The ecological viability of wildlife conservancies in the Greater Mara Ecosystem

Laura Sophie Doughty

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Abstract

Wildlife conservancies are being promoted as a potential mechanism for both increasing the overall amount of land available for wildlife conservation and for reducing human-wildlife conflict/competition with domestic livestock. This is achieved by creating a protected area buffer on privately owned land around the gazetted boundary of a designated area - in this research the Maasai Mara National Reserve. As a newly emerging wildlife management initiative it is imperative that their viability be demonstrated and that that empirical evidence emerging from existing wildlife conservancies be applied to future conservancy initiatives. In particular, the development of a predictive tool for future conservancy site selection which ensures the ecological and economic viability of future wildlife conservancies is increasingly being sought by all stakeholders in the Greater Mara Ecosystem (GME).

This research demonstrates that high wild ungulate densities and distributions have been maintained and enhanced in an existing conservancy (OK1), with similar levels of success mirrored in a newly designated conservancy (OK2). Over a three year study period results revealed that for all seven study species (Thompson's gazelles, wildebeest, zebra, topi, impala, Grant's gazelles and giraffe) a positive response in terms of recruitment and distribution has been experienced as a consequence of conservancy creation. Population estimates for all species were obtained using DISTANCE® sampling, with results indicating substantial population increases – impala and zebra doubled in number, while wildebeest more than trebled. Accordingly, ungulate distributions increased significantly in the newly designated conservancy area (OK2), with topi, zebra and Grant's gazelles rapidly establishing significant aggregations, despite being sparsely distributed in OK2 in the first year of study. Increases in habitat heterogeneity and productivity (from remotely sensed data), and analyses of the herbaceous layer, further confirmed that regeneration of vegetation was occurring as a result of the new management regime. These results were combined along with a range of landscape attributes to create a site selection tool that identified 11 areas in the GME as having suitable biotic properties to support additional conservancies. Additionally, large tracts of the GME were identified as potential wildlife corridors and a large proportion of the south of the GME was identified as an important area that, with additional finer scales analyses, could also support suitable conservancy areas.

This study ultimately authenticates wildlife conservancies as a sustainable wildlife conservation model that has the potential to contribute significantly to reversing the declines in wildlife populations experienced in the GME over the last 40 years, particularly if the conservancy network were to be extended on those sites identified in this research via the site selection model.

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Table of Contents

List of Figures and Tables

Chapter 1

List of figures

List of tables

Chapter 2

List of Figures

List of tables

Chapter 3

List of figures

List of tables

Chapter 4

List of figures

List of tables

Chapter 5

List of figures

List of tables

Chapter 6

List of figures

List of tables

Chapter 7

List of figures

List of tables

Acronyms and abbreviations

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
CDS	Conventional Distance Sampling
DEM	Digital Elevation Model
DRSRS	Department of Resource Surveys and Remote Sensing
ETM^+	Enhanced Thematic Mapper Plus
FK	Fuzzy Kappa Analysis
GLM	Generalized Linear Model (GLM)
GME	Greater Mara Ecosystem
ICTZ	Intertropical Convergence Zone
ILRI	International Livestock Research Institute
IUCN	International Union for Conservation of Nature
KDE	Kernel Density Analysis
MCK	Map Comparison Kit
MLE	Maximum Likelihood Estimator
MMNR	Maasai Mara National Reserve
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
OK1	Ol Kinyei Conservancy (1)
OK2	Ol Kinyei Conservancy (2)
RBV	Return Beam Vidicom
RTP	Relative Topographic Position (RTP)
SLC	Scan Line Corrector
TM	Thematic Mapper
TRI	Terrain Ruggedness Index
USGS	U.S. Geological Survey

Introduction

In wildlife conservation management it is becoming increasingly evident that an elevated understanding of how wild animals respond to changes to their environment is essential to successful management. While spatial distributions and mobility are notoriously difficult to quantify in natural systems, Geographical Information Systems (GIS) and species distribution modelling have assisted considerably in this task. In particular they are increasingly being utilised as analytical tools by researchers to increase scientific understanding of wildlife responses to changes in climate, land use management and to develop cohesive decision and management support mechanisms to name but a few. One important application of GIS as an analytical and predictive tool is in the identification of new protected areas (Olson *et al*., 2001; Groves *et al*., 2002; Rodrigues *et al*., 2004; Wood & Dragicevic, 2007). The designation of new protected areas can be a contentious issue particularly in populated areas, with the potential for increases in negative human wildlife interactions (Newmark *et al*., 1994; Ogra, 2008; Dickman, 2010). For this reason it is critical that protected areas can be demonstrated to be both ecologically viable, whilst improving the life of the human inhabitants of the area.

Wildlife conservancies in the Greater Mara Ecosystem (GME) are a new form of protected area located in the pastoral lands that adjoin the Maasai Mara National Reserve (MMNR). Conservancies are areas that have historically been important dispersal areas for wildlife in response to seasonal shifts in resource availability and intensity of predation inside the gazetted national reserve (Stelfox *et al*., 1986; Hopcraft *et al*., 2012; Bhola *et al*., 2012). Wildlife conservancies seek to alleviate the effects of range contraction and fragmentation of free ranging wildlife in the GME, by increasing the amount of land available in areas previously used as livestock grazing land. Although herbivore abundance and dynamics have been extensively studied in the GME, no research had been conducted to date to assess to what extent and at what rate the land set aside for conservancies is utilised by wildlife. The need for this understanding is considerable, as past research investigating population trends of wild herbivores in the GME demonstrated that wild ungulate numbers had declined by two thirds or more between 1977 and 2009 (Ogutu *et al.,* 2011). These figures were applicable to both the MMNR and the pastoral land surrounding the gazetted area. Habitat loss, contraction and fragmentation are all factors that have been suggested as prevalent causes in the decrease of wildlife numbers in areas that historically sustained large numbers such as the rangelands of east Africa (Sinclair *et al.,* 1995; Fryxell *et al.,* 2005; Ogutu *et al.,* 2009; Ogutu *et al.,* 2010; Ogutu *et al.,* 2011). It is in response to these dramatic declines in savannah wildlife numbers that wildlife conservancies are being promoted among politicians and scientists alike.

Wild ungulates are important contributors to key ecological processes such as predation (Soulé *et al.,* 2003) and seed dispersal (Fragoso *et al.,* 2003). They are a group of species that are important in maintaining ecosystem function and resilience, therefore reductions in their abundance can significantly alter the trophic structure of the ecosystem (Soulé *et al.,* 2003; Estes *et al.,* 2011). Herbivory is also a key ecological process which ungulates impact upon and they are commonly acknowledged as drivers of vegetation change in African savannahs (Asner *et al.,* 2009; Pringle *et al.,* 2007). Their presence and species composition can have a direct impact on the abundance (Riginos &Young, 2007) and competitive interactions of both woody and herbaceous vegetation (Scholes & Archer, 1997). Ungulates are therefore considered foundation species as they can have profound effect on their environment, but due to their propensity to be present in high abundance are not considered as keystone species (Soulé *et al.*, 2003). Ungulates also represent the main prey base for savannah predators among which are lions (*Panthera leo*) and cheetahs (*Acinonyx jubatus*), globally listed as vulnerable and endangered respectively (IUCN Red List, 2015). Consequently the maintenance of high numbers of wild herbivores in the GMEs is vitally important to promote the recovery of key predator numbers.

Animal distributions are intricately linked to spatial patterns in vegetation type and structure (Reed *et al.,* 2009) and overgrazing by livestock has frequently been linked to a decrease in palatable herbaceous vegetation, with an increase in unpalatable herbaceous woody vegetation (Scholes and Walker, 1993). Therefore, the study of the successional change in vegetation provides important information relating to the stresses that intensive grazing has on savannah vegetation, in terms of herbaceous species abundance and cover. It will also provide valuable information on the changes that occur with the removal/restriction of intensive livestock grazing to the height and palatability of grazing pastures.

The current creation and expansion of existing wildlife conservancies in the GME provide a unique opportunity to identify and quantify the changes that take place in a savannah ecosystem as a result of the management strategies that accompany their creation. In particular it is important that the ecological viability of wildlife conservancies be demonstrated if we are to continue to advocate their utility. As a newly emerging wildlife protection management initiative, conservancies, which are closely aligned to the wildlife tourism industry, are proving increasingly attractive to local land owners, primarily as a consequence of the economic rewards they can provide. Unsurprisingly, many new potential locations for further expansion of the conservancy concept are being proposed, often with little consideration given to their actual wildlife “potential”. Currently then, it is important that empirical evidence, such as ungulate abundance and changes in distribution patterns, emerging from existing wildlife conservancies be utilised in such a way as to elevate our understanding of where future conservancy initiatives in the GME should be located. To date this has not happened. Consequently then, there is an urgent need to develop a predictive site selection tool which ensures that the ecological and economic viability of future wildlife conservancies have a realistic chance of being achieved. The overarching aim of this research therefore aims to identify trends in ungulate densities and distribution in an existing and a newly created conservancy, using the information collected to develop such a tool, which can be “rolled out” across the GME.

Aims

To assess the ecological viability of wildlife conservancies in the Greater Mara Ecosystem, wild ungulates and habitat heterogeneity were selected as indicators of ecological viability in Ol Kinyei Conservancy and were incorporated into six major aims:

1. Conduct an examination of wild ungulate abundance in an established wildlife conservancy, and compare findings with population abundance in a newly designated and adjacent conservancy area in the three years following conservancy creation (Chapter 3).

2. Describe patterns of spatial distribution of grazing ungulates over the course of a three year period in an established wildlife conservancy and in a newly designated area. Demonstrate how the previously identified numerical fluctuations in population sizes (Aim 1) manifested themselves in the spatial distribution of ungulates in the newly designated conservancy (Chapters 4 & 5).

3. Investigate habitat use and selectivity of ungulates to determine whether ungulate species used habitats present in Ol Kinyei conservancy differentially. Identify those habitats which are most important to the species and are therefore central to the forward management of the conservancy (Chapters 4 & 5).

4. Describe changes to habitat heterogeneity and vegetation productivity from 5 years prior to conservancy creation to the present day (Chapter 6).

5. Investigate changes to the herbaceous layer in term of species composition, cover and grass height and compare these between the established wildlife conservancy and the newly designated area (Chapter 6).

6. Develop a tool to identify areas suitable for future conservancy creation in the Greater Mara ecosystem (GME) by incorporating the empirical evidence collected on wild ungulate abundance and distribution to identify landscape optimum characteristics incorporated via a modelling approach in a GIS (Chapter 7).

Chapter 1

Literature review & Background

1.1 The Maasai GME – Historical context

The Maasai GME has experienced extensive and rapid changes since the 1960's. While there is evidence that the area has been inhabited by pastoralists for the last 2,000 years (Marshall, 1990) there was a large increase in human population density in both the second half of the 20th and throughout the 21st centuries. A study conducted by Lamprey and Reid (2004) identified the temporal changes to human settlement distribution and density in the GME between 1950 and 1999 using aerial photographic datasets. They found that the number of permanent Maasai settlements increased considerably as a result of the human population doubling every 15 years and between 1983 and 1999 they report an annual population growth rate of 4.4%. Alongside these analyses Lamprey and Reid (2004) also investigated changes to the number of livestock and estimated wildlife populations for the area from the Kenya Rangeland Ecological Monitoring Unit (KREMU) aerial surveys conducted from 1977 to 2000. During this time frame livestock and wildlife numbers were found to have fluctuated considerably, with rainfall being the most influential factor in controlling trends in population growth. This element of the study was largely conducted on the Koyaki group ranch which was deemed to be representative of trends across the GME (Lamprey & Reid, 2004). When conditions were favourable (i.e. high rainfall), particularly in the El Niño years of 1997/98, 40,000 cattle were estimated within Koyaki Group ranch. However by 2000, in the aftermath of the 1999/2000 La Niña drought, only 14,000 cattle survived (Lamprey & Reid, 2004). Interestingly, the number of sheep and goats ("shoats") had increased from 7.1% of the total livestock biomass to 9.9% by 2000. This replacement of cattle with shoats was the consequence of them being less selective in their feeding requirements and therefore more resistant to drought (Homewood & Rogers, 1991).

1.1.1 Maasai settlement

In 1913 the il-Purko section of the Maasai tribe were re-located by the colonial authorities from Laikipia (which they had occupied previously) to what is now the north and central Narok County (In: Lamprey & Reid, 2004 from: Lamprey & Waller, 1990). While the area had previously been occupied by Maasai pastoralists a rinderpest pandemic in the 1890's decimated both livestock and wildlife numbers in the area, driving the Maasai away. Between this time and 1913 the GME was sparsely occupied by Dorobo hunter-gatherers and as a result of much lower levels of grazing and bush burning, acacia woodlands and bush lands regenerated. The emergence of woody vegetation resulted in arrival of the tsetse fly (Lewis, 1934) and trypanosomiasis (Ford, 1971). This greatly restricted the amount of land in the area suitable for livestock rearing and therefore limited the area suitable for habitation by the Maasai (Lamprey & Waller, 1990). Prior to the implementation of the experimental bush and woodland clearing conducted by the Maasai in the 1950's the most affected area was the present day Maasai Mara National Reserve (MMNR). With optimal conditions for successful burning and high rainfall and grass production the landscape in the previously bushy and wooded landscape, new areas were opened up to form the large rangelands that the Maasai Mara is now famous for (Lamprey, 1984; Dublin, 1995; Lamprey & Reid, 2004). Additionally, the successful removal of the Tsetse problem opened up new areas for the Maasai, encouraging settlement and livestock grazing in areas previously dominated by wildlife.

1.1.2 Land tenure

Land tenure has changed considerably over the last 40 years in the GME. In the 1970's land ownership was transferred from a definite number of families to form group ranches (Georgiadis *et al.,* 2007). These are livestock production units where a group of people jointly own the freehold title of land, within which they maintain agreed stocking levels and herd collectively (Georgiadis *et al.,* 2007). Over the last fifteen years, the Kenyan government advocated the subdivision of these group ranches to provide families with separate plots, over which they maintain tenure and legal property rights (Seno & Shaw, 2002). The shift in ownership from the communal model to the private ownership of small parcels has been suggested as a key driver of land use change (White *et al.,* 1997). The primary effect of the creation of small parcels of land has been to encourage a shift from the more traditional semi-nomadic pastoral lifestyle to a more sedentary lifestyle which is more reliant on subsistence agriculture (Ottichilo *et al.,* 2000; Serneels & Lambin, 2001a).

1.1.3 Maasai Mara – Conservation area

The GME represents the northern expanse of the greater Serengeti-GME which straddles the Tanzanian/Kenyan border. It is a UNESCO world heritage site (Virani *et al.,* 2011) and is home to the world famous wildebeest, zebra and gazelle migration (Thirgood *et al.,* 2004). The ecosystem is considered to be one of the most biologically diverse and ecologically important savannah ecosystems in the paleotropics (Sinclair *et al.,* 2008).

The Maasai Mara has long been a popular destination for wildlife tourists because as well as playing host to the "great migration" in the months following the long rains (June to September), it is also home to vast resident wildlife populations. The Maasai GME covers approximately 6,500km^2 of arid to semi-arid rangeland (Homewood *et al.,* 2012) and was first gazetted in 1948 to create a hunting sanctuary. In 1961 it was converted in to a Game

Reserve and the area increased to 1,831Km² and was placed in the control of Narok County Council (NCC) (Waithaka, 2004). Further changes were agreed in 1984 in an appeasement exercise with the local community where approximately 321Km² were handed back to the community to use as grazing land, reducing the MMNR to its current size of 1,510Km². In 1995 the part of the reserve located west of the Mara river, the Mara Triangle, was placed under the control of the Trans Mara County Council and in 2001 devolved to a not-for-profit organisation; the Mara Conservancy (Karanja, 2003). Within both sections of the reserve the management authorities collect entry fees and revenue from camps and lodges located within their boundary. Both sections of the reserve remain unfenced, resulting in wildlife ranging over land occupied by the Maasai community. The land surrounding the MMNR is composed of what were formerly group ranches; Koyaki, Ol Kinyei, Lemek, Ol Chorro Oirowua, Siana, Maji Moto, Naikara, Ol Deresi, Kerinkani, Oloirien, and Kimintet. The local population in each of these graze cattle and in some instances, particularly to the west, have settled into large scale arable agriculture (Serneels & Lambin 2001b). Changes to land tenure have resulted in group ranches becoming sub-divided to provide privately owned plots (See land tenure section 1.1.2). This is cause for concern as the group ranches represent the main/key livelihood to the resident pastoralists and historically provided important dispersal areas for wildlife in response to seasonal shifts in resource availability inside the MMNR (Stelfox *et al.,* 1986; Hopcraft *et al.,* 2010; Bhola *et al.,* 2012).

1.1.4 Tourism in the Maasai Mara

Despite covering a considerably smaller area than the Serengeti National Park, the GME (1/12th of the area) still attracts more tourists annually. Visitors to the Maasai Mara represent 17% of total tourism to Kenya (Ministry of Tourism and Wildlife, 2008) and prior to a recent slump in tourist numbers the Maasai Mara received 332,000 visitors who stayed for ~2.5 days per person and contributed $50 million to the economy (Waithaka, 2004). With a view to coping with the increase in numbers of tourists, the last 20 years has seen a considerable increase in the infrastructure to support them. In order to accommodate such vast numbers of visitors, the number of tourist facilities and the attendant infrastructure has increased considerably. The pressure that the ever increasing number of tourist facilities and infrastructure is having on the environment is significant, with rapidly increasing wildlife tourism suggested as a trigger for negative impacts to some of the most fragile aspects of the ecosystem (Blangy & Mehta, 2006). The first permanent lodge in the Mara was established in the 1965, it had 25 beds and two vehicles (Waithaka, 2004). This was the first of many built inside the MMNR owned by private developers on land rented from NCC (Karanja, 2003). A study conducted in 2012 found that the number of tourist facilities in and around the Maasai Mara had reached approximately 180, which amounted to ~3,500 beds (Amoke, unpublished data). Concurrently, large settlements developed around the edge of the reserve to accommodate supplies and staffing required inside the reserve. This rapid increase in the density and distribution of lodges has resulted in high levels of vehicular activity, habitat degradation and fragmentation within and around the gazetted area (Thompson & Homewood 2002; Lamprey & Reid 2004). Very little attention to date has been paid to developing a sustainable system with the potential to optimise revenue to the area and ensure the persistence of elevated wildlife populations that are so vital to the tourism industry.

1.1.5 Threats to Maasai Mara

The impact that human activity has on ecosystems goes a long way to explain how wildlife populations change in abundance, distribution and behaviour (Lamprey & Reid, 2004; Serneels & Lambin, 2001a; Scholes & Archer, 1997). Habitat loss, contraction and fragmentation are all factors that have been suggested as prevalent causes in the decrease of wildlife numbers (see Figure 1.1) in areas that historically sustained large numbers, such as the rangelands of East Africa (Sinclair *et al.,* 1995; Fryxell *et al.,* 2005; Ogutu *et al.,* 2009; Ogutu *et al.,* 2010; Ogutu *et al.,* 2011). Reid *et al.,* (2004) describe the principal processes of habitat change, all of which can be attributed to human activity in the context of the GME. Habitat loss, or conversion, directly modifes the composition of a landscape by transforming 'suitable habitat' into a habitat that has reduced in quality to no longer be 'entirely suitable'. In the Mara this is attributed to expanding permanent settlements and trading centres, conversion of range land to cropland, and the erection of impenetrable fences (Reid *et al.,* 2004).

