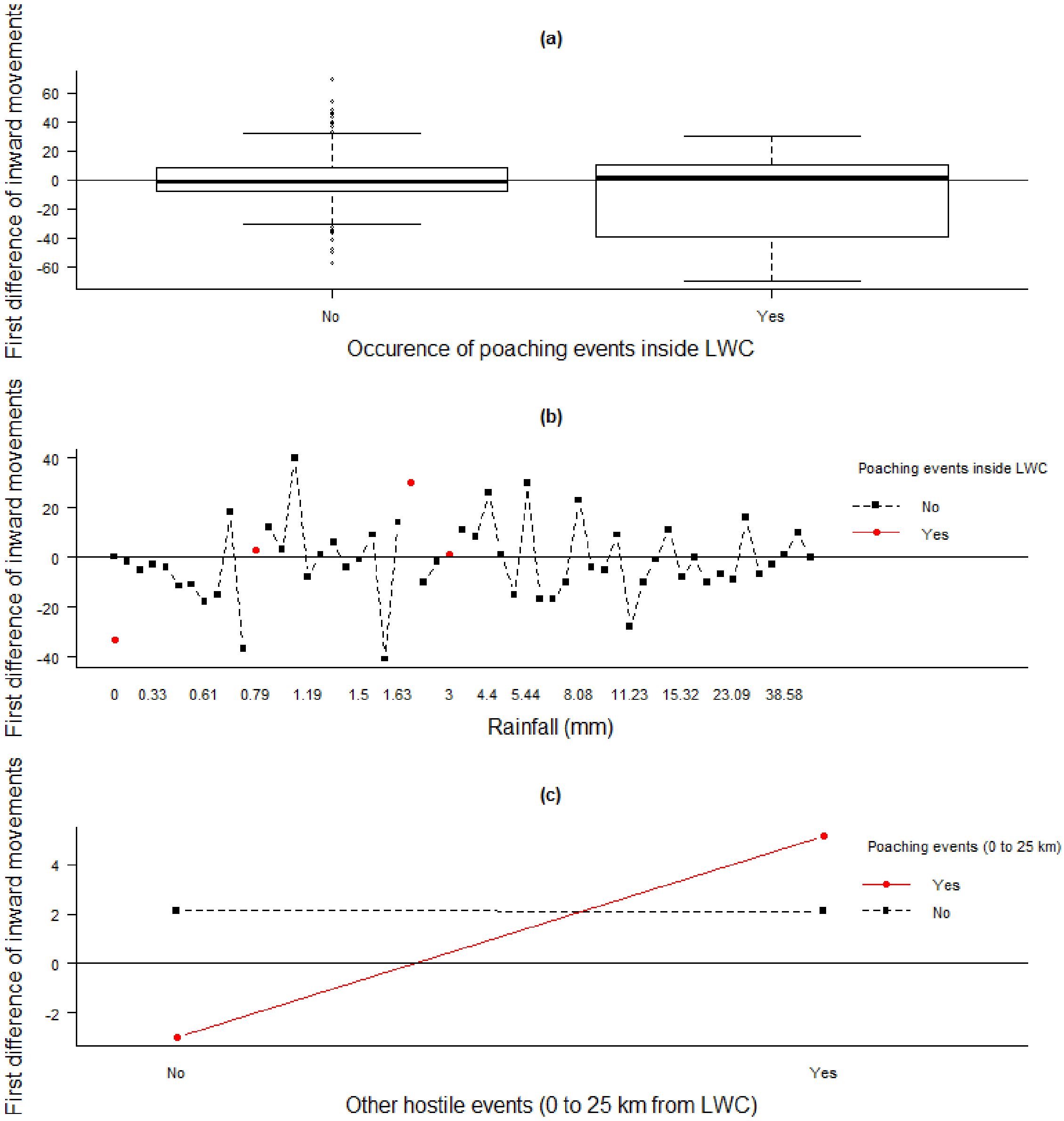

Fig. 3.3 First difference of number of elephants moving inwards with insecurity types and rainfall
(a) poaching (inside LWC), (b) poaching (inside LWC) and Rainfall (c) other hostile events (0-25 km) and poaching (25- 50 km)

Table 3.3 Minimum adequate model for first difference of outward movement of elephants

Explanatory variable/ interaction terms	t value	df	p value
Poaching (25 to 50 km)	1.48	279	0.14
Rainfall	1.38	279	0.17
Poaching (25 to 50 km): Rainfall	-2.67	279	<0.01

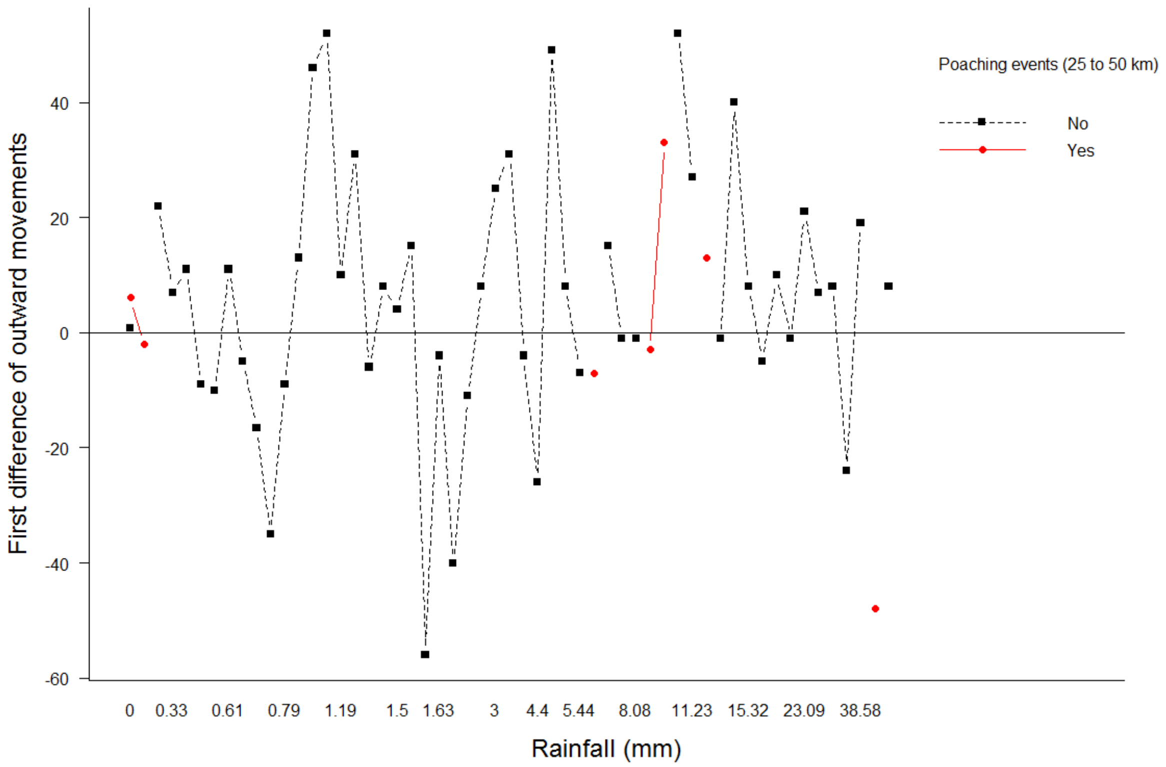

Fig. 3.4 First difference of number of elephants moving outwards with poaching (25 to 50 km) and rainfall

3.2 Movement of elephants inside and outside LWC

All interactions tested except for the three way interaction of altitude slope and NDVI have a detectable effect on the hourly distance travelled by elephants (Table 3.4). Results indicate that location and time of day evidently influence the speed of elephants (Fig. 3.5).

Table 3.4 Average model with estimates for the linear mixed effect model conducted on log hourly speed of elephants

	Estimate*	*z* value	*p* value
Intercept -Location (Corridor) †	5.03	72.53	<0.01
Location (Lewa)	0.22	5.28	<0.01
Location (Outside)	0.16	3.59	<0.01
Time (Night)	-0.32	6.07	<0.01
Altitude	-0.08	3.50	<0.01
NDVI	-0.13	7.34	<0.01
Slope	-0.30	17.97	<0.01
Location (Lewa) : Time (Night)	-0.43	7.74	<0.01
Location (Outside) : Time (Night)	0.14	2.30	0.02
Altitude : NDVI	-0.19	5.65	<0.01
Altitude : Slope	0.25	4.69	<0.01
NDVI : Slope	0.15	4.65	<0.01
Altitude : NDVI : Slope	-0.08	1.05	0.29

*Effect sizes have been standardized on two SD following (Gelman 2008)