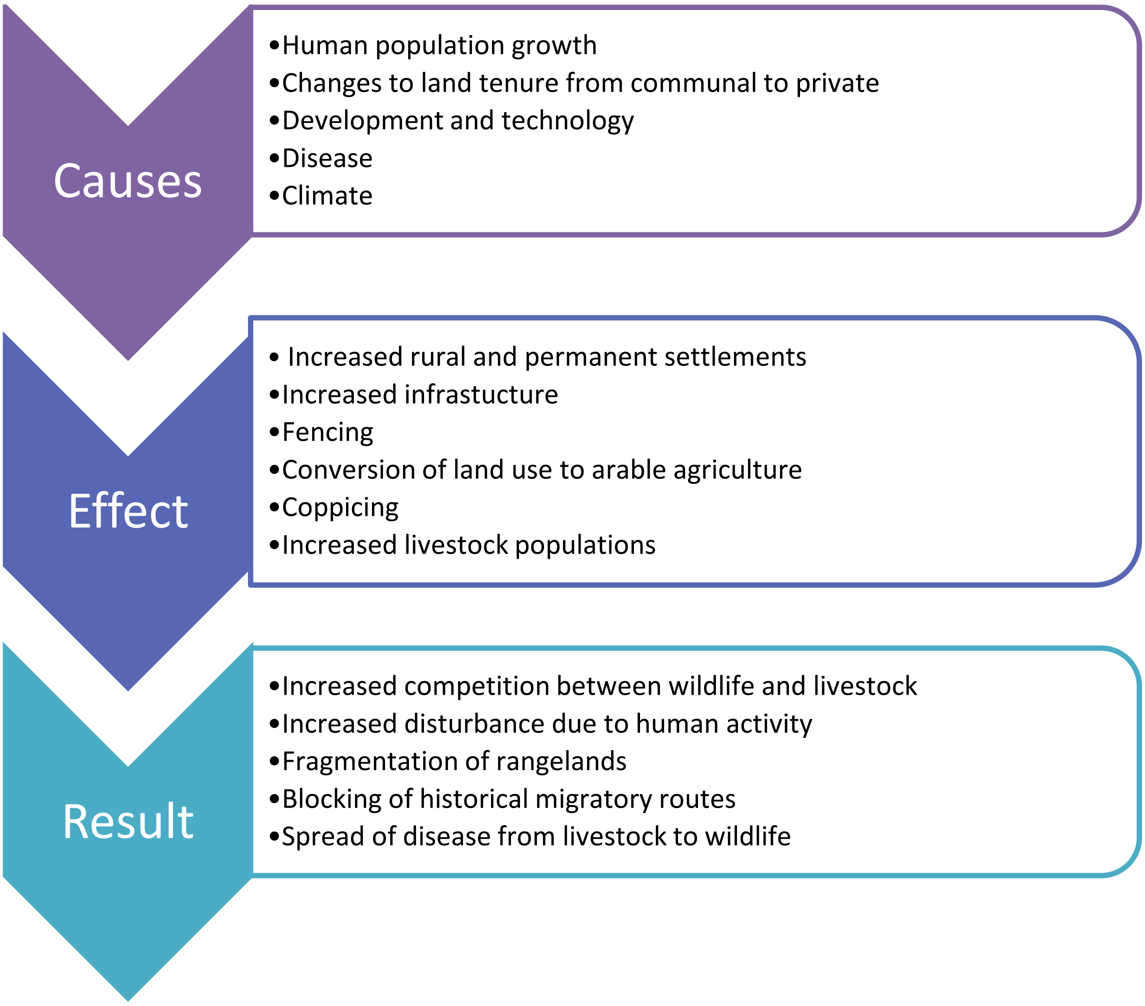


Figure 1.1: Conceptual framework of causes and effects of habitat loss and fragmentation in semi-pastoral landscapes.

The culmination of these anthropogenic pressures mean that over the last 20 years wildlife population numbers have decreased by over 70% in the GME (Table 1.1) (Ottichilo *et al.,* 2000; Homewood *et al.,* 2001; Serneels & Lambin, 2001a). These decreases have been attributed to human activity in the GME (Sinclair *et al.,* 1995 Thompson & Homewood, 2002; Lamprey & Reid, 2004; Fryxell *et al.,* 2005; Ogutu *et al.,* 2009; Ogutu *et al.,*2010; Ogutu *et al.,* 2011).

Table 1.1: Wildlife population trends in the Greater Mara ecosystem

Species	Time Period	Trend GME	Source	Trend Mara Group ranches (GR) vs MMNR*
Wildebeest	1985 - 2004	Decline	Thirgood *et al.,* 2004; Ogutu *et al.,* 2011	GR > MMNR
Zebra	1989 - 2003	Stable	Ogutu *et al.,* 2011	GR > MMNR
Grant's gazelle	1977 - 2009	Increase	Ogutu *et al.,* 2011	GR > MMNR
Thompson gazelles	1977 - 2009	Decline	Ogutu *et al.,* 2011	GR > MMNR
Impala	1977 - 2009	Decline	Ogutu *et al.,* 2009 &2011	GR > MMNR
Topi	1977 - 2009	Decline	Ogutu *et al.,* 2011	GR <MMNR
Giraffe	1977 - 2009	Decline	Ogutu *et al.,* 2011	GR > MMNR

*In Ogutu *et al.,* (2011)

1.1.6 Habitat modification, loss and fragmentation

Habitat modification represents a change that usually results in the habitat becoming less suitable than it was previously to the users (Reid *et al.,* 2004). In the GME this reflects conditions in areas that are heavily grazed by livestock but could still be utilised by wildlife, such as in the heavily used areas in the former group ranches (Prins, 1992). Both habitat loss and modification can contribute to fragmentation and the severity of the effect is highly dependent on the spatial and temporal scale of the change and the focal species habitat and range requirements. A further major threat to savannah habitat is overgrazing. In areas where the incidence of livestock grazing is high, wild herbivores, which vary between grazers, browsers and mixed feeders, often diminish in numbers as a result of disturbance and competition for food (Riginos & Young, 2007; Odadi, 2011). In addition, intensive livestock grazing has frequently been linked to shrub encroachment in sub-Saharan Africa (Scholes & Archer, 1997; Roques *et al.,* 2001; Cabral *et al.,* 2003; Sankaran *et al.,* 2008; Asner *et al.,* 2009); which results in a decrease in palatable herbaceous vegetation and an increase in unpalatable woody vegetation (Scholes and Walker, 1993).

Fencing in the greater GME is increasing at a very significant rate, largely as a consequence of the need to separate wildlife from human settlements, livestock and crops. This has led to several key areas of ecological concern. Most obvious is the disruption to migration routes. The GME is not only integral to the annual Mara-Serengeti wildebeest migration, but also to the “internal” migration of the majority of ungulate species as they move between preferential feeding areas and water sources (e.g. zebra, Topi, Thompson’s and Grant’s gazelles). Often cited in the literature are the negative impacts of fencing to the African elephant, a keystone species in the African savannah. Negative impacts surround restricting the range of the elephant, which in turn lead to disruption of ecosystem structure and function (Guldemond & van Aarde, 2008; Shrader *et al.,* 2010; Valeix *et al.,* 2011; Asner & Levick, 2012). Additionally, there are increasing concerns about the ongoing compression of elephant populations into ever-decreasing amounts of protected area (van Aarde & Jackson, 2006; Valeix *et al.,* 2011; Young & van Aarde, 2011). Restricting the movement of ungulate species also impacts upon predators that must be able to “follow” their prey. Previous authors (Estes *et al.,* 2011) have indicated a likely consequence of this will be an alteration to population dynamics with the possibility of trophic cascades, leading to loss of both ecosystem function and biodiversity.

Perhaps the largest, but as yet most poorly understood impact of the increased amount of fencing relates to climate change and its impact upon animal movement patterns. This was raised by Woodroffe *et al.,* (2014) who concluded that, as climate change increases then so does the importance of wildlife mobility and landscape connectivity, noting that fencing of wildlife should become an action of last resort. Until we are more conversant with the relationship between climate change and animal movement patterns in savannah ecosystems then the precautionary principle of very limited/zero fencing should prevail.

1.2 Wildlife Conservancies

Wildlife conservancies are an initiative that aims to promote the protection of wildlife in ecosystems by creating “protected” areas on privately owned land, formally parts of group ranches. Land owners receive lease payments from private investors who in turn utilise the land as tourism ventures for wildlife viewing. As part of the agreement the land owners agree to a controlled livestock grazing regime with the private investors. Wildlife conservancies are a recent development, with the first conservancy established in 2005. At present they represent a minimal amount of land in the GME (Figure 1.2). The creation of wildlife conservancies around the perimeter of MMNR substantially increases the amount of land available to wildlife, whilst minimising human activity. Areas converted to wildlife conservancies in the GME have historically been used as grazing land for cattle. As a result of controlled livestock grazing, the vegetation in the newly formed conservancy areas is predicted to change, this in turn can be expected to affect the herbivore densities and distributions in these newly available areas (Jacobs and Naiman, 2008; Ogutu *et al.,* 2008).

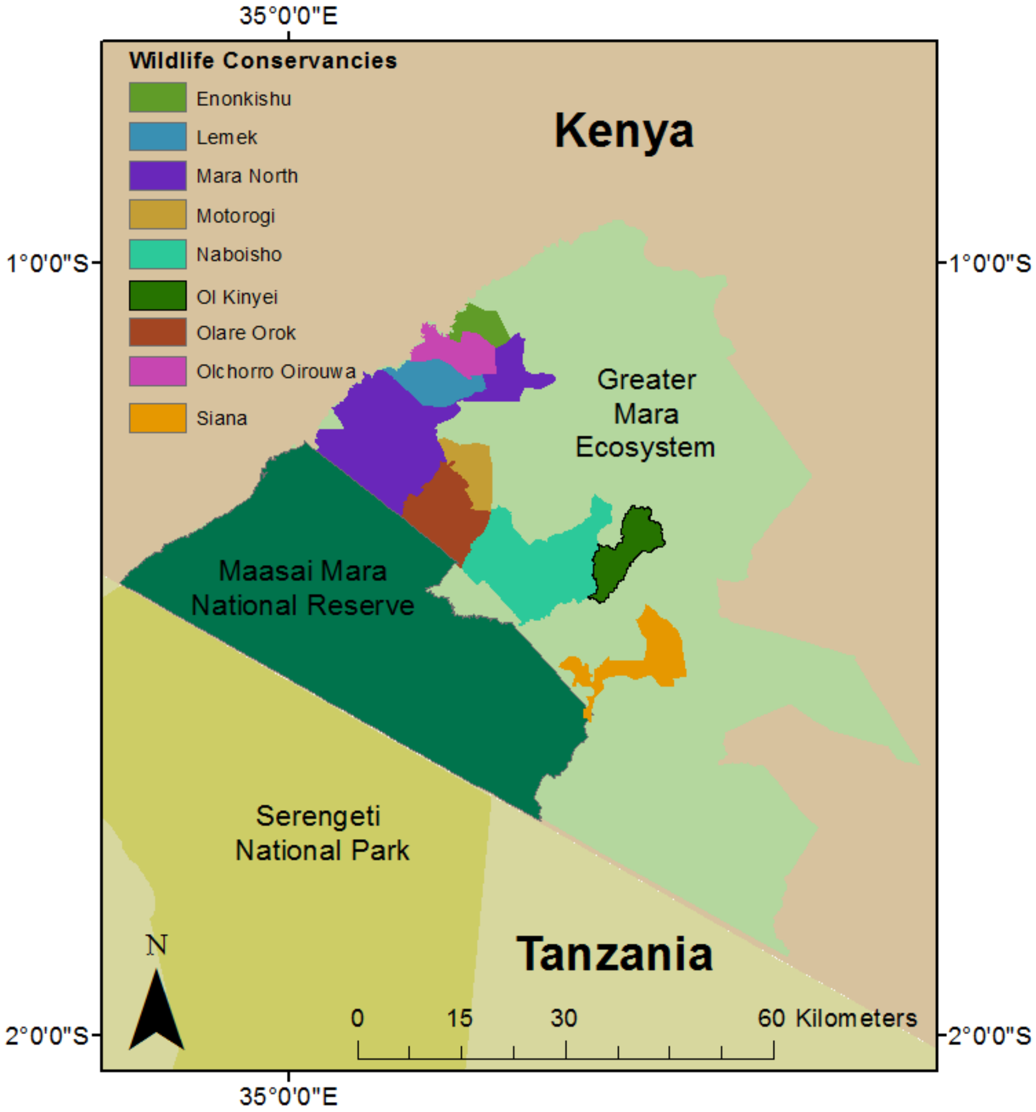


Figure 1.2: Maasai Mara National Reserve (MMNR) and established conservancies in the GME, Kenya.

With the establishment of several pioneer conservancies since 2005, private land owners have benefited from the financial advantages which result from conservancy agreements. This has stimulated an increase in community interest and subsequently there has been a significant increase in locations being proposed as wildlife conservancies. While this is a positive development, the process of creating a conservancy requires careful planning in terms of location, accessibility to wildlife and potential revenue from tourism. Proximity to human settlements and intensive agriculture are important factors that need to be taken into consideration, as well as the overall attractiveness of an area to wildlife. The first wildlife conservancy to be established in the GME was Ol Kinyei Conservancy (Figure 1.2). In this case the investors were "Porini" who, under the umbrella of Gamewatchers Safaris, pioneered the concept in Kenya.

1.2.1 The Porini Conservancy concept

With the inception of the conservancy model developed by Gamewatchers safaris in Ol Kinyei Conservancy, the investors developed a framework within which several important factors with regards to size, lease payment and management strategies were identified as essential considerations in the establishment of a wildlife conservancy in the GME (Porini safari camps 2013). Consequently, in order to be considered viable as a conservancy by the stakeholders in Ol Kinyei a minimum area of 28Km² of un-interrupted land was proposed. This land would no longer be available to the land owners or any pastoralists living in the vicinity as grazing land for their livestock unless controlled or rotational grazing had been pre-negotiated. In the case where controlled grazing was agreed, it was left to the investors to manage the process and develop a grassland management plan. Payment for the use of the land is monthly by acre, not per tourist and ensures that land owners receive consistent payments throughout the year regardless of tourist numbers. Lease payment is made directly to individual land owners, not to any central committee, and all payments are made by the safari operators who operate within the Conservancy. Where possible the camp staff, guides and conservancy rangers are drawn from the families of landowners. If the landowners have been living on parcels to be included in the conservancy they should vacate the area. If the family is not in possession of any land outside the conservancy area, arrangements are made by the investors to provide suitable parcels for habitation. All tourist activities that occur in the conservancy are the direct responsibility of the investors. For example, in order to prevent overcrowding in the conservancy, a maximum density of 1 tent per 700 acres is set with no one camp having more than twelve guest tents, a ratio deemed to impose acceptable levels of disturbance upon the wildlife and the receiving environment.

It was predicted that as result of conservancy establishment and the removal of intensive livestock grazing, that the amount of resources available to wildlife would increase. Wildlife populations and their distributions were expected to increase and as a consequence, over time the quality of the resources would also increase further promoting growth of wildlife populations. As resources improve for the herbivores and their numbers increase (see Figure 1.3) carnivore populations would also be expected to increase. This is important for wildlife tourism, as high densities of carnivores present optimal viewing and encourages repeat visitors. By creating an optimal destination for wildlife viewing the investors are increasing the economic viability of wildlife conservancies and consequently their attractiveness to other investors. This increases interest in creating new conservancies which would further increase the amount of land available to wildlife.

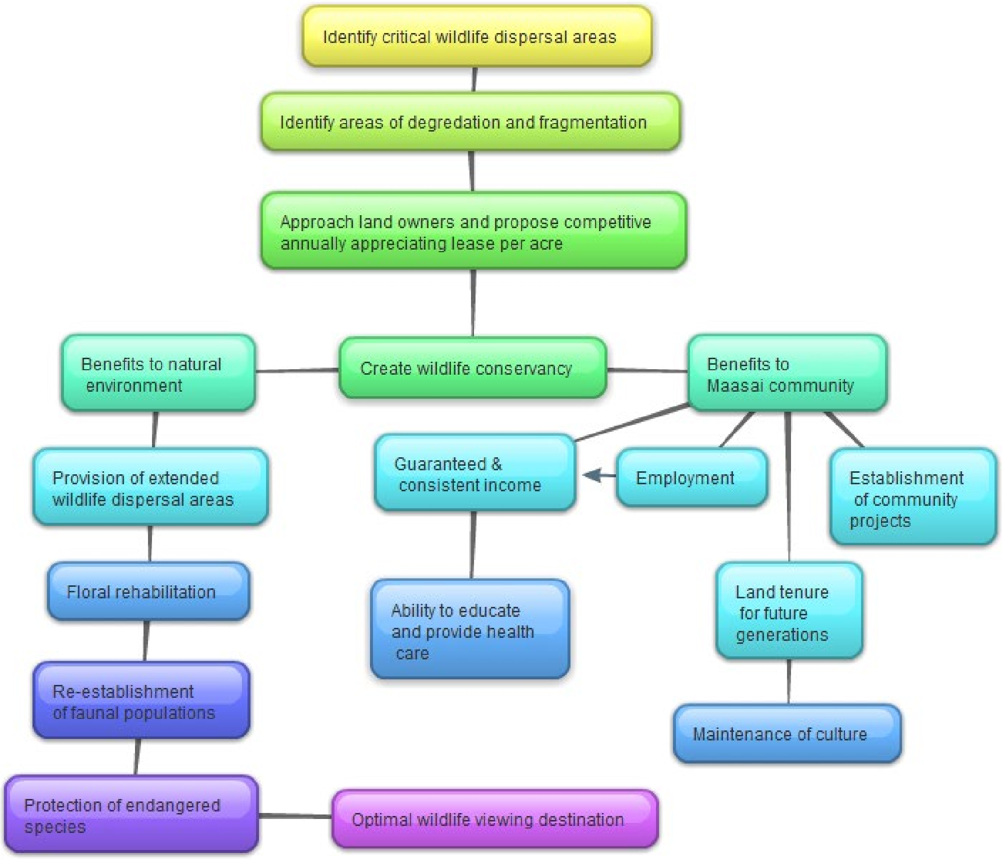


Figure 1.3: Conceptual framework of wildlife conservancies (Adpated from: Porinisafariscamps, 2014).

In order to successfully conserve wildlife it has long been agreed that community involvement is essential to increase the autonomy of the inhabitants by enabling them to benefit directly from the presence of wildlife (Ashley & Roe 1998; Agrawal & Gibson, 1999). The creation of conservancies not only provides an economic incentive to land owners but also provides the opportunity for employment. It also ensures that the legal ownership of the land remains with the Maasai. As part of their outreach programs most investors contribute to local community projects and support local schools and medical facilities. Coupled with the regular monthly payments, these factors contribute to helping the Maasai adapt to a monetary world where education, employment and financial awareness and competence are becoming essential.

1.3 Ecology of the Greater Mara Ecosystem (GME)

The climate in the GME is influenced by the inter-tropical convergence zone (ITCZ) (Serneels & Lambin*,* 2001b) and the topography of the area (Ojwang *et al.,* 2006). The ITCZ is a belt of low pressure that wraps around the Earth near the equator. It results from the meeting of the Northern and Southern hemisphere trade winds, resulting in increased precipitation. The ITCZ oscillates north to south over the area and receives the most intense heating from the sun. As a result in most of Kenya a bimodal rain pattern prevails, with two wet seasons and two dry seasons. In the GME the “long rains” run from March to June and the “short rains” occur between October and December (Norton-Griffiths *et al.,* 1975). Topography is an important component influencing the small scale spatial and temporal heterogeneity of rainfall patterns across the ecosystem. There is a significant gradient in rainfall across the ecosystem with areas in the South-East receiving ~400mm annually to an average of ˜1,200mm a year in the North-western highlands (Serneels & Lambin, 2001b; Waithaka, 2004).

The presence of several permanent rivers in the GME provides constant water sources for resident wildlife and people (Waihaka, 2004). Tributaries of the major rivers, whilst more vulnerable to drying up in the drier seasons, are nevertheless vital features and greatly influence the abundance and distribution of wildfire and livestock in this landscape (Waithaka, 2004; Ogutu *et al.,*2011).

1.3.1 Climate/rainfall

In the GME droughts are becoming an increasing concern, as in recent years there have been more regular and increasing periods without rain. The El Niño Southern Oscillation (ENSO) forces rainfall patterns out of phase and is increasingly cited as being of major concern, not only because wild and domestic animals are heavily reliant on the natural cycle of water availability but also that the recent droughts have resulted in major economic and ecological change. A reduction in surface water availability has direct impacts for both wildlife and livestock populations alike. In addition to substantially elevating mortality rates, droughts often eliminate the least robust age groups creating skewed and unbalanced population demography (Serneels & Lambin 2001b). Future changes in rainfall pattern and periodicity will likely have severe implications for the wildlife of the GME. For example Mduma *et al.,* (1999) found that wildebeest numbers are significantly affected by rainfall in the dry season as it directly affects food availability and will directly affect predator numbers and survival rates.