†Location (Corridor) is the reference category

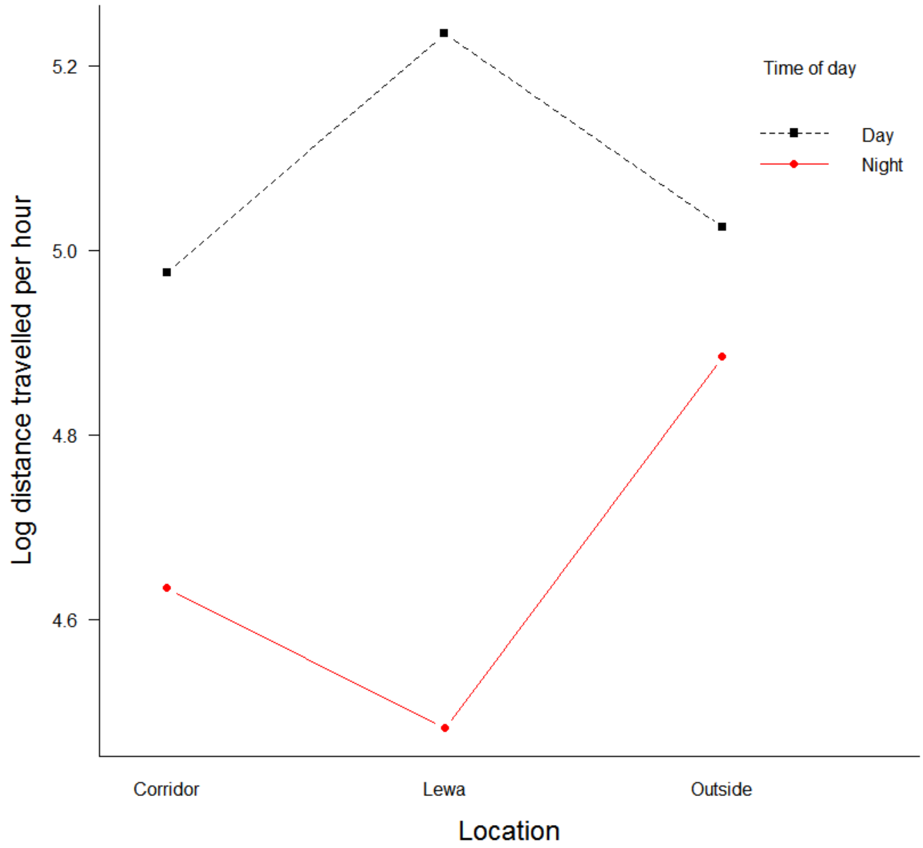

Fig. 3.5 Interaction plot of log of hourly distance travelled with location and time

3.3 Change in green biomass

Change detection maps created comparing annual average NDVI values of 2000 and 2014 (Fig. 3.6) depict that there is a general improvement in vegetation but it does not show that exclusion zones had a specific improvement. Comparison of annual average NDVI values every two years (Fig. 3.7) does not show any trend in change in vegetation. The change in NDVI seem to vary each year with some years showing a considerable increase or decrease in green biomass in relation to the year in comparison.

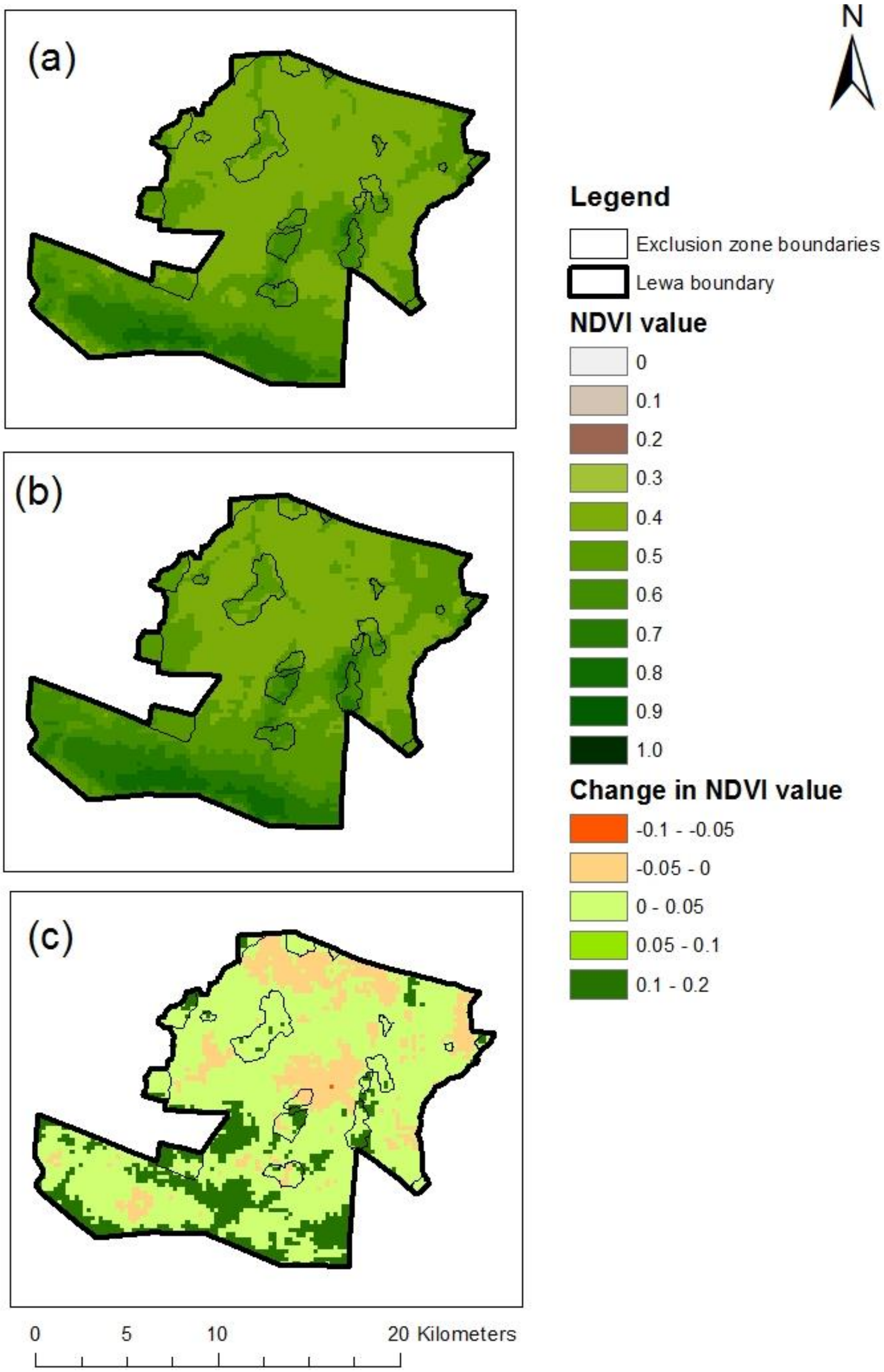

Fig. 3.6 Change in average annual NDVI from 2000 to 2014.

(a)NDVI map for 2000, (b) NDVI map for 2014 (NDVI values <0.1 are barren areas of rock, sand or snow, moderate values of 0.2-0.3 are shrub and grasslands, while high values 0.6-0.8 are temperate and tropical rain forests (Weier & Herring 2000) (c) Change in NDVI in year 2014 compared to year 2000

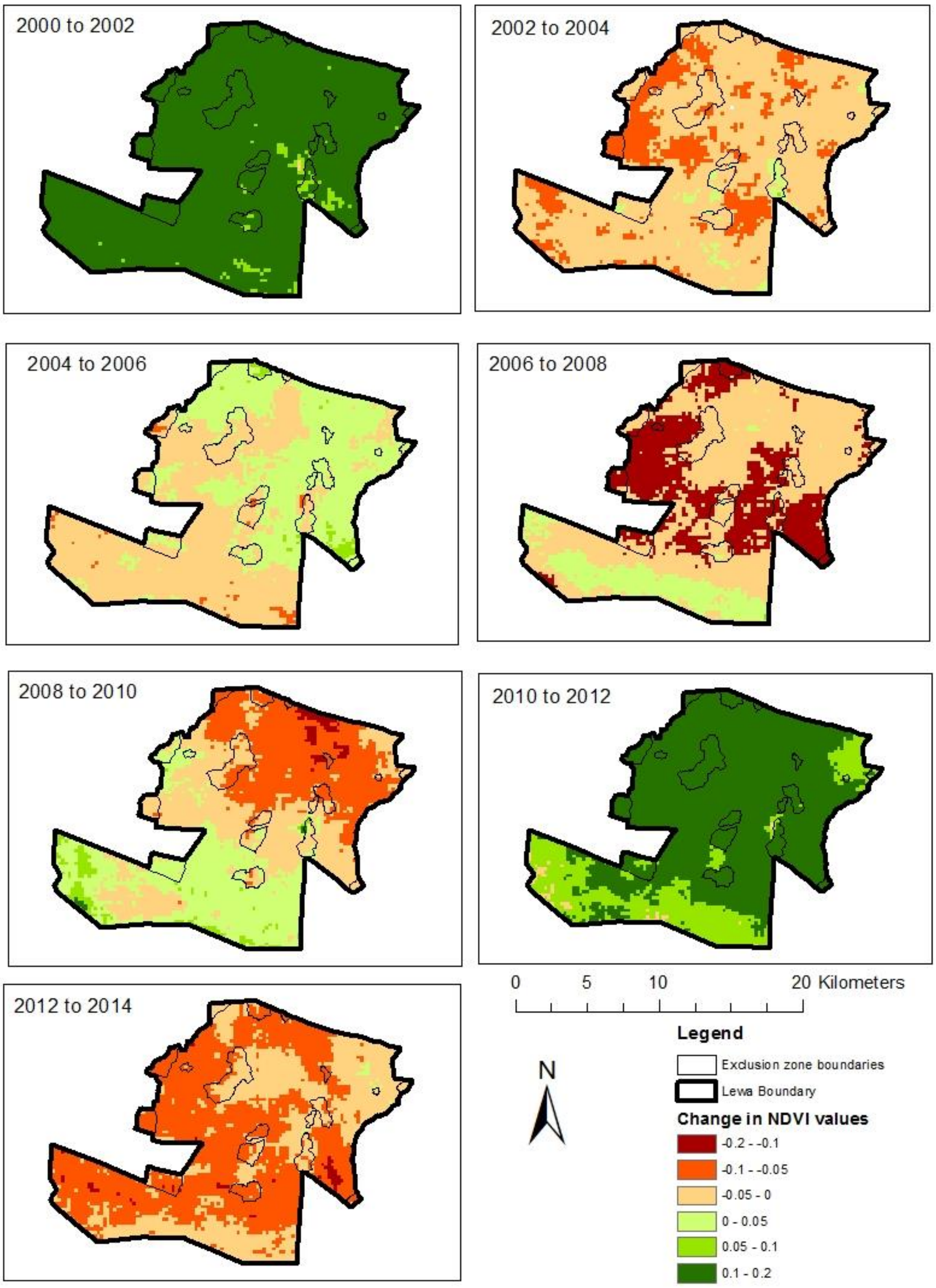

Fig. 3.7 Maps for change in mean NDVI values

Change in mean NDVI values for years 2002, 2004, 2006, 2008, 2010, 2012 and 2014 compared to two years before.