Monthly temperature and rainfall data was obtained from the Kenya Wildlife Trust (KWT), Mara Cheetah project who have been collecting daily since August 2013 (KWT – Mara Cheetah Project, 2015). Average monthly temperature and rainfall, as well as maximum and minimum temperatures ranged between 14.95 C° and 16.05 C° in 2014 (Appendix 1.1). Rainfall data showed that March, September and December had the highest rainfall. In 2013 there was considerably more rain in November than in 2014 while there was more rainfall in August 2014 than in 2013 (Appendix 1.2).

1.3.2 Spatial heterogeneity and herbivore dynamics

The spatial heterogeneity of habitats had long been suggested as an important driver explaining patterns in species richness (Oindo *et al.,* 2000). In the Serengeti-GME, it has been proposed as one of the most important factors in driving ecosystem processes such as the seasonal migration of considerable numbers of wildebeest and zebra (Thirgood *et al.,* 2004; Anderson *et al.,* 2008). The heterogeneity hypothesis (Hudson, 1979) suggests that 'simple' ecosystems (homogenous habitats) are less likely to support large assemblages of biological species than 'diverse' ecosystems where habitat heterogeneity is high (Diamond 1988; Owen-Smith 2004; Fryxell *et al.,* 2005; Cromsigt *et al.,* 2009). Several studies suggest that increased habitat heterogeneity in small areas supports more diverse species assemblages and provides increased resilience to temporal variations rather than large areas with minimal spatial variation (Fryxell *et al.,* 2005; Báldi, 2008; Cromsigt *et al.,* 2009). Habitat heterogeneity has been suggested to be correlated with resource heterogeneity and has consequently been suggested as a conservation paradigm (Du Toit & Cumming, 1999), whereby increased heterogeneity in an environment increases the opportunity for resource partitioning in mixed species assemblages, thus surpassing the importance of extent in determining the carrying capacity and herbivore diversity (Owen-Smith, 2004; Fryxell *et al.,* 2005; Ritchie & Olff 1999; Cromsigt *et al.,* 2009).

Reed *et al.,* (2009) used satellite imagery to study the spatial distribution of vegetation types (habitats) in relation to rainfall and topographic relief in the Serengeti-GME. Building on prior research (O'Brien *et al.,* 2000; Urban & Keitt, 2001; Sankaran *et al.,* 2004) their findings suggest that topography and climate are found to be important drivers in the distribution and species composition of habitat patches in a landscape. Concurrently, results from Reed *et al.* (2009) indicated that in the Serengeti-GME, vegetation diversity and distribution are heavily influenced by annual rainfall and the hydrological condition of the soil. Reed *et al.* (2009) went on to describe a mosaic of eight distinct vegetation structures based on the hierarchical structures outlined by Grunblatt *et al.,* (1989). In this instance classifications were based on the density of the primary life-form, assigned a density descriptor dependent on canopy cover (Table 1.2).

Table 1.2: Summary of habitat classification scheme based on Grunblatt *et al.,*(1989) identification system, adapted from Reed *et al.,* (2009).

Habitat	Description
Forest	Single-stem woody species taller than 1.5m and present at a density larger than 50%
Woodland	Single-stem woody plants taller than 1.5m and present at a density lower than 50%
Shrubland	Multi-stem woody species lower than 2m
Grassland	Herbaceous vegetation dominant
Density descriptors	**Canopy cover (%)**
Closed	80 - 100
Dense	50 - 79
Open	20 - 49
Sparse	2 - 19

1.3.3 Herbivore spatial distribution

Wild herbivore populations are constrained by the availability of resources and predation pressure with individuals requiring access to sufficient resources whist occupying areas where predation risk is minimal (Sinclair & Arcese, 1995). These factors combined determine the number of individuals an environment can support (Sinclair *et al.,* 2003; Hopcraft *et al.,* 2010). Additionally, herbivore distributions have been demonstrated to be heavily influenced by body size, both in terms of vulnerability to predation (Sinclair *et al.,* 2003) and differential resource requirements (Owen-Smith, 1988). Consequently, body size acts as an additional constraint, determining occupancy of the different habitats present in a landscape (Jarman, 1974 cited in: Hopcraft *et al.,* 2010). The savannah's mixed ungulate assemblages are composed of a variety of species that belong to diverse feeding guilds (Table 1.3). A large proportion and the most abundant ungulates are grazers, however a selection of savannah ungulate species are classed as mixed feeders while others are browsers (Hofmann & Stewart, 1972; Owen-Smith & Novellie 1982; McNaughton, 1984). The diverse feeding strategies exhibited by east African savannah ungulates facilitate species coexistence by reducing inter-specific competition between herbivores for resources. Browsers feed exclusively on woody vegetation (shrubs or trees) and mixed feeders feed on both grass and woody vegetation depending on the season and habitat (Pérez-Barbería *et al.,* 2001). When forage is not readily available or has become more fibrous and less nutritious (Fritz & Duncan, 1994; Olff *et al*., 2002; Bhola *et al*., 2012) mixed feeders adjust their feeding behaviour and habitat selection to browse in shrublands or woodlands.

Wild ungulates are frequently referred to as living in a “Landscape of fear” (Laundre *et al.,* 2001; Brown & Kotler, 2004), their survival being dependent on the constant trade-off between avoiding predation and accessing suitable quantities of quality nutrients (Houston *et al*., 1993; Lima, 1998). Small and medium bodied species are more vulnerable to predation than larger bodied species and have been shown to spend a larger proportion of their time exhibiting vigilant behaviour than feeding (Underwood, 1982; Sinclair *et al.,* 2003). Probability of predation in African savannahs tends to increase with vegetation cover; most African predators are ambush predators and therefore rely on vegetation cover to conceal them (van Orsdol, 1984). As a result of the trade-off between acquiring optimum resources and maximising vigilance from predators, small bodied ungulates are expected to occupy areas of open grassland where forage is readily available and the lack of woody vegetation increases vigilance opportunities, while browsing species are expected to occupy more vegetated areas to fulfil nutritional needs. Riginos & Grace (2008) found that even giraffes, which are browsers, utilised open habitats more than densely vegetated areas indicating that habitat preference for browsing herbivores in the savannah environment also appears to be driven by visibility rather than browse availability.

Savannah herbivores also vary greatly in digestive efficiency in correspondence to body size and feeding guild, with mammalian metabolic rate scaling proportionally by three-fourths with body size (Hopcraft *et al.,* 2010). The feeding strategies of ruminants vary according to their body size. Small-bodied ruminants, which have corresponding small rumens and narrow mouths, have a higher metabolic rate than larger bodied species and therefore require the most digestible components of plants in order to efficiently ingest vital nutrients (Illius & Gordon, 1992). Larger ruminants, with wider mouths, have the ability to ingest larger amounts of food of lower quality graze which they can digest efficiently because their proportionally larger rumens allow for slower passage rates, enabling them to extract necessary nutrients from the lower quality forage (Sinclair *et al.,* 1998; Gordon & Illius, 1996; Hopcraft *et al.,* 2010). Medium-bodied hind gut fermenters such as zebra are classified as bulk feeders yet tend to consume a mix of high quality and coarse forage (Foose, 1982; Clauss & Hummel, 2005).

Table 1.3: Description of body size, feeding guild and vulnerability to predation of abundant savannah herbivores in the GME.

Species		Body size		Feeding guild			
Scientific name	**Common name**	**Gender**	**Body weight (kg)**	**Feeding behaviour**	**Digestive biology**	**Vulnerability to predation**	
Connochaetes taurinus	Wildebeest	M	171-242	BG	R	Adults	High
		F	141-186			Juveniles	High
Gazella thomsomii	Thompson's gazelles	M	17-29	G	R	Adults	High
		F	13-23.5			Juveniles	High
Gazella grantii	Grant's gazelles	M	58-81.5	MF	R	Adults	Low
		F	38-67			Juveniles	High
Damaliscus lunatus	Topi	M	104-126	G	R	Adults	Low
		F	105-118			Juveniles	High
Alcelaphus buselaphus cokii	Coke's hartebeest	M	129-171	G	R	Adults	Low
		F	116-148			Juveniles	High
Equus burchelli	Plains Zebra	M	220-322	BG	HGF	Adults	High
		F	175-250			Juveniles	High
Aepycaros melampus	Impala	M	53-76	MF	R	Adults	High
		F	40-53			Juveniles	High
Kobus ellipsiprymnus	Waterbuck	M	198-262	G	R	Adults	Low
		F	161-214			Juveniles	Low
Giraffa camelopardalis	Giraffe	M	800-1 930	B	R	Adults	Low
		F	550-1 180			Juveniles	Low
Loxodonta africana	Elephant	M	5 000	MF	HGF	Adults	Low
		F	3 000			Juveniles	Low
Syncerus caffer	Buffalo	M	686	BG	R	Adults	Low
		F	576			Juveniles	Low
Madoqua kirkii	Kirk's Dik-dik	M	5.1	MF	R	Adults	High
		F	5.5			Juveniles	High
Tragelaphus oryx	Eland	M	500-600	MF	R	Adults	Low
		F	340-445			Juveniles	Low

G = grazer; BG = Bulk grazer; MF = mixed feeder; R = ruminant; HGF = Hind-gut fermenter Adapted from Estes (1991)

As a consequence of the variation in savannah herbivores in body size, feeding ecology and vulnerability the availability of heterogeneous vegetation is imperative to support these mixed species assemblages which persist as a result of resource partitioning (Ritchie & Olff, 1999; Cromsigt & Olff, 2006).

1.4 Ungulates

1.4.1 Classification and biology

The term ungulate refers to a group of medium to large bodied terrestrial mammals adapted to herbivory in open environments. They are adapted to locomotion which provides speed and sustainable energy consumption. They have achieved this via adaptation to the tarsal and meta-tarsal bones which have been reduced, lengthened, and compressed to form hooves. Additionally, the movement of the limbs is restricted to a forward/backward rather than sideways motion allowing for movement which is mechanically and energetically more efficient.

Classification divides ungulates into two groups: perissodactyls (odd-toed) and artiodactyls (even-toed). A further distinction that exists between perissodactyls and artiodactyls is the way in which they have adapted to processing cellulose, an indigestible component of plant tissues. Perissodactyls are hindgut fermenters with a single stomach, a caecum and microorganisms in the colon that ferment the cellulose in the final stages of digestion (Shorrocks, 2007). Hindgut fermenters only chew food once, unlike artiodactyls which are ruminants, with a four-chambered stomach. Ingested food enters the first chamber, the rumen, where the coarse cellulose particles are regurgitated to be re-chewed. After rumination the food matter passes back through the four stomach chambers; the rumen, the reticulum, the omasum, the abomasum, and finally the colon (Shorrocks, 2007). At all stages different biochemical processes break down and filter the plant matter. In contrast to hindgut fermenters, cellulose digestion occurs prior to normal digestion. Artiodactyls, can also recycle urea giving them the ability to conserve water and reducing their dependence on water. Hindgut fermenters do not have this adaptation making them more water dependent.

The differences in the digestive biology between hindgut fermenters and ruminants have a direct effect on the ecology and most importantly feeding behaviour of species. Hindgut fermenters are not as efficient at breaking down cellulose as ruminants; this is evident in the coarse consistency of their dung (Shorrocks, 2007). They are classified as bulk feeders that are considerably less selective of palatability and cellulose content. They are more dependent on acquiring sufficient biomass to offset food that remains largely undigested. Ruminants tend to be more selective when feeding. They are also more susceptible to loss of physical condition in drier seasons because their digestive system is slower, making them vulnerable to protein deficiency (Shorrocks, 2007). Some species have adapted to these limitations by relying less heavily on graze when grass swards are least nutritious in dry seasons, by browsing on woody vegetation to prevent loss of condition.

1.4.2 Study species

1.4.2.1 Perissodactyls

1.4.2.1.1 Plains Zebra

Plains Zebra (*Equus burchelli*) are large, odd-toed ungulates (Family: Equidae) (Table 1.3). Geographically widespread across much of sub-Saharan Africa, they occupy a broad range of savannah habitats and are classified as bulk grazers and hindgut fermenters. Plains zebra are highly adaptable and successful grazers (Estes, 1991) and are one of the pioneer grazing species in the African savannah that move into areas ahead of more selective feeders to feed on tall and flowering grasses (Shorrocks, 2007). They are usually found in small family units of 4 to 8 individuals - with one dominant male presiding over several females and their offspring. Of all ungulate species found in the Mara, zebra is among the most water dependent (Bell, 1971 in: Estes, 1991). Zebra in the GME are both migrant and resident where the migrant population follow the same route as the wildebeest (Serengeti to Mara after the rains in April to June) whilst resident populations are present in the GME in varying densities throughout the year. They are often considered to be a pioneer species that migrate first to consume the bulk of the high grass swards before the wildebeest appear (Bell, 1971 in: Estes, 1991).

1.4.2.2 Artiodacyls

1.4.2.2.1 Common Wildebeest

The white bearded wildebeest (*Connochaetes taurinus*) is one of the most abundant herbivores on the African sub-continent. Despite being ruminants they are bulk feeders that leave behind short swards. In the Serengeti-Mara ceosystem wildebeest are famous for their yearly migration. They follow the rains (and resultant grass growth) moving from South (Serengeti) to North (Mara) in June/July after the rainy season that occurs in the Mara (April to June) to feed on the large amounts of grass available. In September/October they migrate south again to follow the rains back to the Serengeti.

The migrant population consists of several million individuals but the ecosystem does also have a resident wildebeest population. Wildebeest can be found in group sizes ranging from a couple of individuals to several hundred. They are highly mobile, moving through areas rapidly once resources begin to be depleted, and their wide mouths and incisors provide them with the ability to close crop graze at a rapid rate (Estes, 1991).

1.4.2.2.2 Topi

Topi (*Damaliscus lunatus jumela*) is classified in the same tribe (Alcelaphini) as the hartebeest (Family Bovidae - *Alcelaphus buselaphus cokii*) and is endemic to the GME. They are slightly smaller than the hartebeest in size (shoulder height: 1.2m, weight 126-140kg as opposed to: 116-171Kg for hartebeest). They are grazers that tend to be found in scrub and open woodlands and are highly selective; feeding primarily on longer new growth of more palatable grasses and prefer long grass. Topi are usually found in groups up to six individuals and are composed of one male, several females and their offspring.

1.4.2.2.3 Thompson's Gazelles

The Thompson's gazelle (*Gazella thomsonii*) is a small bodied ungulate (shoulder height: 55-65 cm & weight: 15-25kg) most commonly found on open grasslands and shrublands where the grass is short. It is very selective in terms of grass height (for both feeding and vigilance) and heavily dependent on access to water. Although predominantly gregarious they can be found in small to large groups comprising up to several hundred individuals (Estes, 1991). In the Mara there are both migrant and resident populations of Thompson's gazelles. The migrant population appear once the grass has been grazed to short swards by bulk feeders, such as wildebeest and zebra. In the GME, particularly on community grazing land and conservancies, they are among the most abundant herbivore species.

1.4.2.2.4 Grant's Gazelles

Grant's gazelle (*Gazella grantii*) are larger than the Thompson's gazelle (shoulder height: 80-95cm & weight: 35-80 kg). Whilst primarily a grazer they also readily browse and are consequently found across a variety of habitats particularly scrub and open woodland. Similarly to Thompson's gazelle they are both migrant and resident in the GME.

1.4.2.2.5 Giraffe

The Maasai giraffe (*Giraffa camelopardalis tippleskirchi*), the largest of the study species is adapted to browsing Acacia, Comniphora and Termilalia tree species in tree savannah habitats. Ranges of different giraffe sub-species are debated (Brown *et al.,* 2007) the Maasai giraffe is mostly found in the open to closed savannahs of Kenya and Tanzania. Because giraffe feed from treetops they need to be highly mobile in order to have access to sufficient browse in a landscape where trees can be dispersed. They can be found in groups ranging from a few individuals up to 30 or more with the fission and fusion of groups highly dependent on resource availability.

1.4.2.2.6 Impala

Impala (*Aepyceros melampus*) are mixed feeders, feeding on grass when new growth emerges and relying on browse in drier seasons. They are often found in scrub, open woodlands and ecotonal boundaries near riverine forest. Impala are highly adaptable and more resilient to disturbance than most other savannah herbivores. They can be found in herd sizes that range from small family units up to 50 plus individuals. Herds consist of one dominant male, and several females and their offspring; males who have failed to secure a harem tend to form bachelor herds which are a common feature of the Mara landscape.

Chapter 2

Overview of data analysis

2.1 DISTANCE® sampling & analysis

Wild animal monitoring should be dynamic, cost effective, and adaptive. The outputs produced should appeal to varying audiences (other scientists, managers and lay persons) and most importantly provide implementation strategies to assist managers and policy makers. However yielding precise and non-biased estimates as outputs from wildlife population monitoring is notoriously difficult (Pollock *et al.,* 2002; Buckland 2004). When designing a monitoring project in a natural system many components require careful consideration to ensure that the outputs are truly representative of the target populations.

Target species and study area are important in determining the scale, intensity, accuracy and precision required from the survey design and should be identified with careful consideration of research questions and desired outputs (Buckland, 2004). In natural systems it is challenging to obtain absolute counts of wild animals, consequently samples of the total population or of the distribution of the target species must be monitored and extrapolated to the larger area of interest (Pollock *et al.,* 2002). In survey design, detection probability must be considered, relative indices that produce population estimates rely on the assumption that estimates calculated are directly representative of the true population; they assume that all target individuals within the sampling areas are detected. However few if any, methods assure 100% detection certainty in natural systems and for that reason detection error, by determining a detection probability, must be accounted for in the analytical stages of a wildlife monitoring project (Buckland *et al.,* 1993; Buckland *et al.,* 2001; Buckland 2004).

Within selected sampling sites, spatial heterogeneity should be considered to be representative of the ecological scale of the target species and diversity in habitats. Stratification should be utilised where the detection probability of the target species differs between habitats (Buckland, 2004). To maximise sightings surveys should be carried out when the animals are most visible and sampling intensity should be indicative of the rarity of the target species.

DISTANCE® sampling is a technique that is used extensively to monitor biological populations (Ashenafi *et al.,* 2005; Acevedo *et al.,* 2012; Biswas & Sankar, 2012; Broekema & Overdyck, 2012). It models detection probability from data and incorporates it into all calculated results (Buckland *et al.,* 1993; Buckland *et al.,* 2001; Buckland *et al.,* 2004). Norwell, *et al.,* (2003) compared population estimates derived from DISTANCE® and analysis with conventional relative abundance estimations (measure of target species mean number of individuals per sample site). They examined outputs from the two methods of data collection and analysis to produce population estimates of riparian birds and concluded that trends identified from the conventional relative abundance estimations were strongly influenced by the scale upon which the data was collected and did not account for variations in detectability of individuals. They reported that DISTANCE® sampling methods produced results that were more exact to variations in detectability across habitats and time, more robust to exploitations of assumptions and were more suited to large scale and multispecies monitoring exercises (Norwell *et al.,* 2003).

The Research Unit for Wildlife Population Assessment (RUWPA) at the University of St Andrews have conducted extensive research on wildlife population assessments and survey design (Thomas *et al.,* 2010). The DISTANCE® project has given rise to DISTANCE® software (http://distancesampling.org/)) which enables users to design and analyse distance sampling surveys in a way which captures all of the outlined concerns, resulting in the most accurate wildlife population size estimation tool (Thomas *et al.,* 1998).

2.1.1 Data collection DISTANCE® sampling

Line transect sampling involves the identification of a number of transects within the study area of a specified length (L). In heterogeneous landscapes, they should traverse the various habitats representatively to allow for stratification. Line transect data is collected by one or more observers who travel along the transect and record the perpendicular distance of all individuals or clusters of the target species detected (Figure 2.1).

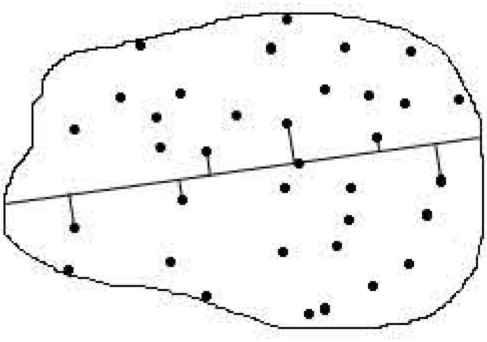


Figure 2.3: Line transect sampling approach, objects are detected and their distances from the transect of length L are recorded (Taken from: http://www.ruwpa.st-and.ac.uk/Research/DistanceSampling/Pictures/LineTransect.jpg on 07/09/15).

In DISTANCE® sampling it is assumed that: (1) all individuals on the line (distance from transect = 0) are detected, (2) the target individuals do not move, (3) the perpendicular distance is measured with precision.

Conventional Distance Sampling (CDS) results are obtained from a combination of design based and model based inference (Fewster *et al.,* 2009; Thomas *et al.,* 2010). The outputs are abundance and density metrics calculated using the distribution of the distance values recorded in the field to determine the proportion of animals that are detected within the sampling strip. A detection function is fitted to the distance distribution and provides the detection probability (Figure 2.2) as a function of the distance from transects, assuming that all objects on transects are detected and that detection probability decreased with increased with distance from the transect.

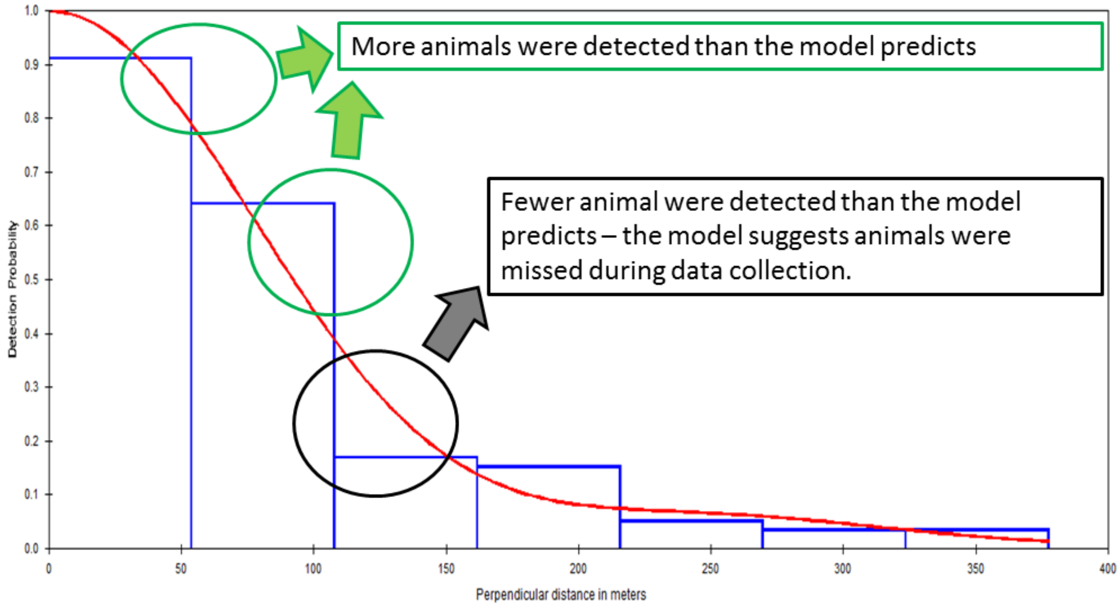


Figure 2.4: DISTANCE® output for detection probability. The bars represent the data collected in the field and the red line the model with the determined detection probability (Example from field data in Season 1).

The same detection function applies to all individuals or clusters (Buckland, 1992). The pooling rigour of CDS ensures that minimum bias occurs as a result of small amounts of un-modelled heterogeneity (Buckland *et al.,* 2004; Thomas *et al.,* 2010). Using a flexible, semi-parametric detection function modelling framework where parametric key functions are paired with series adjustment terms (Table 2.1), an algorithm of maximum likelihood fitting of model is obtained (Figure 2.2) (Buckland, 1992; Fewster & Jupp, 2009; Thomas *et al.,* 2010).

Table 2.1: Combinations of key functions and adjustment terms recommended for CDS (in Thomas *et al.,* 2012).

Parametric key function	Adjustment term
Uniform	Cosine
Half-normal	Cosine
Half-normal	Hermite polynomial

Models are selected using Akaike Information Criterion (AIC), a relative estimate representative of the complexity and the goodness of fit of the model to the data. The smallest AIC output represents the best fit to the data and is presented in a Qq plot which represent the quantiles of the data.

The final outputs from the DISTANCE® software include: density and population size outputs, coefficient of variance, standard error and the 95% confidence interval (upper and lower) for each estimate, detection probability, encounter rate and cluster size (Equations: Appendix 2).

2.2 Kernel Density Estimation

To determine the distribution of species, data collected using DISTANCE sampling can be used. With records of the observer's X,Y co-ordinates, whenever an object or cluster was recorded, and with the distance parameter required for DISTANCE sampling, it is possible to project the actual position of the object using a Geographical Information System (GIS). The distribution of the target species can therefore be mapped and analysed using density mapping (Powell, 2000). Kernel density estimation (KDE) is a non-parametric way to determine the density distribution of a variable. Based on a sample of a population KDE makes inferences as to the density of the entire population, by employing smoothing parameters (Method & equations: Appendix 3). In ArcGIS® the results of KDE are map outputs which represent continuous surfaces of density values over a study area.

2.3 GEODAT – hotspot analysis

To identify density hotspots, Anselin's Local Moran's Index of autocorrelation using GEODAT software (https://geodacenter.asu.edu/software) was used (Anselin *et al.,* 2006). Anselin's Local Moran's analysis is a measure of autocorrelation that calculates a Local Moran's I value, a Z score, a p-value, and a code representing the cluster type for each weighted feature providing an empirical statistical description of distributions (Anselin, 1995). The tool identifies points of similar magnitudes based on neighbourhood.

Additionally the tool identifies points whose neighbouring points are significantly dissimilar in magnitude and classifies them as outliers.

Results are presented in map format and classified using regression analysis to identify areas where: high values are clustered (HH), low values are clustered (LL), areas where a high value was surrounded by low values (HL), and where a low value was surrounded by high values (LH) (Anselin *et al.,* 2006). When combined with the statistical values generated from the autocorrelation analysis, these classifications further detail the nature of relationships between neighbouring points, or observations, which can then be inferred to describe fluctuations in wildlife distributions. In tandem a corresponding map is produced to quantify the statistical significance of the classified clusters (Equations: Appendix 4). A scatterplot is also produced to represent a regression of the global Moran Index with automatically lagged values for the density variable on the Y axis and the original values for the density variable on the X axis (Anselin, 1995; Anselin *et al.,* 2006). The slope represents the global Moran *I* statistic, which is the autocorrelation metric calculated for the whole study site.

Additionally, bivariate analysis can be conducted to compare two variables, or data from different sampling seasons in term of spatial autocorrelation (Anselin, 1995; Anselin *et al.,* 2006). These analyses help to identify temporal changes in wildlife distributions. The axes of the regression for bivariate analysis represent the standardized values for two variables being compared. In this instance means that similarities between the two variables are classified in the same way as in the univariate analysis to represent areas where values remained similar or changed significantly (Anselin *et al.,* 2006). Also, the map layer outputs can be incorporated in a GIS for further analysis and inclusion in modelling exercises.

2.4 Map Comparison

To determine the levels of similarity between density maps generated for each sampling season Fuzzy kappa (FK) analysis was conducted using the Map Comparison Kit (MCK) Hagen-Zanker *et al.,* 2006 a&b). MCK is software developed by the Netherlands Environmental Assessment Agency and the National Institute for Coastal and Marine Management (Hagen-Zanker *et al.,* 2006a). The software was developed to combine the quantification, visualisation, modelling and validation of spatial models to compare sets of raster maps as well as comparing information contained in the map, spatial relationships such as; neighbourhood analyses, proximity, connectivity and clustering.

Fuzzy kappa analysis categorises values by employing set theory, where of membership to a set is derived from the concept of Cohen’s Kappa statistic (Dou *et al.,* 2007). In fuzzy case, the Cohen’s Kappa coefficient is calculated by transforming the fuzzy sets into set classes and is calculated by the proportion of the observed agreement and the agreement expected by chance. Based on a function of membership to a category, the agreement function and probability distribution formulate the expectation agreement between maps (Cohen, 1960). Fuzzy Kappa analysis calculates an index statistic (0 to 1) that indicates the similarity of categories at a location on one map (the value of a cell) with the categorical value of the matching cell of the map being compared. It also calculates the similarity of cells in the direct vicinity of the corresponding cells on the map being compared (Hagen-Zanker, 2006). Fuzzy-Kappa analysis which is used for categorical data (Hagen, 2003; Hagen-Zanker *et al.,* 2005) and can also to be used on continuous numerical data (Hagen-Zanker, 2006b).

Fuzzy kappa analysis produces two outputs; an index (0 to 1) of the overall map similarity and a map that represents similarities at cell level (0 to 1) (Figure 2.3).

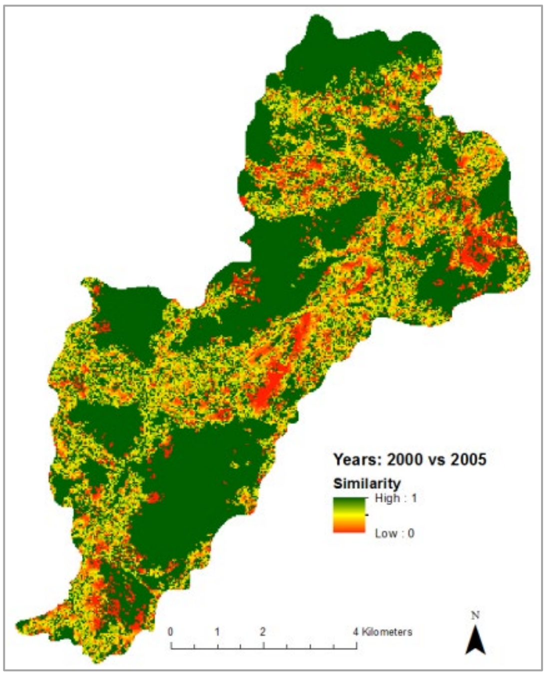


Figure 2.3: Example of map output of fuzzy kappa analysis in the MCK for habitat classifications between season sample 1 and season 2. (Fuzzy kappa statistic = 0.472).

The Fuzzy kappa index provides a single measure of the maps' overall agreement while the Fuzzy kappa map represents the similarity at pixel level (Equations: Appendix 5).

2.5 Remote sensing data

2.5.1 Landsat and Image acquisition

A suite of satellites (Landsat 2 to Landsat 8) launched as a result of collaboration between NASA and the U.S Geological Survey (USGS) have generated the largest amalgamation of space-based, remotely sensed freely available data available to date. The Landsat satellites capture images that span over the entire globe at a high spatial resolution (60 to 30 m) (NASA – Landsat Science, 2015b). The image acquisition is repetitive, spanning over 38 years with several images taken approximately on an 18 day cycle (NASA – Landsat Science, 2015a). The first satellite in the Landsat series was Landsat 2 launched in 1975 closely followed by Landsat 3 in 1978. The images from these early satellites used a Return Bean Vidicom (RBV) and a multispectral scanner (MSS) which returned images with an 80 meter resolution (NASA – Landsat Science, 2015a). The RBV was composed of three cameras which took images of several multispectral bands. While the MSS scanned the earth's surface along a perpendicular track along which six lines were scanned at the same time to represent four spectral bands (NASA – Landsat Science, 2015a). New technology on Landsat 4 and 5 – launched in 1982 and 1984 respectively – the Thematic Mapper (TM), increased ground resolution of images to 30 metre. Landsat 7 which is still in operation today, was updated with the Enhanced Thematic Mapper Plus (ETM$^+$) which returns eight bands of high resolution images (30m) for bands 1-5 and 7, while band 6 is at a 60m and band eight is at a 15m resolution (NASA – Landsat Science, 2015a).

Table 2.2: Landsat 7 band assignations.

Band Number	Wavelength (μm)	Resolution	Spectral response
1	0.45-0.515	30m	Blue (visible)
2	0.525-0.605	30m	Green (visible)
3	0.63-0.69	30m	Red (visible)
4	0.775-0.90	30m	Near- Infrared
5	1.55-1.75	30m	Intermediate Infrared
6	10.4-12.5	60m	Thermal Infrared
7	2.08-2.35	30m	Intermediate Infrared
8	0.52-0.9	15m	Panchromatic

(GDSC, 2015)

2.5.2 De-striping Landsat 7 SLC off

Images taken by Landsat 7 from the 31st of May 2003 are all subject to an error that occurred on the Scan Line Corrector (SLC) which has resulted in about 22% of information loss per scene (Figure 2.4). The SLC acts in compensation for the forward movement of the satellite and consequently results in strips of data missing particularly towards the edges of scenes (see example Figure 2.4).

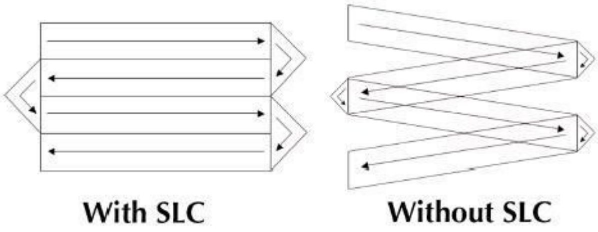


Figure 2.4: Scan Line Corrector failure from 31st May 2003 on Landsat 7 (fromhttp://landsat.usgs.gov/images/products/products_slc_graphic.jpg).

To use Landsat 7 images for analysis some corrections can be applied to 'fill in' the stripes with no data using the interpolation analysis tool.

2.5.4 Supervised classification

Classification using maximum likelihood classifiers is a well-established method for the interpretation of satellite and a remotely-sensed data (Wang, 1990; Muchoney *et al.,* 2000; Keuchel *et al.,* 2003). It is a modelling tool that identifies the statistical relationships between the input variables and the ground-truthed habitats and consequently classifies the satellite image to correspond to the ground-truthed data (Wang, 1990). The raw data (satellite image) represents the spectral properties of the objects the light is reflected off and this is used to create a characteristic signature for each habitat type. The training samples, derived from data collected on the ground to delimit specific habitats act as 'cookie-cutters' by assigning those areas specific spectral values (Wang, 1990). The identified spectral properties for each habitat are then used to create the habitat signature files. The signature files represent the statistical probability calculated using the maximum likelihood estimator (MLE). Each habitat has a signature and when combined they form a signature catalogue which can then be applied to the whole image (Figure 2.5).

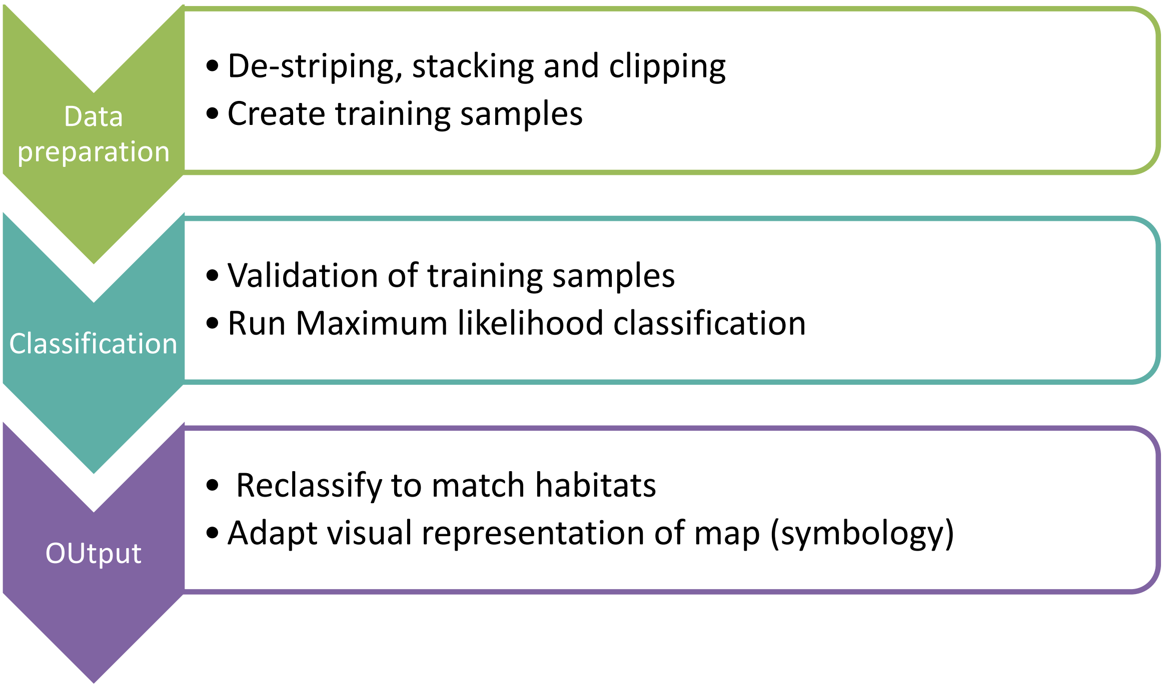


Figure 2.5: Supervised classification process in ArcGIS for habitat classification of remotely sensed data.

2.5.5 NDVI

The Normalized Difference Vegetation Index (NDVI) is a numerical indicator of net primary productivity and evapotranspiration that describe the relative density and health of vegetation for each pixel in a satellite image by assigning values that range from +1.0 to -1.0 to each pixel (Oindo *et al.,* 2000). In savannah environments, vegetation cover and productivity is intricately linked to climatic variability (Richard & Poccard, 1998), where vegetation responds rapidly to sporadic rainfall (Griffin & Friedel, 1985). Sparse vegetation such as shrubs and grasslands or senescing crops result in low NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as temperate and tropical forests or crops at their peak growth stage (Rouse, 1973). Short term variations in NDVI in savannah environments are most likely to represent responses to climatic variations of the herbaceous layer. Grasses respond more rapidly and dramatically to rainfall than trees as a result of their shallow root systems that can capture rainfall and differences in photosynthetic pathways (Scanlon *et al.,* 2002). Consequently, increases in NDVI in the herbaceous layer indicate an increase of biomass that will support larger numbers of grazing ungulates. Intermediate NDVI values have been shown to promote increased species richness in semi-arid environments and high NDVI values represent areas that are densely vegetated with trees but not necessarily areas that support high levels of species richness (Oindo *et al.,* 2000).

By transforming raw satellite data into NDVI values, researchers can create images and other products that give a coarse measure of vegetation type, amount, and condition of land surfaces (Carlson & Ripley, 1997; Oindo *et al.,* 2000). NDVI utilises the visible (RED) and near-infrared (NIR) bands of the electromagnetic spectrum and is directly related to other parameters commonly associated with vegetative productivity and 'health' such as percent of ground cover, photosynthetic activity, leaf area index and vegetative biomass. Pigments in plant leaves strongly absorb wavelengths of visible (RED) light (Carlson & Ripley, 1997). The leaves themselves strongly reflect wavelengths of near-infrared light, which is invisible to human eyes and generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light (Carlson & Ripley, 1997). As a plant canopy changes from early spring growth to late-season maturity and senescence, these reflectance properties also change. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light (Carlson & Ripley, 1997). Bare soils on the other hand reflect moderately in both the red and infrared portion of the electromagnetic spectrum (Holme *et al.,* 1987).The bigger the disparity between the NIR and the RED reflectance, the more productive in terms of vegetation cover (and growth) the areas is. The NDVI algorithm subtracts the red reflectance values from the near-infrared and divides it by the sum of near-infrared and red bands: NDVI= (NIR-RED) / (NIR+RED).

2.5.6 Texture analysis

Species distributions and behaviour are influenced by terrain characteristic and heterogeneity (Riley & Dood, 1984; Fabricius & Coetzee, 1992). To provide informative measures of terrain characteristics as a component of habitat distributions, digital elevations data acquired from USGS were incorporated into a GIS to calculate landscape metrics pertaining to the texture of the terrain within the study site. Topographic roughness, the vertical texture of a terrain, can be calculated from smoothed digital elevations models (DEM) using the standard deviation of elevation or the slope (Ascione *et al.,* 2008). The map output will represent elevation in relation the lowest point in the study area as opposed to elevation scaled from sea level. To calculate the standard deviation of elevations, two additional map layers are derived from the original DEM.