3.4 Utilisation of vegetation in exclusion zones

3.4.1 Selection of plants by elephants and rhinos

A total of 891 plants belonging to 26 species were sampled during the survey. According to results of the chi square test conducted on the vegetation damage utilisation by elephants and rhinos, there is a difference in the level of damage caused to different height and DBH classes. There is also a difference in the utilisation of different exclusion zones and species of plants. Mosaic plots in Fig. 3.8 to Fig. 3.14 also reveal that the height category, DBH category, exclusion zones and species utilised by elephants and rhinos are almost complementary. See Table D. 1 in Appendix D for the list of plants and their abbreviations. No seedlings (height category 1) were recorded during the study.

Length of each box on either side of the mosaic plot represents the proportion of the particular category out of the total sample. The boxes coloured in red (lower standard residuals) are those that are underrepresented and boxes coloured in blue (higher standard residuals) are those overrepresented. For example in Fig. 3.8 plants in height category nine and not damaged (ND); the left side bottom corner box, are underrepresented meaning that tall undamaged plants are far few in relation to the total sample, but number of plants with moderate and heavy damage are overrepresented meaning larger proportion is experiencing moderate or high damage.

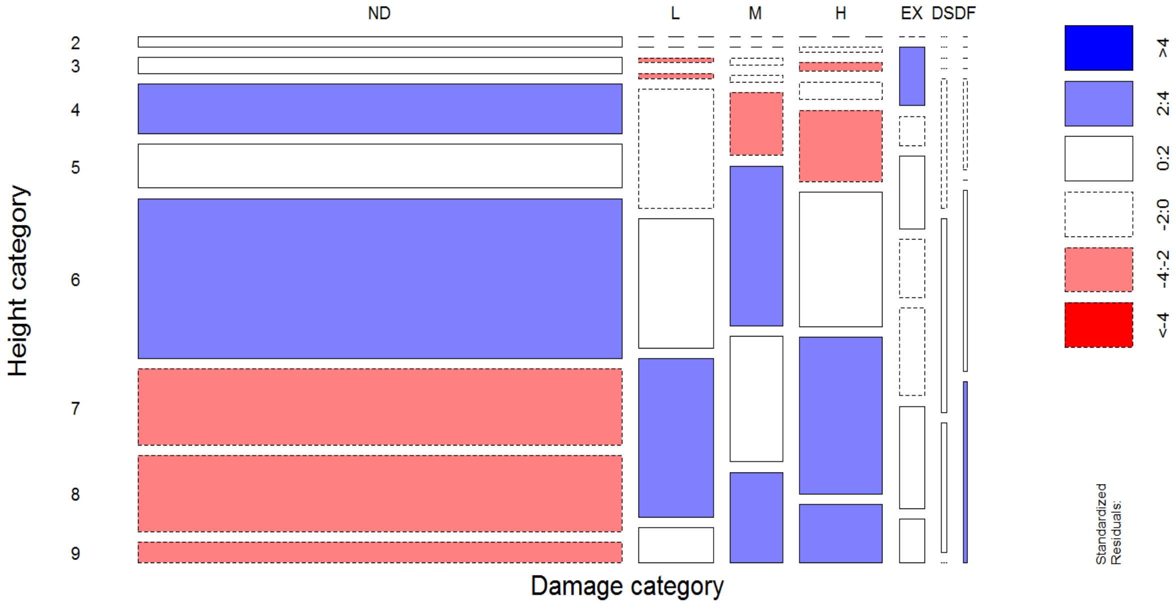

Fig. 3.8 Damage caused by elephants to plants of different height categories

Preference for different plant height categories by elephants is different with taller plants being more damaged than shorter plants (χ^2= 161.08, *df*= 42, *p*<0.01).

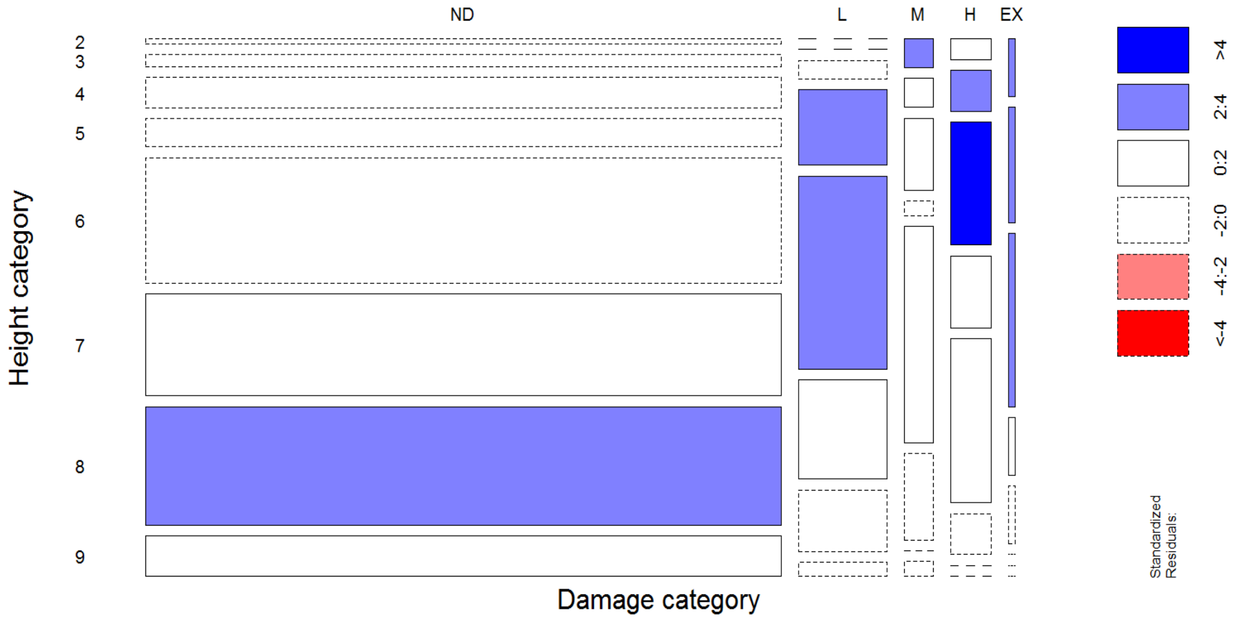

Fig. 3.9 Damage caused by rhinos to plants of different height categories

The preference for different plant height categories by rhinos is different, with shorter plants particularly being damaged than taller plants (χ^2= 142.19, *df*= 28, *p*<0.01).

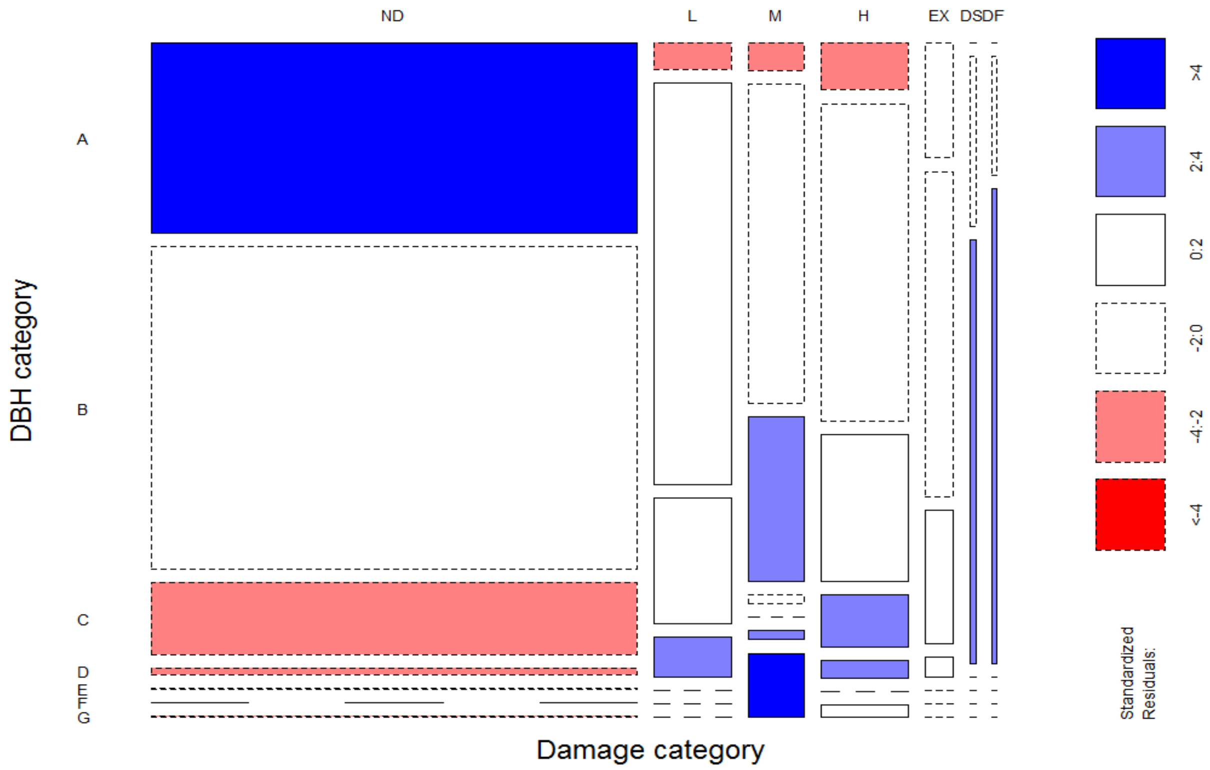

Fig. 3.11 Damage caused by elephants to plants of different DBH categories

The preference for different plant height categories by elephants is different, with plants with larger DBH being more damaged than smaller ones (χ^2= 213.36, *df*= 36, *p*<0.01).

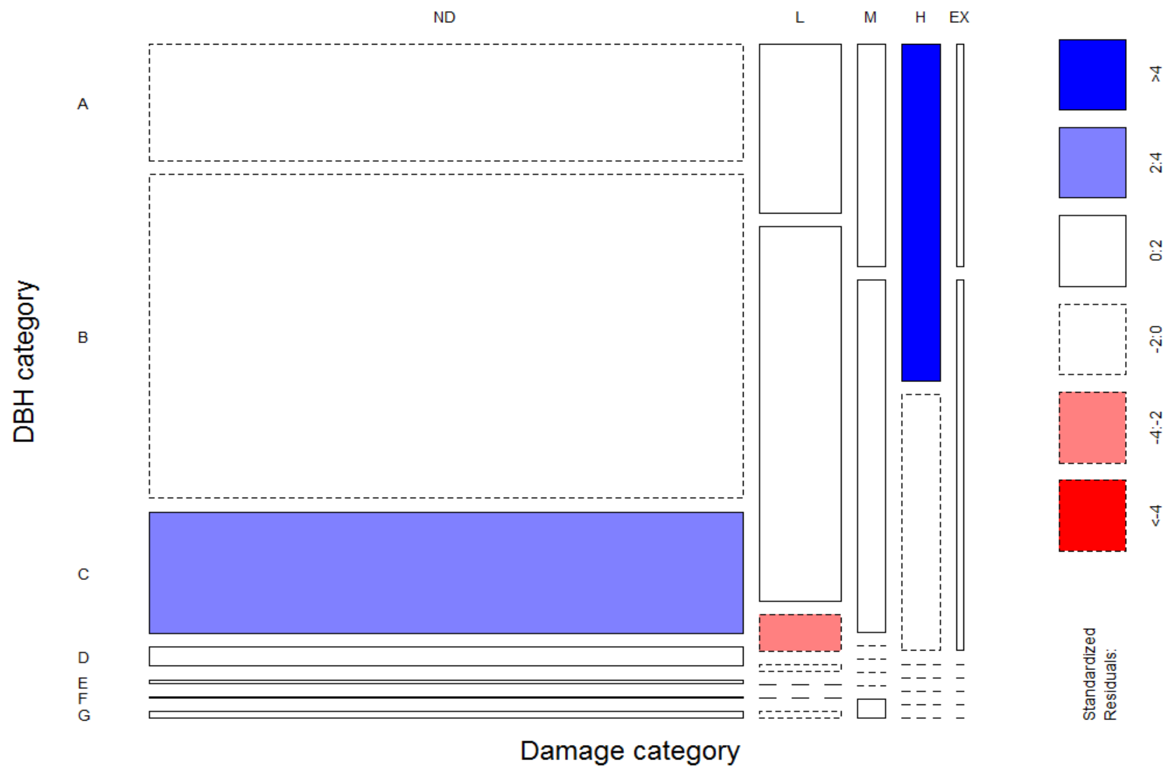

Fig. 3.10 Damage caused by rhinos to plants of different DBH categories

The preference for different plant height categories by rhinos is different, with plants with smaller DBH being more damaged than larger ones (χ^2= 64.67, *df*= 24, *p*<0.01).

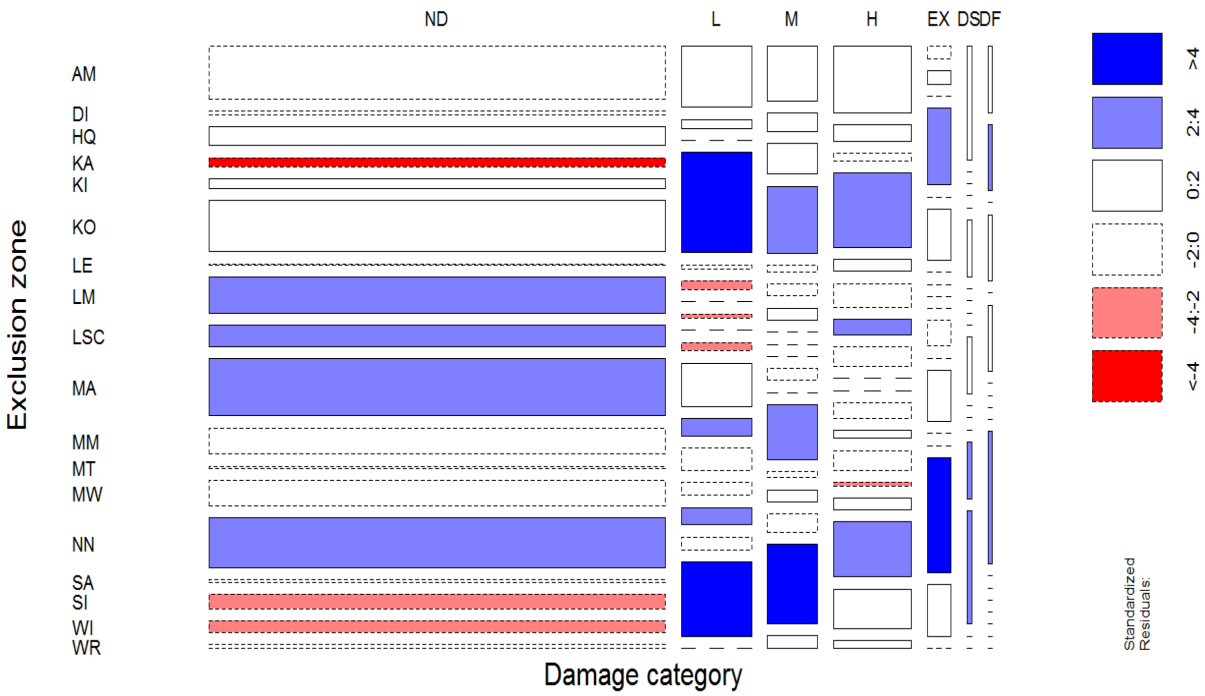

Fig. 3.13 Damage caused by elephants to different exclusion zones

Utilisation of exclusion zones by elephants is different, with Karionga (KA) Sirikoi (SI) and Willie Robert (WI) being more damaged than the others (χ^2= 407.54, *df*= 102, *p*<0.01).

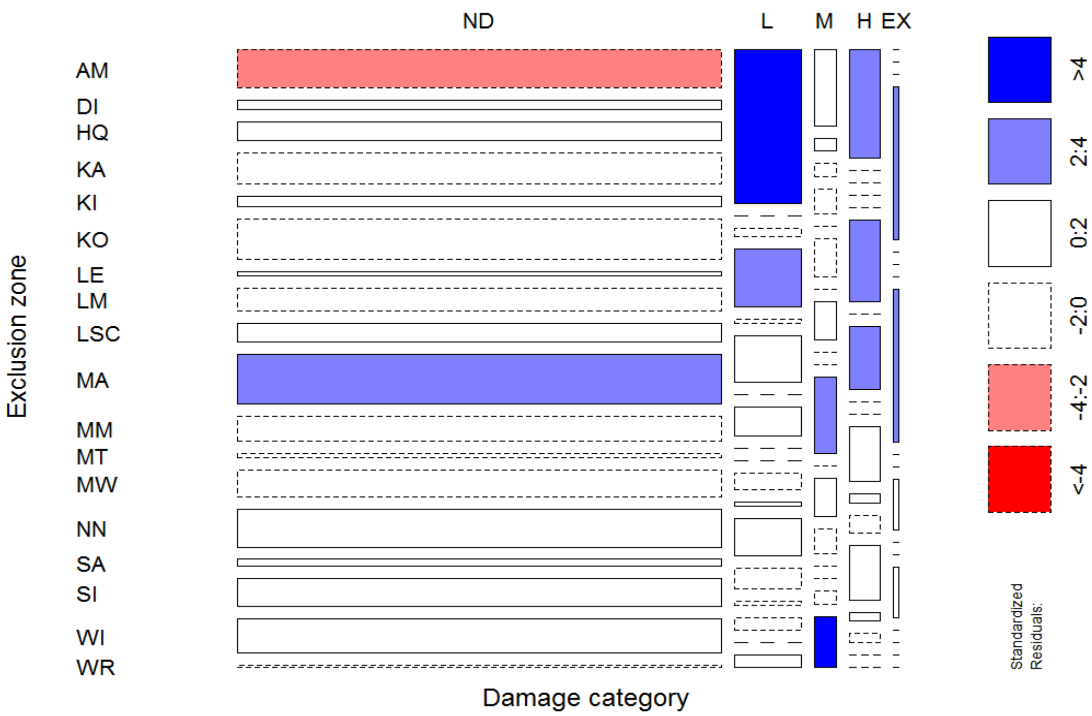

Fig. 3.12 Damage caused by rhinos to different exclusion zones

Utilisation of exclusion zones by rhinos is different, with Anna Merz (AM) being more damaged (χ^2 =224.11, *df*= 168, *p*<0.01).