ArcGIS steps (GIS4Geomorhpology, 2015):

- Create mean elevation raster, Spatial Analyst > Neighborhood > Focal Stats: Statistic = mean > Output = meanDEM
- Create elevation range raster, Spatial Analyst > Neighborhood > Focal Stats: Statistic = Range > Output = rangeDEM
- In Spatial Analyst > Map Algebra > Raster Calculator > (“meanDEM” – “DEM”) / “rangeDEM” = values ranging from -1 to 1.

Additional descriptors of terrain texture such as the Relative Topographic Position (RTP) can be calculated to provide a ‘ruggedness metric’ that is useful for identifying landscape patterns and boundaries that may correspond with rock type, soil type, vegetation cover, and water drainage (Parker; 1982; Jenness, 2002). Here, the topographic position of each cell is identified with respect to its relative position to neighbouring cells.

ArcGIS steps (GIS4Geomorhpology, 2015):

- Create a minimum elevation raster, Spatial Analyst Tools > Neighborhood > Focal Statistics: Statistic = Minimum > Output = minDEM
- Create a maximum elevation, Spatial Analysis Tools > Neighborhood > Focal Statistics: Statistic = Maximum > Output = maxDEM
- Create a meanDEM using Spatial Analysis Tools > Neighborhood > Focal Statistics: Statistic = mean > Output = meanDEM
- In Raster Calculator: RTP = (DEM – minDEM) / (maxDEM- minDEM) = values ranging from 0 (flat) to 1 (rugged)

The Terrain Ruggedness Index (TRI) provides classifications of terrain heterogeneity where the sum change in elevations is calculated for each cells in relation to its neighbouring cells (Riley, 1999; Sappington, 2007). The classification scheme states that the terrain texture is:

- Level = 0-80m
- Nearly level = 81-116m
- Slightly rugged = 117-161m
- Intermediately rugged = 162-239m
- Moderately rugged = 240-497m
- Highly rugged = 498-958m

- Extremely rugged = 959-4367m

ArcGIS steps (GIS4Geomorhpology, 2015):

- Create a minimum elevation raster, Spatial Analyst Tools > Neighborhood > Focal Statistics: Statistic = Minimum > Output = minDEM
- Create a maximum elevation, Spatial Analysis Tools > Neighborhood > Focal Statistics: Statistic = Maximum > Output = maxDEM
- In Spatial Analyst > Map Algebra > Raster Calculator > SquareRoot(Abs((Square(maxDEM) – Square(minDEM))))
- In Spatial Analyst > Reclass > Reclassify tool: using 7 classes and Break Values at 80, 116, 161, 239, 497, 958 & maximum value of raster

2.6 Model building

Species distribution modelling is extensively used in the field of ecological research and conservation management (Elith & Leathwick, 2009), it can be applied to understanding biological and ecological processes at varying spatial scales in relation to environmental and geographical properties (Mac Nally, 2000) or to predict possible or future species distributions across a landscape as a result of management strategies, changes in resource availability or climate change (Elith & Leathwick, 2009). The influence that environmental and geographical parameters have in species distributions can be ranked in a hierarchical manner in terms of effect each parameter has on distribution (Cushman & McGarigal, 2002; Pearson & Dawson, 2003), commonly this is achieved from observational distribution data and identification and quantification of the influence of environmental parameters on the patterns observed. The selection of environmental variables (or independent variable) should be made by inferring on existing knowledge of the dependable variable (species distribution), its ecology and characteristic of its environment.

2.6.1 Generalised Linear Models

The term Generalized Linear model (GLM) refers to class of models suggested by McCullagh and Nelder (1989) that include linear regression, ANOVA, Poisson regression, log-linear models and usually refers to conventional linear regression models for a continuous response variable, given continuous and/or categorical predictors. GLM's can accommodate complicated situations and analyse the simultaneous effects of multiple variables, including mixtures of categorical and continuous variables. A GLM is directly based on the theoretical and analytical framework of a linear multiple regression for a single dependent variable. The general purpose of multiple regressions is to quantify the relationship between several independent or predictor variables and a dependent variable (Pearson & Lee 1908). Multiple linear regressions model how the mean expected values of a continuous response variable depend upon a set of explanatory variables:

Equation 1

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k$$

Where: k is the number of predictor variables and 'b_1 … b_k' are the regression coefficients. These are values that quantify how variable X_1 is correlated with the Y variable, after regulating for all other independent variables.

In GLM's, the focus is on estimating the model parameters that provide descriptions of interactions and quantify the strength of associations between parameters. It is a generalization of a multiple linear regression model to the case of more than one dependent variable, as in a multiple linear regression, but the errors do not follow a multivariate normal distribution. Generalized linear models may be used to relax assumptions about variables (dependent and response) and their errors (Assumptions: Appendix V).

2.6.2 Fuzzy overlay

Fuzzy Overlay analysis is based on set theory; the mathematical discipline quantifying the membership relationship of events to specific sets/ or classes (Bo *et al.,* 1996; Jiang & Eastman, 2000; Yu *et al.,* 2004; Mesgari *et al.,* 2008). Fuzzy Overlay Analysis reclassifies or transforms data values to a common scale and the transformed values define the possibility of belonging to a specified class by being transformed into the possibility of belonging to the preferred suitability set (from 0 to 1, with 1 preferred) (Mesgari *et al.,* 2008). Events or objects such as land-use category, soil type, suitability weighting, road class, and vegetation type are predominantly classified when being described. Most overlay techniques require defined sets where membership/ or classification is binary and the boundaries between classes are sharp. However, ambiguous categorization rules, ambiguity and imprecision of the boundaries between classes are not always clear (Mesgari *et al.,* 2008). Fuzzy logic addresses the inaccuracies in attributes and in the geometry of spatial data. In addition to ambiguity and imprecision in defining class boundaries, additional inaccuracies occur in the measurement of the phenomenon which would define the weighting of parameter in the model (Mesgari *et al.,* 2008). Both of these sources of inaccuracies, especially in the definition of the classes, can cause imprecision in assigning cells to specific classes which can affect decision making by focusing on modelling the inaccuracies of class boundaries.

In fuzzy overlay the transformed values represent possibilities of membership to sets, the input raster's which represent the various parameter being explored do not require weightings (Jian & Eastman, 2000). Fuzzy Overlay analysis quantifies each location's possibility of belonging to specified sets from the combined input raster layers.

ArcGIS steps:

- Scale all raster layers (significant response parameters) to fuzzy membership: Spatial Analyst > Overlay > Fuzzy membership > Outputs = All layers scaled from 0 to 1 (0 = not suitable 1 = most suitable)
- Combine parameters > Spatial analyst > Overlay > Fuzzy overlay: Overlay type = And > Output = Raster scaled from 0 to 1 (0 = not suitable 1 = most suitable)

2.6.3 Site Identification

In order to identify potential locations for the future designation of wildlife conservancies in the GME, outputs from the GLM's will determine which of the environmental variables considered in the study should be included (and how they should be ranked) in the fuzzy overlay analysis. With refinement – aggregation and neighbourhood analysis - the outputs from the fuzzy overlay analysis can be extrapolated to represent areas of varying levels of suitability and connectivity between patches. The most suitable areas will be those that have 'high suitability and connectivity to other areas of high suitability'.

Chapter 3:

Wild ungulate abundance in Ol Kinyei Conservancy 2012- 2014

3.1 Introduction & Aims

Ol Kinyei Conservancy was first established in 2005 and covered 36 km²; in 2012 its area was doubled with the addition of a further 36 km² to the North East of the original conservancy area. It was the first conservancy of its kind to be established in the GME. The initial area, Ol Kinyei 1 (OK1) represents the longest established example of a conservancy in this ecosystem. Conversely, the area most recently incorporated into the conservancy, Ol Kinyei 2 (OK2), represents an emergent conservancy. For the purpose of this study OK1 and OK2 are used as sampling blocks to reflect temporal changes that occurred post-conservancy creation. Within these two blocks ungulate population estimates were estimated using DISTANCE® sampling. These results will provide a comparison and narrative of the two areas that represent the of the short and long term responses of ungulate species to conservancy creation in the GME.

The aims of this chapter are to:

- Produce population estimates of the most abundant ungulates in Ol Kinyei Conservancy form a three year study period.
- Compare and contrast spatio-temporal ungulate abundance trends/patterns in those ungulates, in an already established conservancy versus a newly created one.

3.2 Methods

3.2.1 Base Map

A habitat map (Figure 3.1) was created by delimiting the boundaries between different stands of vegetation on foot with the use of GPS waypoints and GIS representation. Ecotonal boundaries between stands were assessed visually and all habitats classified (Table 3.1) in accordance with Grunblatt *et al.,* (1989).

Table 3.1: Habitat classifications, as described by Grunblatt *et al.,* (1989).

Habitat	Dominating Strata	Height (m)	Density (%)	Notes
Forest	Single stemmed woody vegetation	>1.5	>50	Largely riparian
Woodland	Single stemmed woody vegetation	>1.5	<50	
Shrubland	Multi-stemmed woody vegetation	<2		Often the transitional area between two biomes
Grassland	Herbaceous vegetation. Includes grasses and sedges	<2		Scattered trees and shrubs *

*Woody vegetation may be classified as sparse (2-19% cover), open (20-49% cover), dense (50-79% cover) or closed (80+ % cover).

To obtain population estimates for wild ungulates across the conservancy and over the two sampling blocks (OK1 and OK2), 9 transects were established aiming to cover as much of the conservancy as possible (Figure 3.1). A large section of Ol Kinyei 2 (north western corner) was not covered by transects, as the terrain made access unsafe.

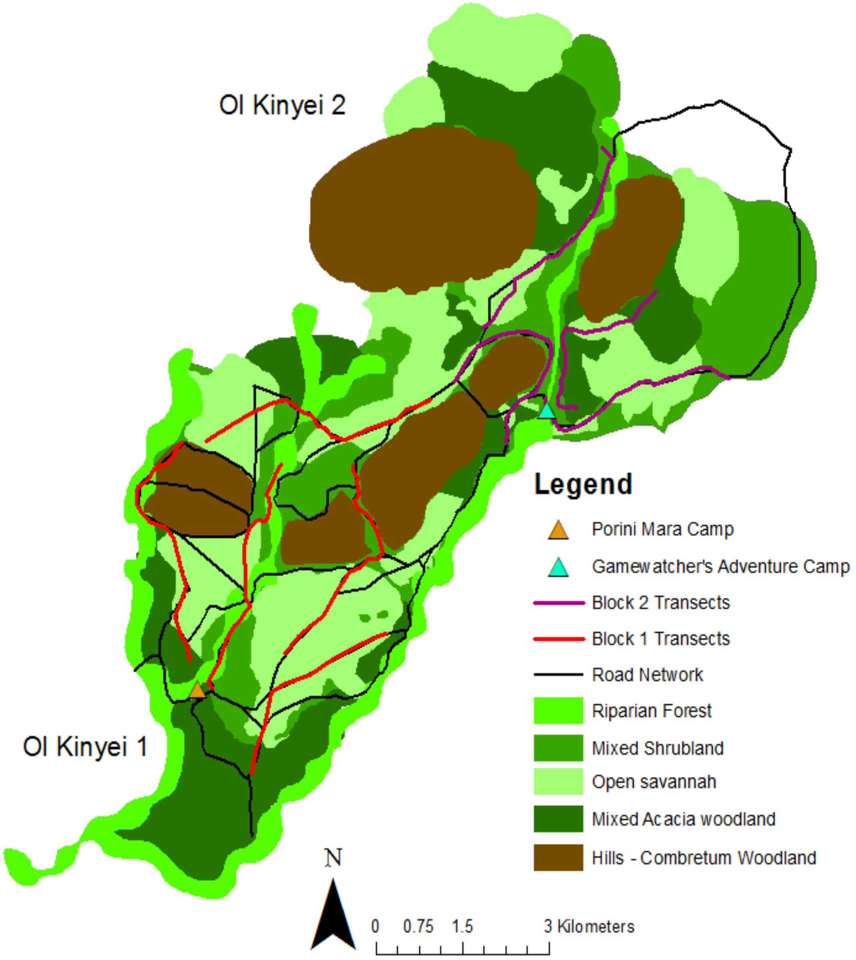


Figure 3.1: Distribution of roads and game transects and tourist lodges in the study site

Transect location was highly dependent on the existing road network. In OK1, which has been a wildlife tourism destination since 2005, there was already an extensive road network in place. Conversely, at the start of this study, OK2 had very few established roads. For this reason five game transects were established in OK1 and only four were established in OK2. All transects were 4 km long and traversed the various habitats and water courses found within the conservancy (Figure 3.1).

2.2.2 Field seasons

This study focuses on resident wildlife numbers. For this reason it was decided that data should be collected over three years between October and December (before the short rains) and between February and March (after the short rains) (Table 3.2) in order to avoid sampling the transient populations of migrating zebra, wildebeest and Thompson’s gazelle. Data was therefore collected over four field seasons; three times in the October/November period and once in February/March 2014 (Table 3.2).

Table 3.2: Outline of planned and completed field seasons. Numbered seasons 1-4 are those described throughout results section.

Sample season	Dates	Year	Notes
-	May to June 2012	2012	Completed – Base map
1	October to December	2012	Completed – data collection
-	January to March	2013	Cancelled – security concerns
2	October to December	2013	Completed – data collection
3	January to March	2014	Completed – data collection
4	October to December	2014	Completed – data collection

2.2.3 Study Species

This study focused on seven species of wildlife ungulates covering herbivore dietary guilds - grazers, mixed feeders and browsers (Table 3.3).

Table 3.3: Description of wild ungulate study species

Species	Common Name	IUCN status	Habitat preference	Dietary guild	Water dependence	Dispersion pattern
Giraffa camelopardalis	Maasai Giraffe	LC	SL & OW	Browser	High	Resident
Gazella granti	Grant's gazelle	LC	SG & OW	Mixed feeder	High	Migratory*
Aepyceros melampus	Impala	LC	SL & W	Mixed feeder	High	Resident
Gazella rufifrons	Thompson's Gazelle	V	SG	Grazer	Low	Migratory*
Damaliscus lunatus	Topi	LC	OG	Grazer	Low	Resident
Connochaetes taurinus	Wildebeest	LC	OG	Grazer	High	Migratory*
Equus burchelli	Burchell's Zebra	LC	OG	Grazer	High	Migratory*

Abbreviations: LC – Least concern; V – Vulnerable; SL = shrubland; OW = open woodland; W= woodland; SG = short grassland; OG = grassland; *Are also present in established resident population outside the migration season. Adapted from Estes (1992), & IUCN (2015)

3.2.4 Data collection

In order to produce accurate and non-biased population estimates, DISTANCE® sampling was used, whereby the observer counts the number of individuals of each target species, in this case all specified ungulate species (Table 2.3). These were observed while driving along a predetermined line of a fixed length – 4 km. All transects were sampled ten times in early morning (6:00 to 9:00) and ten times in late afternoon (15:00 to 18:00) over the course of each of the two month study visit. Variables collected for each record (individual or cluster of individuals of a species) were:

- Species
- Geographical position (Decimal degrees)
- Total number of adults
- Total number of juveniles
- Radial distance (m) with a laser rangefinder
- Angle (˚)

All data were recorded and stored on a specifically designed data recording form using Wildknowledge® on a mobile device with inbuilt GPS.

3.2.5 DISTANCE analysis

Population densities were generated for the seven study species (Table 3.3) employing distance analysis (Section 3.3) using DISTANCE 6® software. In order to account for variation in the detection probability in different habitats, the data were initially incorporated into a GIS in order to classify each record by habitat. From this the total length of transect (or effort) was determined for each habitat and the total area surveyed was calculated using a buffer function in ArcGIS® to the maximum distance recorded. From the radial distance (m) and angle (˚) recorded in the field the perpendicular distance (m) was calculated in ArcGIS® as required by DISTANCE® analysis. Estimates were then generated for each habitat and extrapolated to generate estimates for the conservancy as whole in accordance to the different densities calculated per habitat and their respective total coverage in the conservancy.

Population estimates obtained in the four sampling seasons were examined for Ol Kinyei Conservancy as a whole to determine whether there was a significant difference in wildlife numbers over the three years of study. Data collected in sample season 3 (February/March 2014) was used to determine seasonal variations in ungulate densities as a consequence of seasonal weather patterns. Further analysis was conducted by calculating population estimates for Ol Kinyei 1 (OK1) and Ol Kinyei 2 (OK2) separately. This provided information on how wild ungulate populations changed in areas recently converted to the conservancy management model (OK2) and to also identify how rapidly these recently designated areas began to hold similar amounts of wild ungulates to longer standing conservancy areas (OK1). The demographic makeup of the study species was also investigated to identify differences between years and seasons.

3.2.6 Identifying significant differences

In order to determine whether there were significant differences in population estimates for each species between years and between OK1 and OK2, conventional hypothesis testing could not be applied in this context, as the statistical comparison of two values (population estimates) with certainty and rigour is not possible. Consequently for the purpose of this study population estimates were compared using confidence intervals. This method of identifying significant differences between values has been proposed as an effective alternative to hypothesis testing (Cohen, 1994; Branstätter, 1999). 95% confidence intervals symbolize the confidence with which a population estimate stands between minimum and maximum values (or confidence limits) should estimates be extracted an indefinite number of times from the study population at an error level of 0.05 (Cohen, 1994; Branstätter, 1999; Balluerka *et al.,* 2005; Lasa *et al.,* 2009). Therefore, when comparing two estimates using confidence intervals, it is assumed that if the confidence intervals do not overlap, the variance in potential estimates represented by the confidence intervals do not match. We therefore conclude that there is a true difference between the estimates (Branstätter, 1999; Lasa *et al.,* 2009) which in this research is indicated by the term “significant”, with the converse being true when there is no overlap i.e. “not significant”.

3.3 Results

3.3.1 Wild ungulate estimates for the whole conservancy (Figure 3.2)

Wild ungulate population estimates for the whole of Ol Kinyei Conservancy were produced for the four sampling seasons and results revealed that Thompson's gazelles and wildebeest were the most abundant species in the conservancy followed by zebra and impala. Population estimates for Grant's gazelles, topi and giraffe were considerably lower, not exceeding 1,000 individuals (Figure 3.2).

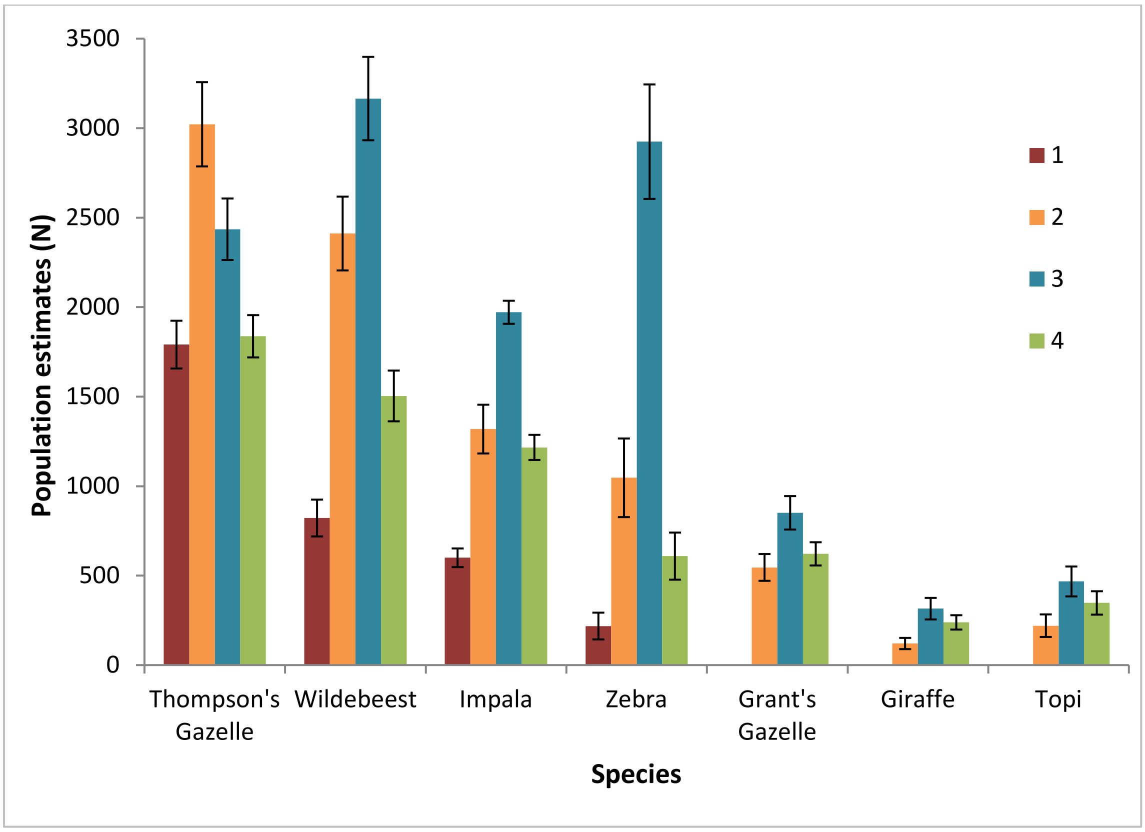


Figure 3.2: Wild ungulate population estimates 95% confidence intervals over four sampling seasons (1 - 4) in Ol Kinyei Conservancy (values: Appendix 7.1)

With the exception of Thompson's gazelles, estimates were significantly higher for all species in sampling season 3 (after the rainy season in December/January), than in the sampling seasons that took place before the rainy season (October/November) (Figure 3.2).