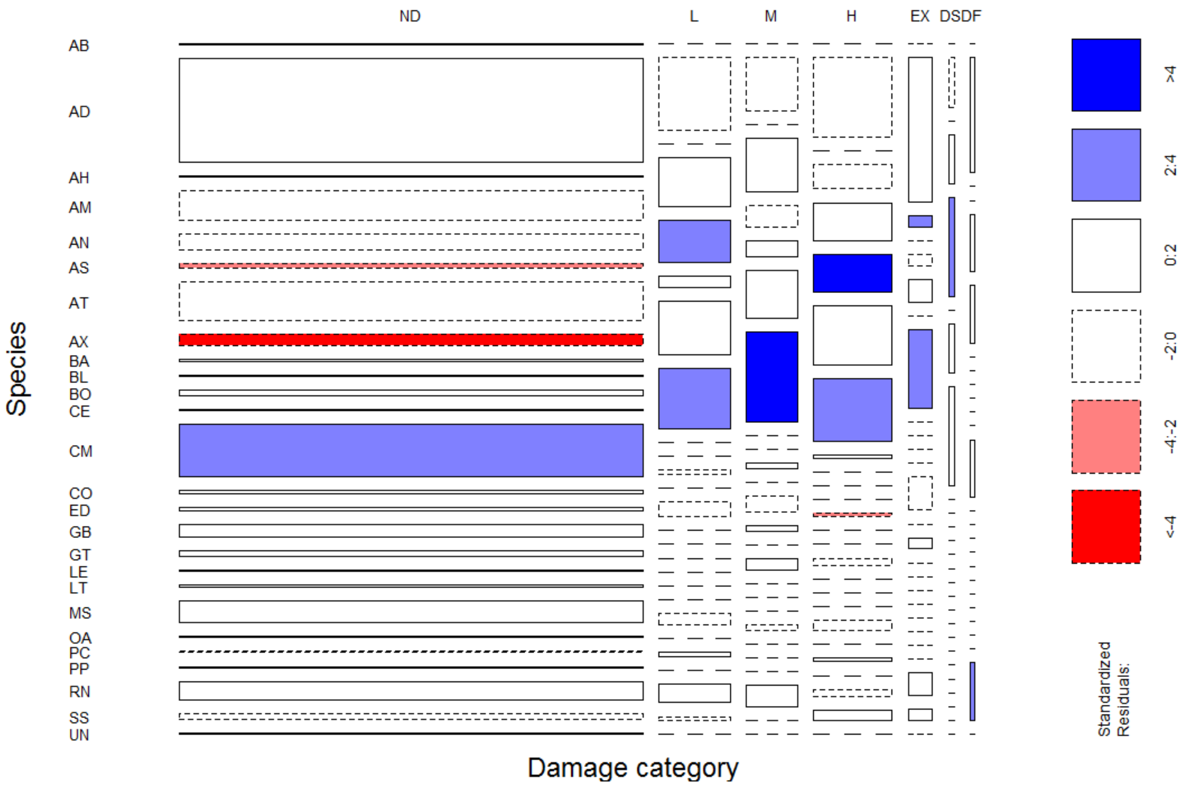

Fig. 3.15 Damage caused by elephants to different plant species

Preference to different plant species by elephants is different, with *Acacia xanthoploea* (AX) and *Acacia seyal* (AS) being over utilised compared to others (χ^2=239.01, *df*= 156, *p*<0.01).

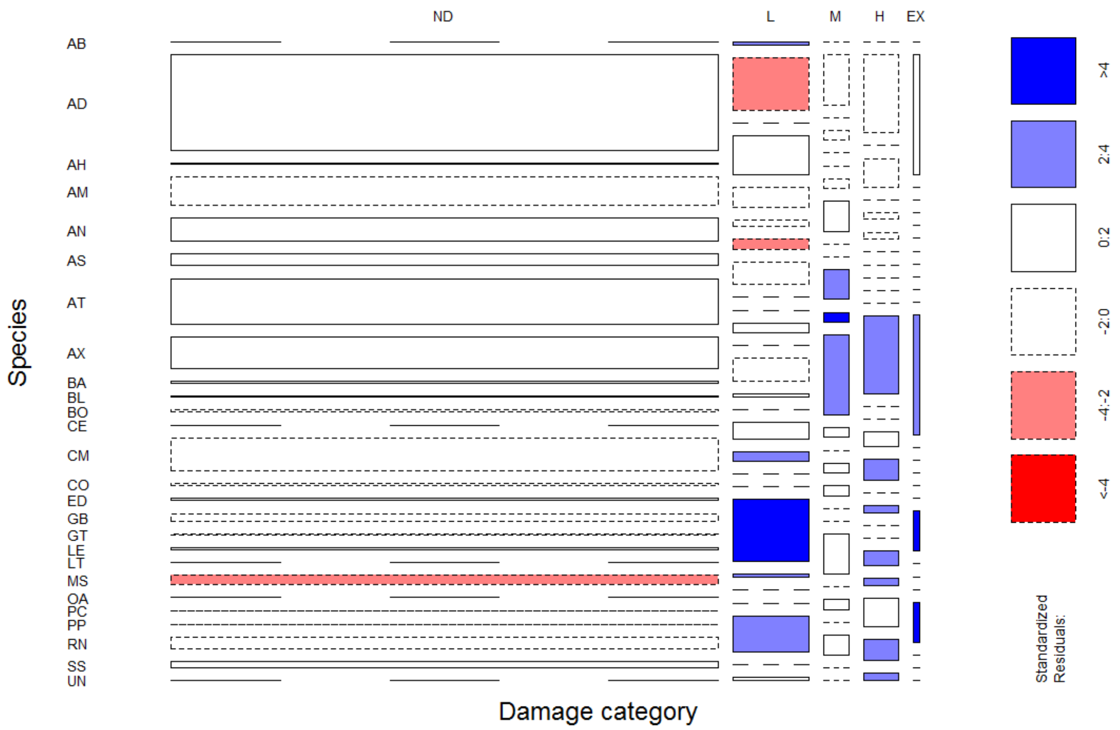

Fig. 3.14 Damage caused by rhinos to different plant species

Preference to different plant species by rhinos is different, with *Maytenus senagalensis* (MS) being over utilised compared to others (χ^2 =364.07, *df*= 104, *p*<0.01).

3.4.2 Intensity of damage to plants and fence breaking events with diversity and density

Results depict that the proportion of damaged plants by elephants displayed no detectable relationship with diversity, but had a negative relationship with density (z = -5.32, df = 16, $p < 0.01$). Exclusion zones with high plant densities seem to be less damaged than those with lower plant densities (Fig. 3.16). Density or diversity did not have any relationship with number of fence breaking events. Spearman correlation test conducted on log transformed fence breaking events and percentage damage caused to plants in exclusion zones also did not show a correlation ($r_s = 0.2$, df=17, p = 0.46).

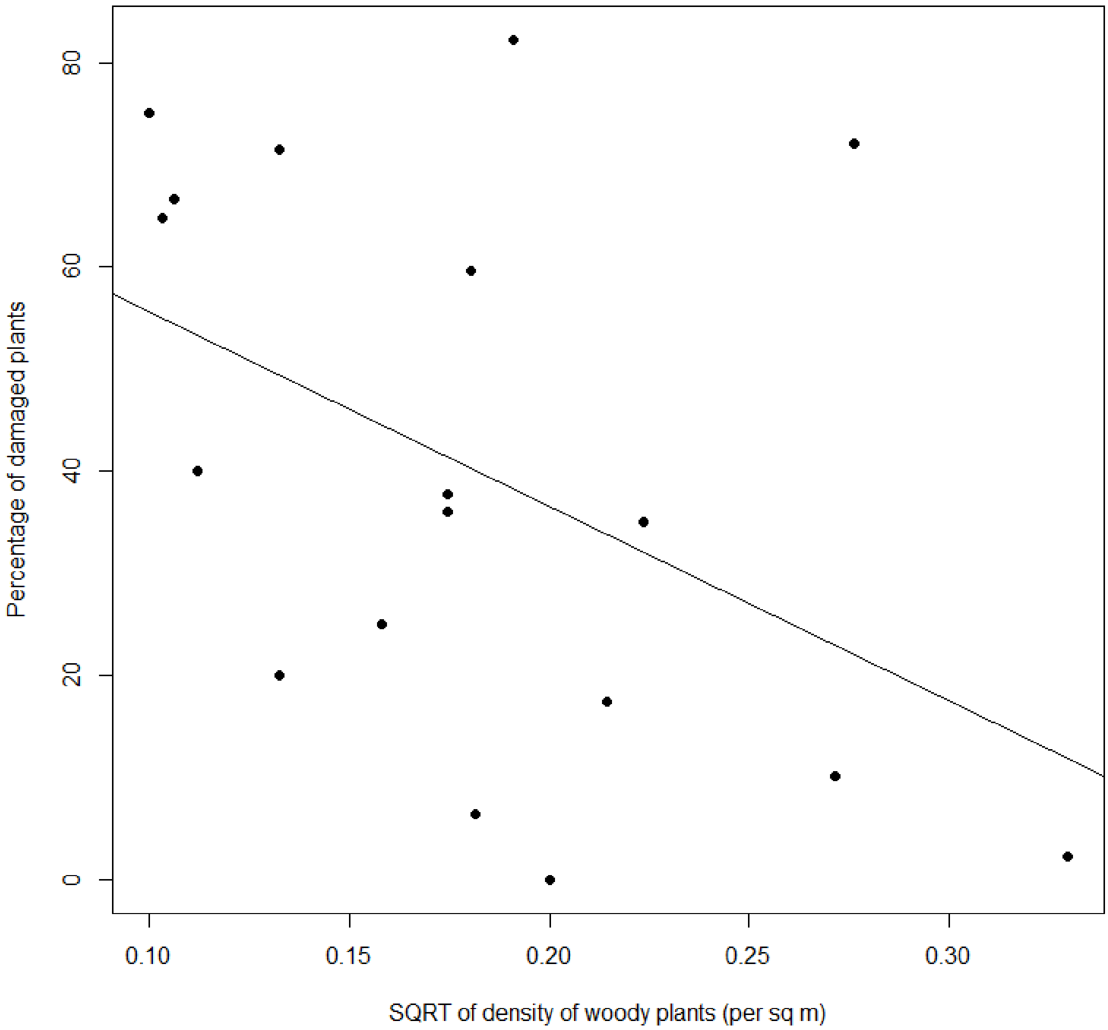

Fig. 3.16 Percentage of damaged plants in different exclusion zones with density of plants

3.4.3 Secondary damage to plants

During the study it was observed that some plants are experiencing secondary damage by insects who bore in to the exposed soft tissue of the damaged plants. This had gradually resulted in death of the tissue and sometimes death of the entire plant. During this study 24 plants were observed with secondary damage by insects belonging to *Acacia xanthophloea, A. tortilis, A. nilotica,* and *Rhus natalensis.*

3.5 Fence breaking incidents captured by the camera traps

3.5.1 Methods of fence breaking

Camera traps set up at Karionga and Digby's exclusion zones were successful in capturing five fence breaking events. See figures 3.13 to 3.18 for incidents captured during the study. There was one video captured of an elephant failing to break the fence by pulling it backwards. In addition, there were many photos captured, with elephants already inside the exclusion zones, or the fence already broken due to elephants snapping wires nearby but beyond the sensitivity of the camera.

Elephants break the two wired exclusion zone fence by pulling the live wire back with their tusks. They sometimes reduce the tensile strength of the wire by pulling them back and step on them. Elephants also creep under the wires. Out of events captured two were by detusked elephants. Detusked elephants used their short stumps to pull or push down the wires to loosen them. In the incident captured in Figs. 3.16 and 3.17, there were a series of photos that revealed the steps taken in the attempt to break the 12 strand fence with the net. The elephant lifted his trunk and using the short tusks pulled the live wires upwards to break or short circuit them. Then it raised its body and stepped on the net. A video taken by the elephant monitoring officer at LWC shows clearly how the elephant steps on loose low lying wires to walk over them. Also younger elephants are sometimes pushed under the fence by other elephants to displace the wires for easy entry of other elephants (S. Rouse, pers comm.).

Fig. 3.17 Elephant pulling the live wire with its tusks

Fig. 3.18 Elephant about to step over the fence

Fig. 3.19 Elephant creeping under the fence

Fig. 3.20 A detusked elephant pushing the live wires down and pulling it back

Fig. 3.21 Elephant stepping over the net of a fence

Fig. 3.22 Detusked elephant pulling the wires back

3.5.2 Fence design and reconfiguration

Exclusion zone fence is usually a two strand fence with a live and earth wire placed about 2 m above ground, allowing smaller animals to pass under the fence. Some exclusion zones however have certain sections with stingers protruding outwards, this is mainly found at locations where there is a tourist lodge or camping site nearby. Different exclusion zones are maintained at variable voltages ranging from 4 to 9 kV with few exclusion zones having sections with a voltage different from the rest of the particular exclusion zones.

Currently LWC is reconfiguring the fence design of exclusion zones. They are modifying the earlier two strand fence to a sturdier, two strand fence with stingers protruding out of the exclusion zones to prevent elephants approaching the fence. It is hoped that this will significantly reduce the number of fence breaking incidents in the future. However, during the study period there were several incidents of elephants penetrating even the new fence. They have already learnt to crawl under the new fence (Fig. 1.1). Comparatively the short fence with stingers encircling the Lewa Safari Camp exclusion zone seem very successful in excluding all animals and had only two records of elephants penetrating in during the last two years. However, the short fence does not fulfil LWC’s objective as it does not allow the small herbivores to go through.

4 Discussion

The focus of this study was to look in to the issue of high elephant numbers in Lewa Wildlife Conservancy and their concern that these elephants are damaging the vegetation protected for rhinos within exclusion zones. This study comprised of several sections and each section will be discussed separately and final conclusions and recommendations made.

4.1 Movement of elephants through gaps in relation to insecurity events

Number of daily entries and exits in 2013 and 2014 have a moderate positive correlation, hence the overall number of elephants seem to have been constant within LWC. However, insecurity events have had an impact on the first difference of inward and outward movements in different ways. The number of elephants in LWC may have remained more or less the same, because elephants could be returning to their previous location when conditions are satisfactory after an incident had occurred, if it is part of their home range (Whyte 1993).

In this study, occurrence of both events which recorded gunfire and other insecurity events inside LWC, evidently increased the number of elephants moving out the next day after events had occurred. According to Fig. 3.2 (a) decrease in outward movement when only gunfire events had occurred in LWC could have been affected by the time of year they may have occurred. Availability of dry season surface water is known to affect elephant density (Chamaillé-Jammes et al. 2007; 2008). LWC consists of permanent water sources that drives elephants to LWC during the dry season (Mutinda & Chege 2013), which could be affecting them to remain in LWC despite the insecurity events. Increase in human population in pastoralist areas could also drive elephants to LWC during dry seasons as competition for water increases (Thouless 1993).

Occurrence of other events (with no gunfire being recorded) within 25 km and up to 50 km from LWC had visibly decreased outward movements after events had occurred. Occurrence of events that recorded gunfire outside LWC had no detectable influence on elephant movement. This shows the impact other insecurity incidents outside LWC have on the decision to remain inside LWC and tells us that it is important to give attention to these events, since elephants seem to be getting disturbed by them.

Occurrence of poaching events within LWC had decreased inward movement of elephants, the next day, but the response to poaching in LWC was also dependent on rainfall. Poaching events that occurred on days with high rainfall seem to have increased the number of entries to LWC. Elephants are known to disperse over large areas during wet seasons (De Beer et al. 2006) and more importantly are known to respond to localised rainfall and resultant vegetation (Whyte 1993). This could be the reason for the increase in number of elephants moving inwards after rainfall, despite the occurrence of poaching events. Poaching and other hostile events within 25 km from LWC boundary had increased the number of elephants moving inwards the following day, but occurrence of just poaching events in this region seemed to have decreased inward movement, which may be due to the direction in which the event occurred that could play a role in determining elephant movement. Thus further investigation of events with time of event and direction may provide more conclusive results. There had been a decrease in number of elephants moving out of LWC with occurrence of poaching events even within 25 to 50 km from LWC depending on rainfall in LWC. This shows that during rainy periods, elephants may decide to stay within LWC, when there are poaching events occurring outside. This could be related to abundant water and vegetation after a rainfall that would alter the need to move out of LWC to a hostile environment in search of food (Whyte 1993; Chamaillé-Jammes et al. 2008).

The overall response of elephants to insecurity events show that some categories of insecurity had detectable influence on the elephants moving in and out of LWC. Gunfire did not seem to be an important driver of elephant movement, nor did road banditry or theft events influence movement to a detectable level. However, poaching and other hostile events (which included incidents such as gunfire being heard or sighting of armed men) seemed to have influenced elephant movement along with rainfall. It has been found that elephants have the ability to differentiate the level of threat even within human subgroups (Bates et al. 2007). Thus, elephants may be able to identify particular groups of armed men as a threat to them and identify livestock theft and road banditry are not targeted towards them. These results also confirm the previous findings where elephants seem to avoid hostile environments (Hoare & Du Toit 1999; Douglas-Hamilton et al. 2005; Buij et al. 2007), and the influence, rainfall have on decision making over the hostile incidents (Whyte 1993).

It can be also noted that even though insignificant ($p > 0.05$) some of the main effects seem to show the opposite relationship to that of an interaction term. This may be due to weak relationships of these variables resulting in the incorrect sign being assigned to the weak parameter estimate in regression analysis (Gelman & Tuerlinckx 2000). It should also be noted that the residuals of the model were not normally distributed thus could be affecting the real relationships of the variables.