The population estimates generated in sampling season 2 followed a trend of being higher than in sample seasons 1 and 4 for three species; Thompson's gazelles, wildebeest and zebra. Estimates for wildebeest, zebra and impala were significantly lower in sample season 1 than in the three consequent sample seasons, while there was no significant difference for Thompson’s gazelles between seasons 1 and 4 and impala between sample season 2 and 4 (Figure 3.2).

It was not possible to calculate population estimates accurately for Grant’s gazelles, giraffes and topi from sampling season 1 as the number of individuals of all three species were not sufficient to run the analysis (number of observations < 60; Buckland *et al.,* 2004). However, between sampling seasons 2 and 4, a gradual increase in estimates was evident for all three species, indicating that their numbers increased consistently from 2012 to 2014 (Figure 3.2).

3.3.2 Comparison of population estimates in Ol Kinyei 1 and Ol Kinyei 2 separately (Figure 3.3)

Ol Kinyei 1 (OK1) was established in 2005 while Ol Kinyei 2 (OK2) was established in 2012 and both cover approximately 36.5 km^2. Overall population estimates for all species followed a similar pattern in OK1 as they did in analyses conducted for Ol Kinyei Conservancy as a whole, with Thomson’s gazelles and wildebeest identified as the most abundant of the study species. However, results revealed that for sample season 3 zebra were also among the most abundant species in OK1 (Figure 3.3).

In OK1, the estimates for Thompson’s gazelles, wildebeest, impala and zebra were not significantly different between sampling seasons 1 and 4, yet there was a marked increase in population estimates between sampling seasons 1 and 2 which was also consistent with the results found for the whole conservancy and was most notable for Thompson’s gazelles and wildebeest (Figure 3.3). The population size of all study species, apart from Thompson’s gazelles and wildebeest was significantly higher in sampling season 3 than in any other sample season, with zebra demonstrating the most marked increase in number (Figure 3.3).

Estimates for wildebeest indicated that they did not increase significantly in numbers between sample seasons 2 and 3, while Thompson gazelles numbers decreased significantly between those two sample seasons (Figure 3.3). The population trends generated for Grant’s gazelles, giraffe and topi in OK1 from sample seasons 2 to 4 were similar to those obtained for the whole conservancy.

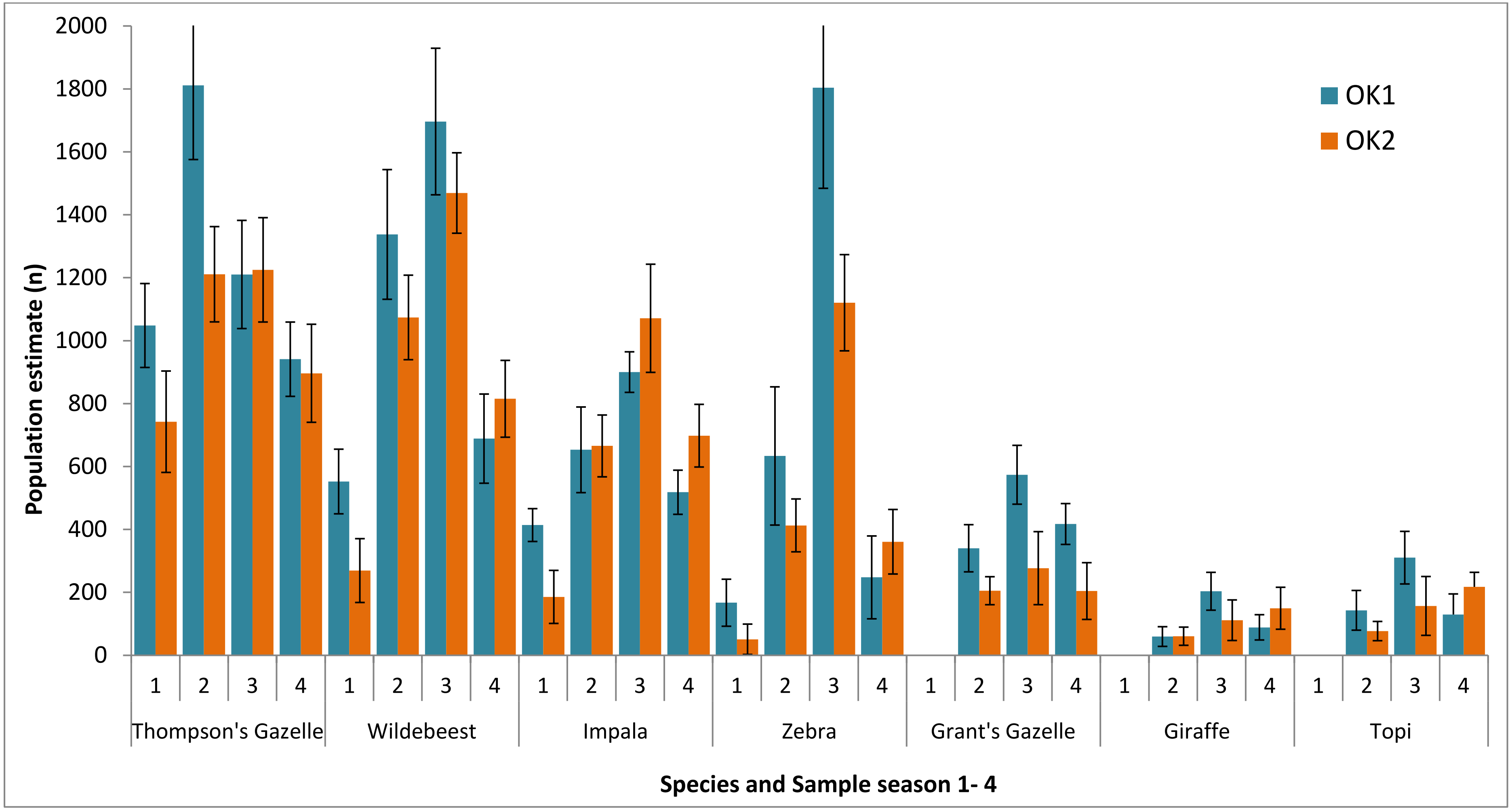


Figure 3.3: Wild ungulate population estimates and 95% confidence intervals for all study species in OK1 and OK2 in four sample seasons (values: Appendix 7.2).

In OK2, population estimates for all species increased significantly between sample seasons 1 and 2 (Figure 3.3). Further significant increases were evident for wildebeest, impala and zebra between sample seasons 2 and 3, but there were no significant increases in population estimates for the remaining study species; Thompson's gazelles, Grant's gazelles, giraffe and topi. Overall estimates for sample season 4 were more similar to those obtained for sample season 2 than sample season 1 as found in OK1, indicating that the most significant change in ungulate occupancy of OK2 occurred between the first and second year of its establishment (Figure 3.3).

Grant's gazelle, giraffe and topi estimates did not differ significantly between sample seasons 2, 3 and 4. However, it is important to note that in sample season 1 insufficient sightings of these three species were recorded to conduct the analyses, yet by sample season 2 there were significant sightings, indicating that there was a significant increase in densities between sample seasons 1 and 2 (Figure 3.3).

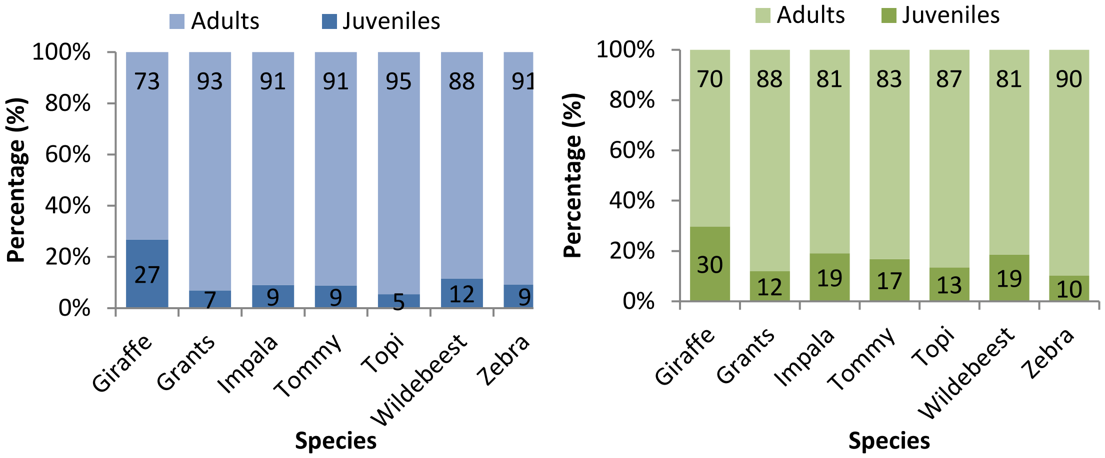
3.3.3 Comparison of wild ungulate population estimates between Ol Kinyei 1 and Ol Kinyei 2 (Figure 3.3).

The difference in population estimates between OK1 and OK2 in sample season 1 was significant for Thompson's gazelles, wildebeest, impala and zebra with OK1 holding higher numbers than OK2 (Figure 3.3). By sample season 2, there were only significantly higher numbers of Thompson's gazelles and Grant's gazelles in OK1 (Figure 3.3). Interestingly, impala were slightly more numerous in OK2 than in OK1 in sample season 2 (Figure 3.3). By sample season 4 only Grant's gazelles were found in significantly higher numbers in OK1 than in OK2. Conversely wildebeest, impala, zebra, giraffe and topi were all present in higher numbers in OK2 than in OK1 (Figure 3.3).

In sampling season 3, the number of zebra and Grant's gazelles was significantly higher in OK1 than in OK2 (Figure 3.3). There was no significant difference in estimates between OK1 and OK2 for Thompson's gazelles, wildebeest and impala were found to be more abundant in OK2 (Figure 3.3).

3.3.4 Wild ungulate demography

The demographic structure of ungulate populations determined from data collected in sample season 1 revealed similar patterns to sampling season 2 and 4 (Figures 3.5.a & d). In sample season 2, the proportion of the population classified as 'juveniles' was larger than in the same season the previous and following year (Figure 3.5.b). In sample season 3, the numbers of juveniles in the ungulate populations were overall higher than those found later in the year (Figure 3.5.c).



a) Sample season 1

b) Sample season 2

c) Sample season 3

d) Sample season 4

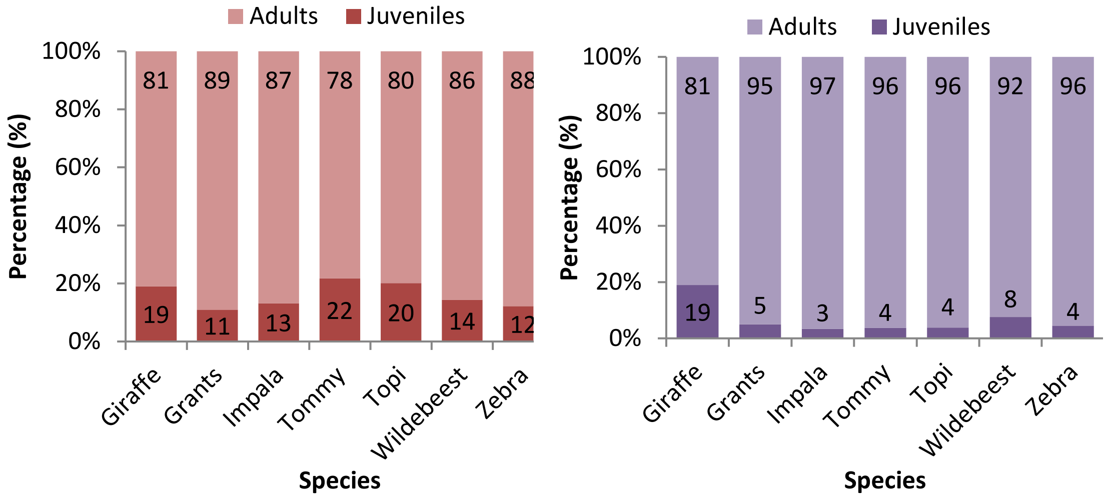


Figure 3.4: Demographic breakdown of population estimates (%) in Ol Kinyei Conservancy in four sampling seasons

3.4 Discussion

3.4.1 Seasonal variation in wild ungulate abundance

The most evident trend was the much higher abundance of all study species in the sample season 3 (February/March 2013), this a consequence of the surveys being conducted almost immediately after the short rains which occur in December/January. The large increase in wild ungulate abundance (see figures 3.2 & 3.3) in the conservancy is likely due to an increase in forage as a result of elevated grass productivity in the wet season. It is also at this time of year that many of the species give birth. Increased resources enable animals to support the high energy diet required to support their offspring. Grass height in the conservancy is grazed short throughout this period, despite the emergence of new palatable growth. The need to protect young from predators drives the ungulates to those areas in Ol Kinyei where increased vigilance is possible as a result of shorter grass swards (Hopcraft *et al.,* 2005; Ogutu *et al.,* 2005). Thompson's gazelles were the only study species not to be present in significantly higher numbers in the February/March season than in the three other sampling seasons that took place in October/November. Their lower numbers in sampling season 3 could be the result of increased competition for resources from other grazing ungulates which were present in considerable numbers at that time. Additionally, Thompson's gazelles are small bodied grazers that rely on high quality forage found in areas of low biomass (Fryxell, 1991; Illius & Gordon, 1992; Hopcraft *et al.,* 2005; Fryxell *et al.,* 2005). It is therefore likely that because of the rains that occurred in the previous months the forage available at the time in Ol Kinyei Conservancy was better suited to less selective feeders such as wildebeest or bulk feeders such as zebra.

Although the Maasai Mara is famous for its annual wildebeest migration from Tanzania, there is another smaller migration that takes place - the Loita migration. This migration progresses from MMNR to the Loita plains (Serneels & Lambin 2001a), which are located to the north of Ol Kinyei Conservancy. Zebra predominantly travel in large numbers to Loita in December to January but land-use changes, fencing, road construction and human encroachment in the Loita area are impeding the migration, resulting in many would be migrants taking a shorter trip from MMNR to Ol Kinyei Conservancy and the rangelands around it. Wildebeest also migrate to Loita, which may also explain their higher numbers in Ol Kinyei between the October/November 2013 and February/March 2014 seasons.

3.4.2 Wild ungulate population changes over time

In order to determine whether any changes to wild ungulate numbers took place over the three years of study, population estimates were calculated for the same season (October/November) in 2012, 2103 and 2014. Overall wild ungulate numbers increased over time; however the results obtained for 2013 (sample season 2) were considerably higher than those found for both the previous (sample season 1) and to subsequent years (sample season 4). Rainfall in 2013 was relatively low in October compared with November (Appendix 1.1). The significant increase seen in the abundance of wild ungulates in 2013 is likely due to increased resources as a result of unexpected rainfall in November. The considerable increases in population estimates obtained between sample seasons 1 and 2, could also be the result of the increase in resources available to the wild ungulates with the creation of OK2. The competitive release that will have resulted from the reduced livestock grazing in OK2 most likely had a significant impact on the attractiveness of OK2 to wild ungulates as a result of the increased availability of food and reduced levels of disturbance from anthropogenic activities.

In the first year of study numbers were too low to accurately estimate the abundance of several species (Grant's gazelles, giraffe and topi) using DISTANCE® analysis, but by 2013 the sample size for these species was large enough to conduct the analysis. Giraffes are strict browsers, relying entirely on trees – particularly acacia species - for browse. Their increase in the conservancy is likely to be a result of movement from areas in the MMNR where the amount of wooded areas dominated by acacia species is much lower than in the conservancy and reduced human disturbance in the area will also have increased their presence in the area. Topi are grazers that prefer to feed on long swards of new growth of palatable grasses. The reduction of intensive livestock grazing will have resulted in the increase in the abundance of palatable grasses. The heterogeneity of habitats found in Ol Kinyei Conservancy is beneficial to topi as they prefer shrublands and open woodlands, but also utilise open grasslands for lekking (Estes, 1991). Similarly Grant's gazelles are usually found in shrublands and open woodlands. They are mixed feeders, heavily dependent on heterogeneous habitats that allow them to both graze on high quality savannah grasses and to feed on new growth from bushes.

Thompson's gazelles are the only species for which there was no significant difference between the abundance found in 2012 and 2014. The reason for this is likely to be increased competition from other wild grazers. Increased predation could also explain the lower numbers. With large increases in wild ungulate biomass and a reduction in human disturbance the area became more densely populated with predators. This is evidenced by the large lion pride (approx. 20 adult individuals) which now holds Ol Kinyei Conservancy as its territory. Although they utilise OK2, their core territory is located the centre of OK1 (pers. comm. Niels Mogensen; Mara Lion Project). Additionally, in Ol Kinyei there is a relatively high density of cheetah's and jackals (pers. obvs). Both of these species will readily predate on Thompson's gazelles due to their small body size. The presence of predators may therefore be displacing the gazelles into the community grazing land surrounding the conservancy. Wildebeest, zebra and impala increased in abundance significantly between sample seasons 1 and 4. This suggests that the resident populations in the Maasai Mara are spreading out from the reserve into the conservancies where grass may be shorter but the quality of the forage is higher because it is not exposed to the intensive grazing that the MMNR receives during the great migration in June to August.

3.4.3 Wild ungulate population estimates in Ol Kinyei 1 and Ol Kinyei 2

In order to identify differences in the wild ungulate population of an established conservancy as opposed to an emerging conservancy, population estimates were generated for OK1 and OK2 separately. Overall the population estimates obtained for OK1 followed a similar pattern to those calculated for the whole conservancy however the difference in abundance between sample seasons 1 and 2 was not significant for any of the study species. The main difference was found in Thompson's gazelles, they were less abundant (n= 941) in OK1 in sample season 4 than they were in sample season 1 (n = 1048). The fact that the population sizes did not change dramatically between sample season 1 and 4, even though there were significant increases in sample season 2, may suggest that the wild ungulate populations in OK1 have reached equilibrium. It is likely that in the initial years after the creation of the conservancy wild ungulate numbers fluctuated more significantly, however after nearly 10 years wildlife populations can be expected to have stabilised, though they are still experiencing fluctuations in response to biotic factors. In contrast, the changes in population estimates were more significant in OK2. In the year following the creation of the OK2 population estimates for all study species increased significantly with their numbers appearing to be moving towards equilibrium by sample season 4. Most species showed significant increases in abundance between sample seasons 1 and 4, in particular wildebeest and zebra. Thompson's gazelles remained the most abundant species, however by sample season 4 wildebeest and zebra reached population sizes similar to those of Thompson's gazelles. Only Thompson's gazelles and wildebeest population estimates were significantly higher in sample season 2 (2013) in OK2 than at the same time of year in 2012 and in 2014. All of the other species were present in similar numbers in sample seasons 2 and 4.