This analysis was limited to years 2013 and 2014 and ignored the direction and effect of time of the event could have on movement. These insecurity events are classified details that cannot be disclosed with exact location for security reasons. LWC could further investigate these insecurity events internally to find areas of high threat for animals so resource distribution for security can be done more effectively. However, this may require the insecurity database to be maintained with more specific details such as time and exact location.

Maintenance of the current database had not been done with the intention of carrying out a scientific study and many limitations were experienced during data extraction. It is recommended that the security team should look into modifying the current data base with separate columns for date and time, location and exact location with GPS points and/or rough distance and direction from LWC. Some of the locations recorded were local names or some have multiple locations with the same name posing difficulties in identifying the exact location. Consistency in the details being recorded with a predefined classification of insecurity categories is important. The classification used in this report with further modifications as necessary may be used in the future. The gap movement data can also be recorded with time of entry. With more details available, data could be further analysed to check for directional effects and more specific temporal effects.

4.2 Movement of elephants inside and outside LWC

All variables tested (location, time, slope, altitude and vegetation biomass) had a strong influence on the hourly distance travelled by elephants. In addition to the slope, altitude and vegetation availability, that were previously found to have an effect on elephant movement (Wall et al. 2006; Bohrer et al. 2014), the focus of the analysis in this study was, the effect of time and location to determine how elephants perceive LWC compared to outside the Conservancy. The hourly distance travelled by elephants varied between time of day and between locations. In previous studies, fast movement at night was considered as an indication of elephants perceiving the particular area as a risk, and that darkness is used as a risk avoidance strategy (Graham et al. 2009). Elephants in this study showed detectably high hourly speeds at night, outside LWC, in line with the initial hypothesis that areas outside LWC are more hostile. This is also an indication that most areas outside LWC are used as travel corridors between protected areas (Douglas-Hamilton et al. 2005).

However, in contrast to Graham et al. (2009) elephants in this study moved comparatively faster during the day than at night in all locations, with a greater speed observed in LWC in particular. In Graham et al. (2009) hourly speeds were high during the day only in ranches, but in all other land use types (small holder, forest and pastoral) speed was higher at night where most areas were perceived to be elephant intolerant. The mentioned study also revealed that speed was greater in open habitats. Thus high speed of elephants during the day in LWC could be due to most of the current habitat being open. However, further investigation by categorising locations outside LWC according to land use types and considering tree cover as another variable, reason for high speed movement during the day could be explained.

Elephants prefer areas with low level of human disturbance (Buij et al. 2007; Graham et al. 2009). So with this study on impact of insecurity events on elephant movement to LWC, and analysis of speed it can be suggested that threats to elephants outside the conservancy may be influencing the speed of movement at night. This analysis was however, limited to seven individuals who had their collars active from 2013 to May 2015. This could be expanded with more individuals that have intersected LWC in previous years, taking in to consideration sex of the animal to determine how movement of males and family groups vary inside and outside LWC. Further, by comparing speeds in protected and human dominated areas, unsafe travel corridors used by elephants outside LWC (Douglas-Hamilton et al. 2005) could be identified.

4.3 Detection of change in green biomass

The difference in green biomass measured by mean NDVI value per year do not show a drastic change between 2000 and 2014. Comparison of mean NDVI values per year every two years from 2000 to 2014 also do not show a clear increasing or decreasing trend. The change in NDVI values show that in some years there was an improvement in certain areas and a decrease in other areas. However, it is noteworthy that from 2012 to 2014, there seems to have been a decrease in biomass in the entire conservancy which should be given attention to see if this trend continues. It is not noticeable that there is an improvement or a decrease in biomass in exclusion zones in particular. NDVI images before year 2000 were not available for the study location. Therefore, a comparison of biomass when LWC was densely forested versus now, could not be carried out. Mean NDVI values for 2014, suggest that a high greenness (NDVI values from about 0.4 to about 0.7) is being maintained in exclusion zones. This analysis could be modified further to see the seasonal change in biomass and also relate to other environmental variables such as rainfall and temperature that have an effect on biomass production over a specific time.

4.4 Effectiveness of exclusion zones

Main objective of creating exclusion zones was to protect vegetation for rhino browse. Therefore, comparing utilisation of plants by rhinos with elephant damage was important. The results indicate that there is a definite difference in the way these animals utilise the plants and it appears to be complementary. Elephants utilise trees that are >2 m in height and >10 cm of DBH more than others and rhinos utilise shorter plants with smaller DBH. However, there seem to be a significant damage caused to certain plant species such as *Acacia seyal* and *Acacia xanthophloea* which are also included in the rhino diet. Previous studies have also revealed that shorter plants (Mwalyosi 1987) and plants with stem diameter less than 2 cm (Lewis 1987, cited in Jacobs & Biggs 2002) are damaged less by elephants. It has been also found that elephants select plants between 2-3 m in height in their diet (Jachmann & Croes 1991).

There is also a possibility that if elephants are not allowed to utilise these plants and plants are left alone to grow, they may grow beyond rhino browsing height. Previous studies have found elephant densities to positively correlate with certain species of herbivores (Skarpe et al. 2000; Rutina et al. 2005; Makhabu et al. 2006). This could be true for rhinos as well, because trees pushed over by elephants may produce more vegetation at a more convenient height for rhinos to browse, through coppicing. Thus elephants in LWC could be important as habitat engineers, generating more vegetation for rhinos. Therefore, a certain level of damage by elephants may be necessary to maintain habitat structure.

This study also shows that intensity of damage is inversely related to the density of plants. This, however, is an indication that damage has resulted in the considerably lower density of plants in the particular exclusion zones at present. Previous studies have shown that density and tree cover to decrease in areas of high elephant damage (Cumming et al. 1997). During the current study no seedlings were recorded. If both larger reproductive trees and smaller seedlings decrease, it could lead to a poor recruitment rate, resulting in a declining population. Underrepresentation of younger plants have been observed in previous studies as well (Lewis 1987; Gadd 2002; Helm 2011). Seedlings are highly selected by elephants (Campbell et al. 1996, cited in Gadd 2002). However, previous studies also suggest that other herbivores too contribute to lack of young plants (Lewis 1987). Thus this situation in LWC could be due to other herbivores predating on them.

Not detecting any seedlings could have also been due to observer errors, where reduced visibility due to the presence of tall grass grown after the rains, resulted in inability to detect short plants. In addition to this, not detecting seedlings could be due to a seasonal effect. Since it was the end of a rainy season, most plants of seedling stage would have reached saplings stage by the time of the study. However, if the reason is poor recruitment, action may need to be taken to resolve this issue. Therefore, further study is recommended to investigate the vegetation population dynamics and analyse the recruitment rate.

This study also revealed that there seem to be a number of plants experiencing secondary damage by insects. This is another interesting phenomenon which has been recorded in previous studies (Jacobs & Biggs 2002). This should be investigated further, especially to see if this insect damage is seen only in plants damaged by animals and if these plants are mainly damaged due to elephant activity.

4.5 Fence breaking methods and design of fences

Elephants use various tactics to break fences such as pulling and snapping wires using their tusks, loosening wires using tusks and/or stepping over fences and even crawling under fences. In the video captured it seemed that the elephant failed to snap the wires because of the low tensile strength of the wire. However, when the wires are loose the elephants can easily step over them and walk. LWC carried out a detusking operation on several of the problem elephants identified. This decreased the fence breaking events drastically immediately afterwards (Mutinda et al. 2014). However, camera traps in this study captured two incidents of detusked elephants attempting to break fences. Thus, showing that there could be a gradual increment in detusked elephants breaking fences again. Elephants quickly learn to use their tusk stumps, get assistance from companions to break fences or use other body parts such as head, body, trunk or feet to break fences (Mutinda et al. 2014).

Elephants have learnt methods to penetrate the new reconfigured fence as well. It would be beneficial to compare the intensity of fence breaking events before and after reconfiguration to see how effective the modification is in serving the purpose. If the new fence is ineffective, it will be more costly to repair any breakage by an elephant, compared to the previous two strand fence, which mostly required only the broken wires to be reconnected.

4.6 Conclusions and recommendations

High number of elephants within LWC has transformed the vegetation structure and landscape compared to 50 years ago, creating a concern that the availability of rhino browse would be affected. However, this study shows that the damage caused to plants in exclusion zones does not seem as severe as assumed. The most important thing to take in to consideration is the complementary utilisation of vegetation by elephants and rhinos, and the possible positive effect that elephant damage may have in maintaining rhino browse. It would be beneficial to carry out a thorough vegetation assessment and recruitment rate to determine the demographics of the plants. It is also recommended that the impact of secondary damage to plants to be assessed and action be taken if necessary to control insect damage. As studied previously for other herbivores, a future study to determine the effect of elephant density on rhino population would provide information that would assist future management decisions.

It is recommended that a study of elephant movement within the conservancy, such as a least cost movement analysis, would be valuable to decide the placement of exclusion zones and main boundary elephant gaps. It is also suggested that a long term plan to rotate the exclusion zones may be appropriate to better preserve the vegetation, preventing overgrowth of all plants beyond rhino browsing height and also reduce resistance to elephant movement.

Elephant movement is evidently influenced by insecurity events occurring within and outside LWC. This study proves that elephants move away from human disturbances and also supports previous studies in influence rainfall and availability of surface water has in the decision to enter or exit LWC (Whyte 1993; Chamaillé-Jammes et al. 2007). Thus high elephant numbers, especially during the dry season could be due to the pressure created by insecurity events, as well as competition for water sources in surrounding (Thouless 1993).

To control elephant numbers conservation mangers have several options; facilitating natural dispersal, translocation of problem elephants, use of contraception and the last and most unpopular option of culling. A review by van Van Aarde & Jackson (2007) shows how ineffective culling, translocation and use of contraception are in controlling high elephant numbers. Trying to control the number of elephants in an area only deals with the symptom (Van Aarde & Jackson 2007). Current efforts to control damage to vegetation in exclusion zones and detusking operations also, provide only short term solutions.

In the case of LWC, the main cause for high elephant numbers are insecurity incidents and increased human population in surrounding conservancies that needs attention. Fragmentation and restriction of range due to human disturbances are the causes of the problem which needs to be tackled. Thus facilitation of dispersal is the best solution. Understanding elephant spatial and temporal use of habitat, its adaptations to the modified landscape and its movement patterns is essential for successful management and to mitigate current issues in LWC.

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Appendix A

Classification of insecurity events

Classification according to gunfire

Insecurity events with gunfire: Those records which indicated the exchange of gunfire or gunfire being heard.

Other events: All other records which did not confirm the hearing or exchange of gunfire

Classification according to insecurity type

Poaching

Poaching incidents included poaching of animals such as elephants, rhinos, giraffe and impalas. Some records indicated the case of death of the animal was due to gun shots, poison arrows. However, some records did not indicate the exact type of method of poaching.

Road banditry and Livestock theft

Road banditry events were always by armed men and some incidents resulted in gunfire being exchanged and even death to some passengers. Livestock theft includes both livestock theft incidents as well as recovery operations. Most of the theft incidents or recovery operation resulted in exchange of fire and death or injury to individuals.

Other hostile events.

This category included a vast range of incidents such as, gun fire being heard, sighting of armed men, arrests, human wildlife conflict incidents, animal and human accidents such as drowning falling in to ditches.

Appendix B

Time of damage

Since the study was carried out towards the end of the rainy season method of classification followed by Ben-Shahar (1993) was modified as follows.

Old damage (O) - Damage caused over 4 months ago, during the last dry season or before, tree has turned dark in colour, broken branches have dried out or dead, insects have already started to bore in the stem.

New damage (N) - Damage caused during the present rainy season, debarked tree or exposed tissue has turned brown, but no insect damage can be observed yet and broken branches are still alive or damage is very recent with exposed tissue appearing yellow in colour

Agent of damage/death based on Ben-Shahar (1993) and experience of LWC staff

Elephant

Damage that could be definitely attributed to elephants such as tusk marks present on trunk, branches broken, characteristic browsing by elephants (tooth brush effect), debarking and feeling or uprooting of trees were classified under this category

Rhino

Branches broken or browsed by rhinos had the characteristic scissor effect.

Other damage

- Damage not caused by elephants or rhinos- Tree fallen by wind or other natural causes such as old age and heavy branches, death due to parasitic infection, fire, bark damage due to parasitic infection, damage to bark above browsing height, no indication of any elephant browsing (tooth brush effect) or rhino browsing and browsing is confirmed to have caused by other animals

- Unknown damage- Damage could not be attributed to elephant or rhino with definite. Browsing that could not be specified to a particular species. Fallen tree, or broken branch that could not be classified as natural or caused by elephant.

Damage Categories based on (Jacobs & Biggs 2002)

Living tree

Light (L) - trees with light tusk marks and <50% bark removed from trunk circumference; or secondary and smaller branches broken

Moderate (M) - <50% bark removed from trunk circumference with secondary and smaller branches broken; or >50% bark removed from trunk circumference; or one primary branch broken;

Heavy (H) - >50% bark removed from trunk circumference and primary branches broken; or with more than one primary branch broken

Extreme damage (EX) - ringbarked (100% bark removed from trunk circumference); or main stem broken and coppicing.

Dead trees

Standing (DS) - Causes of mortality for standing dead trees include death due to old age, boring insect activity and ring-barking or heavy damage by elephants.

Uprooted (DU) - Uprooted trees with roots still in the soil were considered dead

Felled (DF) - Trees, of which the main stem was broken and no coppicing had occurred, were classified as felled trees.

Appendix C

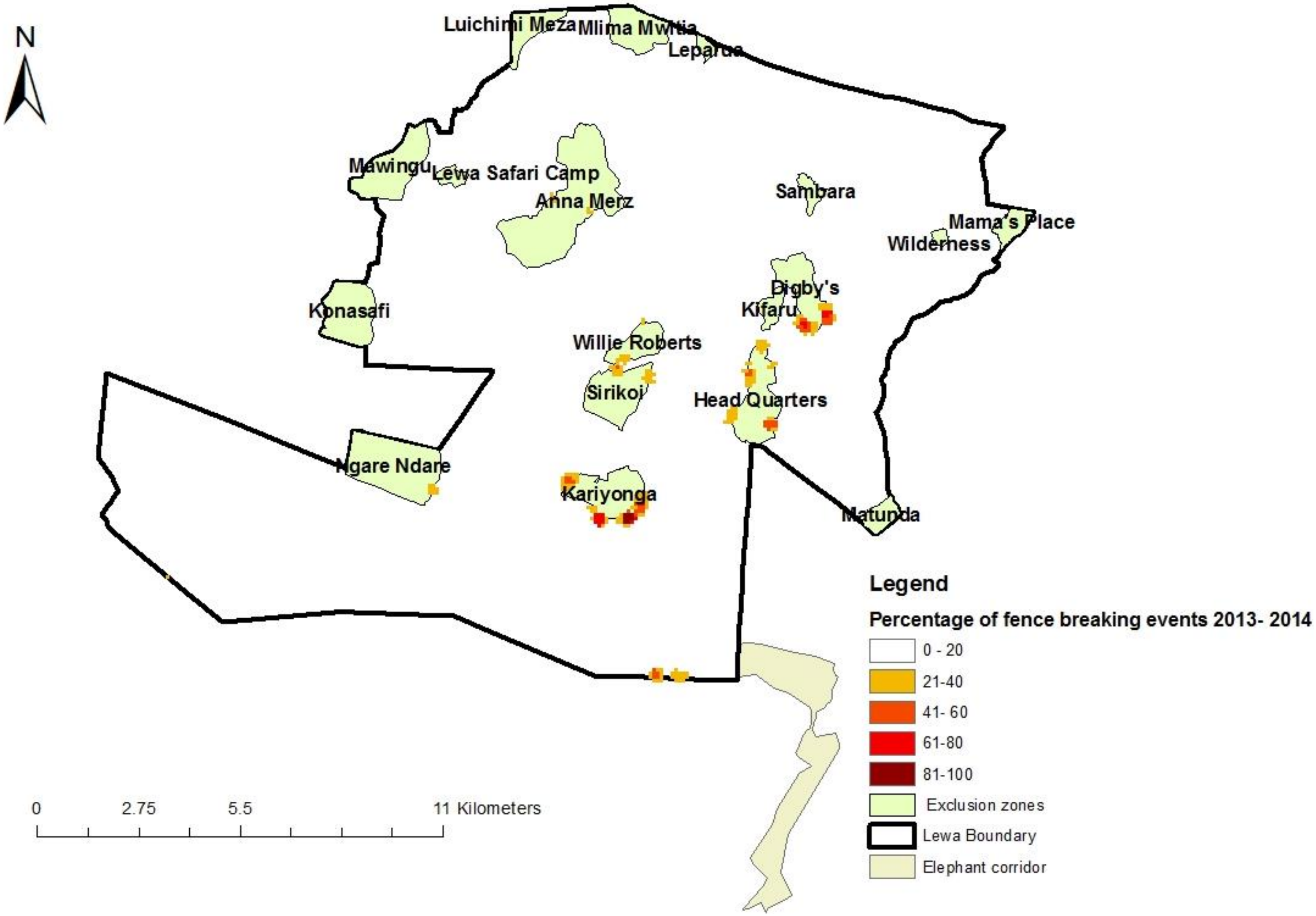

Fig. C.1 Map of percentage fence breaking events in 2013- 2014

Appendix D

Table D. 1 List of plants observed during the study and their codes

	Plant species	Code
1	*Acacia brevispica*	AB
2	*Acacia drepanolobium*	AD
3	*Acacia hockii*	AH
5	*Acacia mellifera*	AM
6	*Acacia nilotica*	AN
7	*Acacia seyal*	AS
8	*Acacia tortilis*	AT
9	*Acacia xanthophloea*	AX
10	*Balanites aegyptiaca*	BA
11	*Barleria spp*	BL
12	*Boscia angustifolia*	BO
13	*Carissa edulis*	CE
14	*Commiphora spp*	CM
15	*Cordia ovalis*	CO
16	*Euclea divinorum*	ED
17	*Grewia bicolor*	GB
18	*Grewia tembensis*	GT
19	*Lannea triphylla*	LT
20	*Lycium europaeum*	LE
21	*Maytenus senegalensis*	MS
22	*Osyris abyssinica*	OA
23	*Pappea capensis*	PC
24	*Pyrostria phyllanthoidea*	PP
25	*Rhus natalensis*	RN
26	*Senegalia senegal*	SS
27	Unknown species	UN