The population estimates for all species calculated were significantly higher in OK1 than in OK2 in sample season 1 (Figure 2.8). Only a few months previously many areas of OK2 were still inhabited by Maasai and heavily grazed by livestock as OK2 was established as a conservancy in early 2012. By sample season 2, only Thompson's gazelles were found in significantly higher numbers in OK1 than in OK2. By sample season 4, only Grant's gazelle numbers were significantly higher in OK1 than in OK2 while wildebeest, impala, zebra, giraffe and topi were more abundant in OK2. This increase in wild ungulate density can be attributed to lower predation rates in OK2 and improved grassland conditions. In OK1 wildlife populations appear to have stabilised, yet still demonstrate the seasonal fluctuations expected in this open landscape that experiences a bimodal patterns of rainfall, resulting in large variation in the amount of resources available. The rapid population increase of OK2 can be attributed to its proximity to OK1, which is acting as an established 'reservoir' for the new area. These findings are encouraging as they demonstrate that the re-population of an area recently converted to a conservancy can be expected to occur relatively rapidly. Naturally the increase in range is highly beneficial to wildlife populations but it is also positive for investors, who can expect to provide good wildlife viewing opportunities for tourists. There is little doubt that the proximity of the new conservancy area to an existing conservancy will have increased the rate of re-population. Should a new conservancy be created to form an island in an area surrounded by land still used by the local Maasai to graze their livestock, the rate of increase in wildlife populations would undoubtedly be slower.

3.5 Conclusions

Ungulate response to the new conservancy management regime was recorded using DISTANCE® sampling. Overall herbivore densities were found to increase across three sampling seasons in both OK1 and OK2 indicating increased recruitment into conservancy areas and elevated reproductive success. Initially numbers were higher in the 'older' part of the conservancy though with time numbers became comparable between the two areas. This suggests that the presence of OK1 has accelerated wildlife colonisation in OK2 due to its close proximity and high densities of most wild ungulate species in OK1. More long term monitoring conducted on a monthly basis would elucidate population increases and fluctuations and provide a better understanding of how ungulate populations respond to conservancies in the GME.

Patterns in savannah ungulate abundance and distributions have been strongly linked to resource availability and habitat heterogeneity (Ritchie & Olff, 1999; Wilmhurst *et al.,* 1999; Arsenault & Owen-Smith, 2002; Cromsigt & Olff, 2006). Therefore a more in depth analysis has been conducted ungulate distributions and how the species utilise the habitats in Ol Kinyei Conservancy to provide a better understanding of how habitat composition drives wildlife abundance in the GME (Chapter 4: Grazers & Chapter 5: Mixed feeders and Browsers).

Chapter 4

Spatial distribution, habitat use and habitat selectivity of wild grazing ungulates

4.1 Introduction

Habitat heterogeneity and patterns in savannah herbivore abundance have been linked to species coexistence as a consequence of resource partitioning (Ritchie & Olff, 1999; Wilmhurst *et al.,* 1999; Asrenault & Owen-Smith, 2002; Cromsigt & Olff, 2006). Larger bodied species are considered to have wider tolerance to low quality forage and therefore occupy a larger proportion and variety of habitats than smaller bodied species which are more dependent on forage quality and safety from predators. Larger bodied species are therefore more evenly distributed in a landscape than smaller species and non-ruminants would be expected to be. In addition, they are also usually less selective of forage quality and therefore less selective of habitat than ruminants (Bell, 1971; Jarman, 1974; Gordon & Illius, 1996).

The pastoral lands on which wildlife conservancies such as Ol Kinyei Conservancy are situated are important dispersal areas for both small and medium bodied grazers, providing essential access to short grazing lawns when conditions in the MMNR are less favourable. Additionally, wildlife conservancies such as Ol Kinyei, where livestock grazing is prohibited or at least restricted, now provide the refuge from increased competition from livestock grazing that the MMNR historically provided.

Aims

- Describe the spatial distribution patterns of grazing ungulates over the course of a three year period in Ol Kinyei Conservancy.
- Demonstrate how the previously identified numerical uplifts in population sizes (see chapter 3) manifested themselves in the spatial distribution of grazing ungulates in the newly extended conservancy
- Investigate habitat use and selectivity of grazing ungulates to determine whether ungulate species use the habitats present in Ol Kinyei Conservancy differentially

4.2 Methods

4.2.1 Study species

Habitat use and distribution of wild grazing species was investigated using distributional data obtained from game transects (Chapter 3: Methods) and from land cover data from satellite imagery classification data (Chapter 6) over four sampling seasons at the study site (Figure 4.1). Four species of grazing ungulates: Thompson's gazelle, wildebeest, zebra and topi are investigated (Chapter 1: Table 1.1). This study focuses on resident wildlife numbers, for this reason it was decided that data should be collected over three years between October and December (Dry) and between January and March (Wet) (Table 3.2), the latter serving as a "control".

4.2.3 Study site

Ol Kinyei Conservancy is the most eastern conservancy established to date in the GME, and with the recent creation of the additional conservancies Naboisho and Olare Orok (Figure 1.1) Ol Kinyei Conservancy is now directly connected to the MMNR by other protected areas.

In order to provide an indication of baseline habitat composition, the habitats in Ol Kinyei Conservancy were mapped using supervised classification (Chapter 2.5.4) of a remotely sensed image from the 1st of November 2014 (USGS Landsat archive) (Figure 4.1).

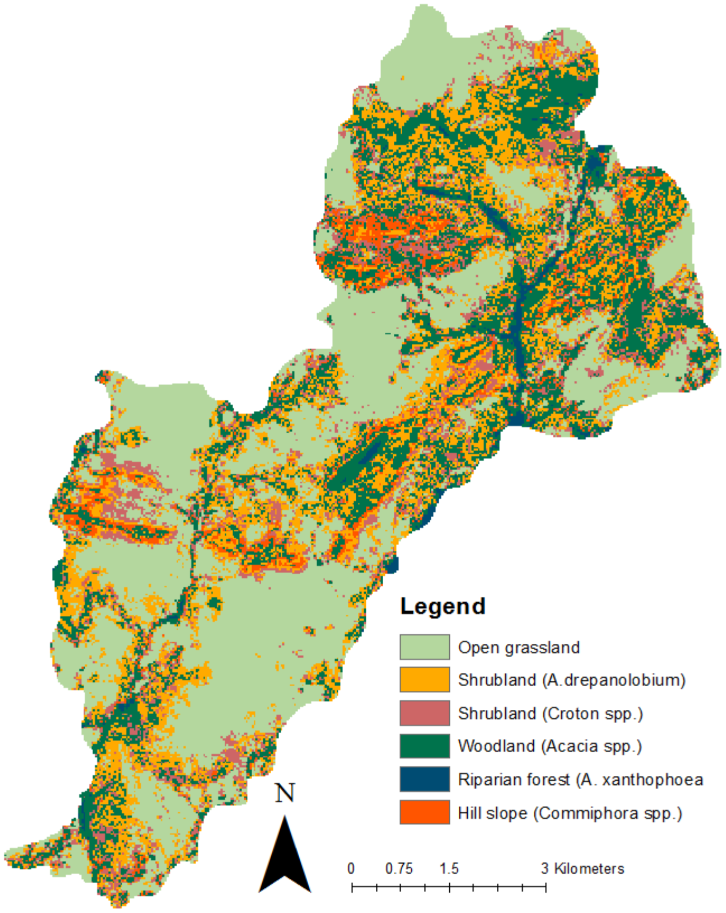


Figure 4.1: Habitats in Ol Kinyei Conservancy classified from satellite image taken 1st November 2014 (Creation of map in Chapter 6).

An additional map was produced to represent three broad land cover classes to enable the description of ungulate distributions in areas with varying degrees of canopy cover; open habitats (open grassland or savannah), partially closed habitat (shrublands, hills) and closed habitats (acacia woodland and riparian forest). In addition, areas of open grassland were numbered to facilitate the description of ungulate distributions in the conservancy throughout this study (Figure 4.2).

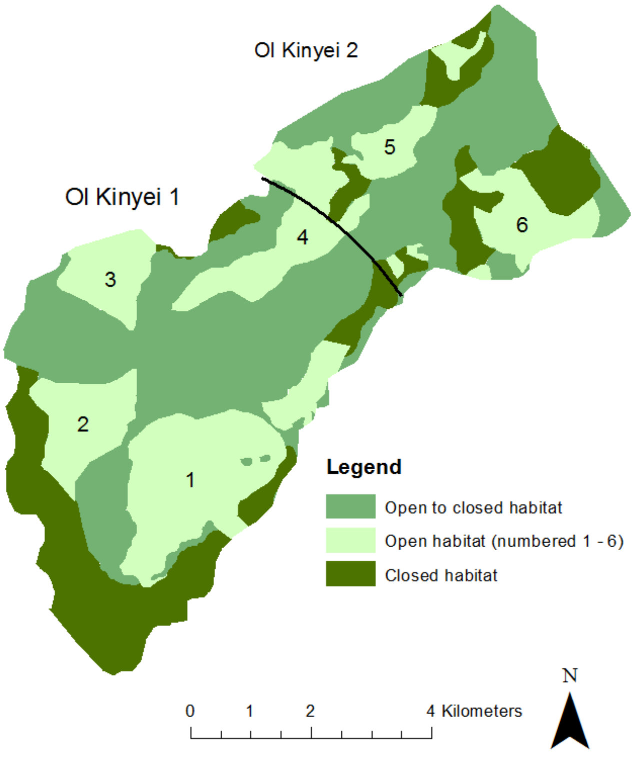


Figure 4.2: Land cover map of Ol Kinyei Conservancy: Open habitats = open grasslands (numbered 1-6); open to closed (or partially closed) habitats = shrublands; Closed habitats = acacia woodlands & riparian forest.

4.2.4 Data collection

Grazing species data were collected along transects (Chapter 3.1), with each transect sampled ten times over the course of approximately two months in each of the four sample seasons. Variables collected for each for each record (individual or cluster of individuals of a species) were:

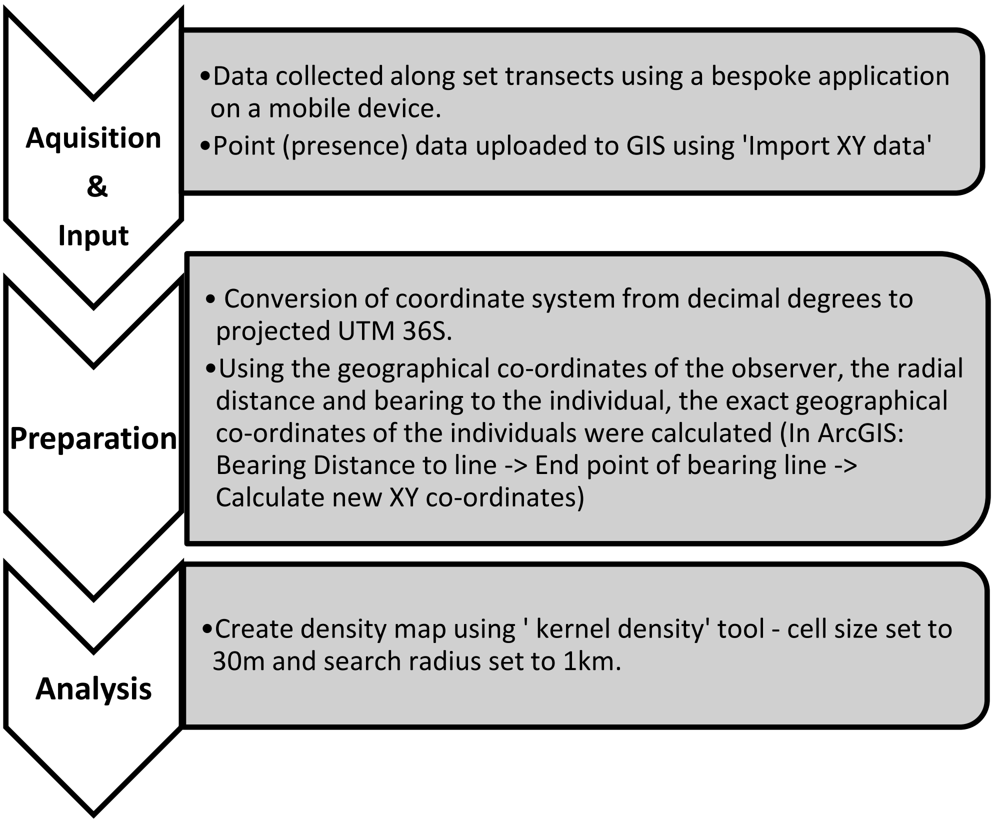
- Species
- Geographical position (Decimal degrees) of observer
- Total number of adults
- Total number of juveniles
- Radial distance (m) with a laser rangefinder
- Bearing (˚)

All data were recorded and stored on a specifically designed data recording form using WildKnowledge® on a mobile device with inbuilt GPS. Once incorporated into a GIS these data were used to represent the exact locations of the individuals recorded.

4.2.3 Data analysis

4.2.3.1 Kernel density estimation

To determine wild ungulate distributions in Ol Kinyei Conservancy, data collected along transects were used to create kernel density maps that represent areas of high use for each of the study species in each of the study seasons (for stepwise description of procedure see: Figure 4.3).



- Data collected along set transects using a bespoke application on a mobile device.
- Point (presence) data uploaded to GIS using 'Import XY data'

- Conversion of coordinate system from decimal degrees to projected UTM 36S.
- Using the geographical co-ordinates of the observer, the radial distance and bearing to the individual, the exact geographical co-ordinates of the individuals were calculated (In ArcGIS: Bearing Distance to line -> End point of bearing line -> Calculate new XY co-ordinates)

- Create density map using ' kernel density' tool - cell size set to 30m and search radius set to 1km.

Figure 4.3: Analytical process from data capture to density output to represent areas of high ungulate use and density increase in Ol Kinyei Conservancy (see Chapter 2: Statistical Methodology).

4.2.3.2 Hotspot Analysis

To identify areas where species aggregated in significant clusters, Anselin’s Local Moran’s I univariate analysis (Anselin, 1994) was performed using GEODAT software (https://geodacenter. asu.edu/software) using the distributions obtained from the kernel density estimations (Appendices 7.1 to 7.4) for each species in each sampling season (See Chapter 2.3: Statistical Methodology).

Additionally, bivariate analysis was conducted to determine whether there was any correlation in the distribution of study species between the sample seasons. Outputs from both the univariate and bivariate analyses include a metric of autocorrelation and a classified map which represents areas where: high values are clustered (HH), low values are clustered (LL), areas where a high value was surrounded by low values (HL), and a low value was surrounded by high values (LH) (see chapter 2.3 & Appendix 4 for detailed description).

4.2.3.3 Raster calculation

To determine where wild grazer densities changed over the three years of study raster calculations were performed on the kernel density estimation outputs. The first comparison was conducted to identify areas where densities change between October/November 2012 (sample season 1) and the same time of year in 2013 (sample season 2). The next calculations were between October/November 2013 (sample season 2) and October/November 2014 (sample season 4).

4.2.3.4 Habitat use and selectivity

- **Habitat Use**

To determine whether grazing ungulates utilised certain habitats more than others, ANOVA's were conducted for each sample season from grid data (250m) extracted from the GIS containing information on the species density (KDE) and the corresponding habitat classification at each point. Analyses were carried out in R 3.2.2 (Script 1; R Development Core Team, 2009), with post hoc Tukey tests subsequently conducted to determine the pairwise relationships between habitats.

- **Habitat selectivity**

In areas where ungulates are clustered in statistically significant hotspots it is assumed they are actively selecting these areas for optimum resources and as an anti-predator tactic. To determine whether species demonstrated any selectivity or avoidance of particular habitats, proportional use was calculated within the areas identified as clustering hotspots. This was calculated by conducting overlay analysis in the GIS, with the total area of each habitat in the hotspots calculated and quantified employing Jacob's correction (1974) of Ivlev's electivity index (1961) where:

Ivlev's electivity index:

Equation 4.1

$$E = \frac{r - p}{r + p}$$

Where r is the proportion of habitat utilised and p is the proportion of habitat available

Jacob's correction:

Equation 4.2

$$J = \frac{r - p}{(r + p) - 2rp}$$

Habitats selected in a larger proportion than would be expected from those available were considered 'preferred' (selectivity index values between 0.5 and +1), those which were under-represented are considered as 'avoided' (selectivity index values between -0.5 and -1) whilst those which have selectivity index values between -0.5 and 0.5 were categorised as 'no preference'.

4.3 Results

4.3.1 Thompson's gazelles

4.3.1.1 Clustering classification and coverage

Over the four field seasons there was a strong positive autocorrelation in the distribution of Thompson's gazelles (Table 4.1) which indicates that they were not distributed in a random manner in relation to one another. However, in all four sample seasons the largest proportion of Ol Kinyei Conservancy was classified as having non-significant clustering, this indicates that Thompson's gazelles were evenly distributed in most of the conservancy. The area classified as non-significant increased throughout the study period with values of 47.80% in the first sample season to 52.38% in the final sample season (Table 4.1).

Table 4.1: Cluster analysis of Thompson's gazelle distribution over four sampling seasons. Classification and significance at individual points (Local Moran's Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Sample Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	5.95	4.81	5.68		16.44	0.989561	Strong positive
	L-L	9.42	10.99	15.35		35.76		
	NS				47.80	47.80		
2	H-H	9.50	6.79	6.87		23.16	0.987839	Strong positive
	L-L	23.93	8.59	6.16		38.68		
	NS				38.16	38.16		
3	H-H	5.64	4.34	5.22		15.21	0.988301	Strong positive
	L-L	11.04	10.18	10.32		31.54		
	NS				53.25	53.25		
4	H-H	5.17	4.83	5.65		15.65	0.988508	Strong positive
	L-L	10.86	9.96	11.14		31.96		
	NS				52.38	52.38		
Comparison 1: 2012 vs 2013							0.530618	Positive
Comparison 2: 2012 vs 2014							0.789947	Strong positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering

In all four sample seasons hotspots (H-H) represented the smallest portion of the conservancy (≈17%), while coldspots (L-L) covered approximately 34% of the conservancy. Both hotspots and coldspots had the highest values in sample season 2 and consequently decreased in area in sample seasons 3 and 4, as indicated by the increase in non-significant clustering (Table 4.1).

4.3.1.2 Clustering spatial distribution

The distribution of hotspots in Ol Kinyei changed significantly between sample season 1 and 2, while in subsequent sample seasons there was considerably less variation in the distribution of hotspots. In sample season 1, two distinct hotspots were evident in OK1 covering two areas of open habitat (Figure 4.1; OH 1 & 3), with another present in OK2 (Figure 4.1; OH 6). Areas where coldspots occurred were invariably those where there is significantly more vegetation cover (Figure 4.4.a).

In sample season 2, two hotspots developed in OK2, with both reaching significance levels of P=0.001 (Figure 4.4.b). In OK1, the distribution of Thompson's gazelles in sample season 2 remained significant in OH1 (Figure 4.1). In addition further smaller hotspots developed around OH 3 & 4 (Figure 4.4.b with reference to Figure 4.1). In keeping with the outputs from sample season 1, results revealed that coldspot areas coincided with closed habitats.

Results from sample season 3 were similar to those found in sample season 2 (Figure 4.4.c) with results from sample season 4 also demonstrating that the distribution of Thompson's gazelles did not vary from the previous two seasons of data collection, despite the significant differences in density described in chapter 3. The hotspots located on OH 1, 4 and 5 were larger than in previous years indicating higher levels of use, while the coldspots were consistently located in the centre of the conservancy indicating that Thompson's gazelles avoided these areas regardless of season or length of conservancy establishment.

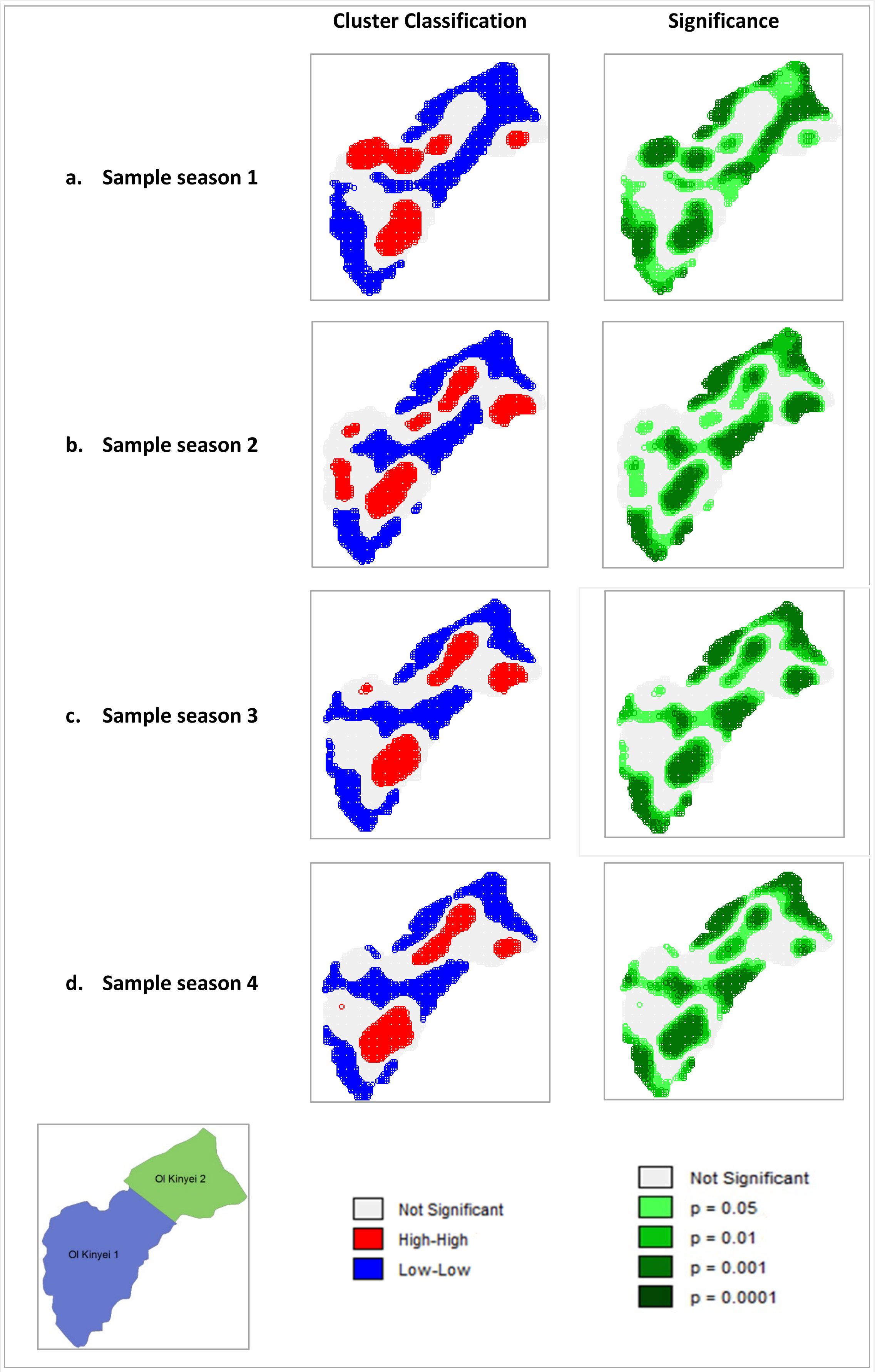


Figure 4.4: Cluster distributions of Thompson's gazelles in sample seasons in Ol Kinyei Conservancy.

4.3.1.3 Clustering comparisons between sample seasons

To determine whether the amount of clustering between sample seasons varied significantly, bivariate Moran's hotspot analysis was conducted. The Global Moran's statistic obtained from the comparison of Thompson's gazelle distributions in sample seasons 1 and 2 (I=0.53; Comparison 1: Table 4.1) indicated that there was a correlation between the levels of clustering in the two sampling seasons. The most significant differences occurred in OK2, where already existing clusters increased in size (Figure 4.5).

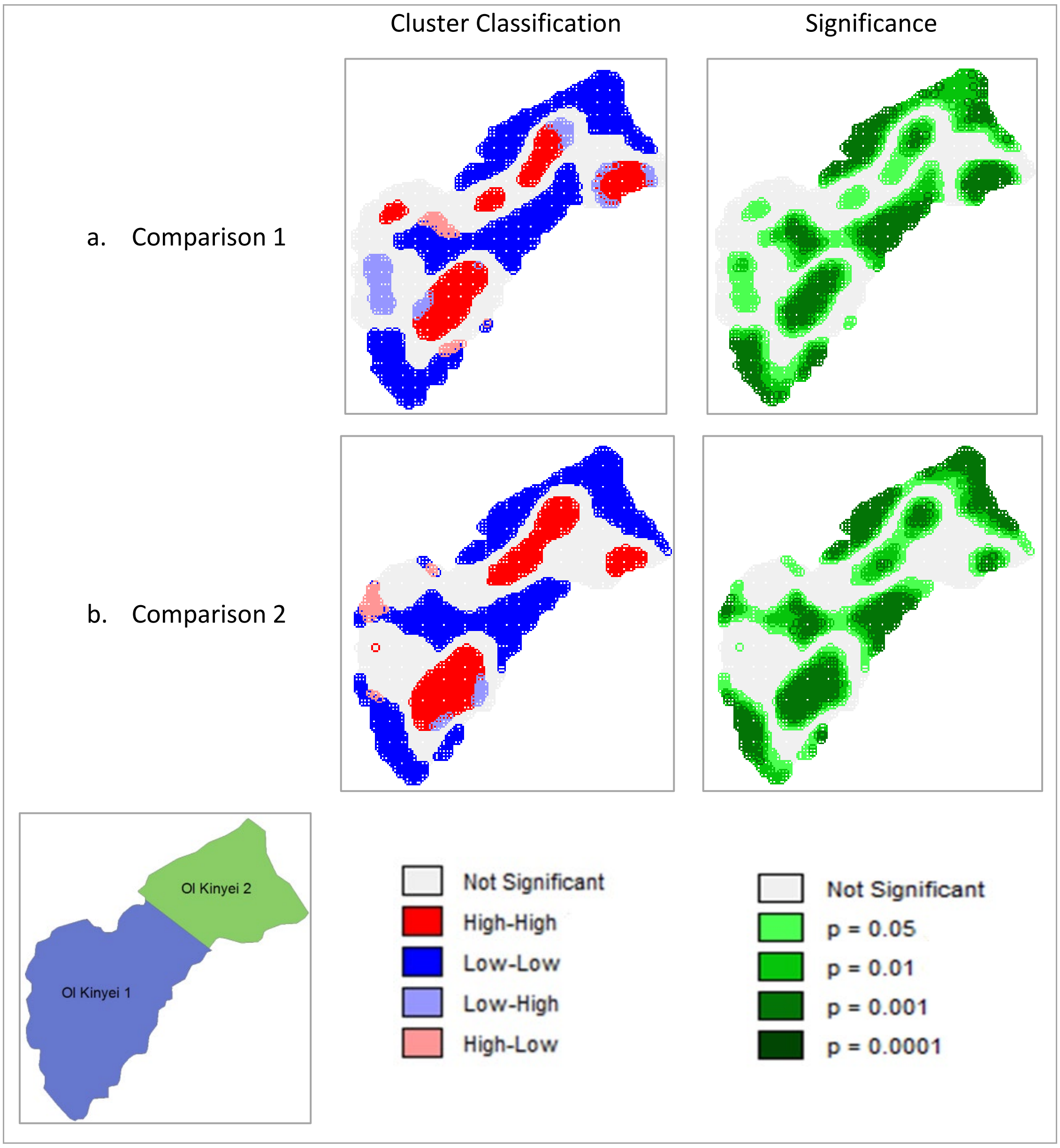


Figure 4.5: Comparison of Thompson's gazelles cluster distribution and between sample seasons 1 and 2 (Comparison 1) and sample seasons 2 and 4 (Comparison 2).

In OK1, a new cluster developed in season 2 on OH2 (Figure 4.5.a: Low-High with reference to Figure 4.1). The difference to the amount of clustering between sample seasons 2 and 4 was less significant, with a higher correlation than between sample seasons 1 and 2 (I=0.78;

Comparison 2: Table 4.1). In OK2 there were no significant changes in cluster patterns (Figure 4.5.b), though slightly higher levels of clustering were detected in the western part of OK1, an area which in previous years had been classified as a coldspot (Figure 4.5.a: High-Low).

4.3.1.4 Spatial distribution of density increases

In OK2 most areas experienced increases in the density of Thompson's gazelles over the three years of study. In addition, there were substantial areas in OK1 where densities increased between sample season 2 and 4 (Figure 4.6).

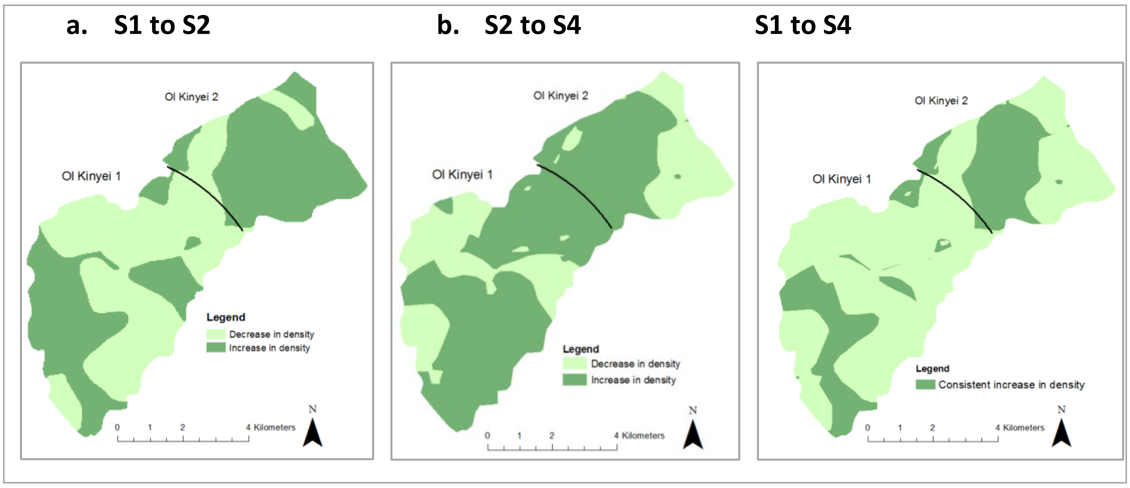


Figure 4.6: Areas of density increase of Thompson's gazelle between years a) sample season 1 & sample season 2 b) sample season 2 & sample season 4 c) incremental increase from Season 1. Where: Dark green = increase in density; light green = decrease.

4.3.1.5 Habitat use

To determine whether grazing ungulates were using certain habitats more than others, data was extrapolated from the KDE's and habitat classifications to reveal patterns of distribution in relation to habitat availability. To establish whether there was a significant difference between density and habitat classification, ANOVA's and post hoc Tukey tests were performed, the results indicating that the habitat use of Thompson's gazelles was significantly different between habitats in all four sampling seasons at p=0.001 significance level (Appendix 8.5).

To identify where the differences in habitat use of Thompson's gazelles lay, post hoc Tukey tests were conducted. Results from all four seasons indicated that there was a significant difference in use between habitat 1 (open grassland) and all other habitats (Appendix 8.6). The confidence intervals between habitat 1 and 6 for all seasons were larger than any other pair-wise comparison, due to the small area of habitat 6 (riparian forest) present.

4.3.1.6 Habitat Selectivity in clustering hotspots

The results for selectivity of Thompson's gazelles correlate strongly with the findings from habitat use in the conservancy. Thompson's gazelles showed a strong preference for open grassland in all four sampling seasons (Table 4.2), no preference (or avoidance) of shrublands was detected indicating that these areas are used, but not intensively. Closed habitats such as woodlands, riparian forest and hill slope were avoided (Table 4.2).

Table 4.2: Habitat selection of Thompson's gazelles within areas of high use (hotspots) calculated with Jacob's correction (J) of Ivlev's electivity index in each sampling season

Habitat	Sample Season 1	Sample Season 2	Sample Season 3	Sample Season 4
Open Grassland	0.752	0.641	0.672	0.693
Shrubland (Acacia)	-0.469	-0.385	-0.439	-0.382
Shrubland (Croton)	-0.475	-0.345	-0.373	-0.496
Acacia woodland	-0.754	-0.575	-0.582	-0.649
Riparian Forest	-0.987	-0.946	-0.952	-0.972
Hill slope	-0.864	-0.661	-0.728	-0.776

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

4.3.1.7 Summary - Thompson's gazelles

At the inception of the project Thompson's gazelles were well established throughout OK1, however by the second sample season their range had expanded in OK2 with the results revealing significant increases in hotspots. The clusters in OK2 remained present and similarly distributed over subsequent field seasons, demonstrating the establishment of Thompson's gazelle's range in the newer part of the conservancy regardless of season. The hotspots identified over all seasons corresponded with areas identified as open habitats, while significant cold spots were concentrated in areas with closed habitats such as woodland or riparian forest. When investigating the increase in density over the whole conservancy between 2012 (sample season 1) and 2014 (sample season 4) results indicated that Thompson's gazelles densities increased over the majority of the conservancy.

ANOVA's revealed that there were significantly different levels of use between habitats across all four field seasons with post-hoc analyses revealing that open grasslands were significantly more occupied than all other habitats. Within the areas of high use, or the hotspots identified, Thompson's gazelles showed selectivity towards open grassland, no selectivity of the two shrublands classified and avoidance of woodland, riparian forest and hill slope habitats (Table 4.6).

4.3.2 Wildebeest

4.3.2.1 Clustering classification and coverage

Over the three field seasons there was a high level of clustering in the distribution of wildebeest (Table 4.3). In all four seasons the larger proportion of Ol Kinyei Conservancy was classified as having non-significant clustering, sample season 2 had the highest value (%=59.04) followed by season 4 (%=54.09) while sample seasons 1 and 2 both had values close to 52% (Table 4.3). Between sample seasons 1 and 4, the area of coldspots had decreased by 6.46%, while the area covered by hotspots increased throughout the four seasons rising from 11.67% in sample season 1 to 16.84% in sample season 4.

Table 4.3: Cluster analysis of wildebeest distribution over four sampling seasons. Classification and significance at individual points (Local Moran's Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	4.49	2.81	4.37		11.67	0.988454	Strong positive
	L-L	9.63	12.91	12.99		35.53		
	NS				52.80	52.80		
2	H-H	4.82	3.56	5.18		13.56	0.987119	Strong positive
	L-L	10.38	7.50	9.52		27.39		
	NS				59.04	59.04		
3	H-H	4.35	5.02	6.31		15.68	0.988036	Strong positive
	L-L	10.63	9.96	11.31		31.90		
	NS				52.42	52.42		
4	H-H	3.58	4.93	8.33		16.84	0.983755	Strong positive
	L-L	10.60	8.52	9.95		29.07		
	NS				54.09	54.09		
Bivariate Global Moran's	Comparison 1: 2012 vs 2013						0.133275	Weak positive
	Comparison 2: 2012 vs 2014						0.576831	Positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

4.3.2.2 Spatial distribution of clustering

The distribution of hotspots in Ol Kinyei Conservancy changed significantly between sample seasons 1 and 4. In sample season 1, two hotspots were located in OK1 while in in OK2 there was one hotspot on OH6 on the eastern boundary (Figure 4.7.a).

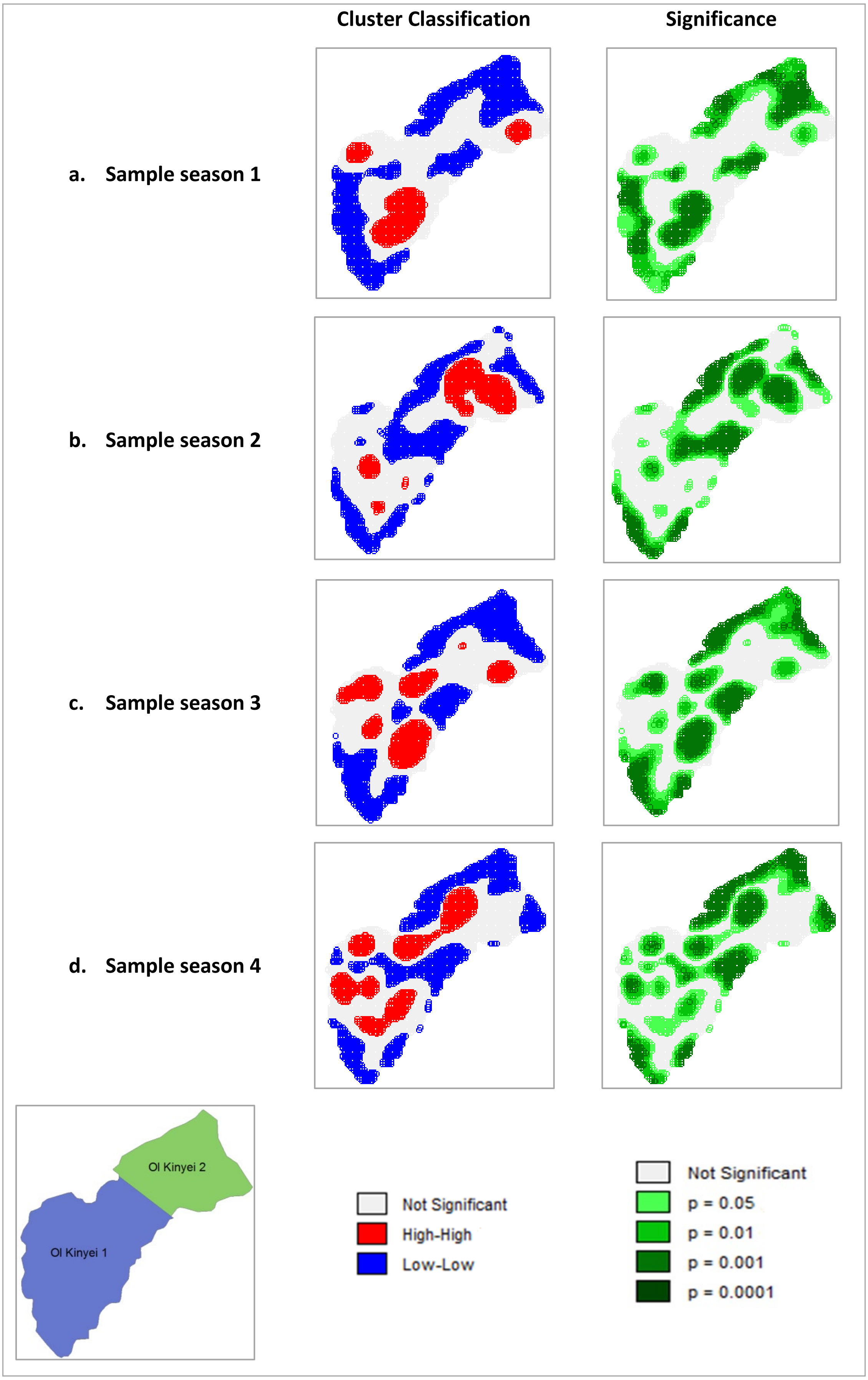


Figure 4.7: Cluster distributions of wildebeest in sample seasons in Ol Kinyei Conservancy

Coldspots were located in the closed habitats and generally located around the perimeter of the conservancy. Wildebeest distributions in sample season 2 were largely concentrated in OK2, where one hotspot occupied a large portion (Figure 4.7.b). In OK1 three small hotspots with a statistical significance of p=0.05 remained on OH1 within an area of open grassland and closed shrubland (Figure 4.7 & Figure 4.2). Significant coldspots remained around the perimeter of the conservancy, particularly to the North/West and also around the Southern perimeter.

A significant coldspot in sample season 2 was located through the middle of the conservancy, an area composed of hilly shrublands. In sample season 3, significant clusters of high density values were largely in OK1 (Figure 4.7.c) on OH1, 3 and 4, and one cluster remained in OK2 (p=0.01) on OH6. Four hotspots were identified in sample season 4, three in OK1 on OH1, 2, 3 and one extended from OK1 (OH4) into OK2 (OH5) (Figure 4.6.d). On OH6 in OK2, where in previous years there had been significant hotspots, all locations were identified as non-significant.

4.3.2.3 Clustering comparisons between sample seasons

The Global Moran's statistic comparing density distributions for sample seasons 1 and 2 (I=0.13; Table 4.3) indicated that there was no correlation between the levels of clustering in the two sampling seasons. There were however large areas where significant clustering increased in season 2, particularly in OK2 (Figure 4.8.a: Low-High).

The comparison between sample season 2 and 4 yielded an autocorrelation statistic of I=0.57 (Table 4.3), indicating a degree of correlation in the amount and location of hotspots between the two years (Figure 4.8). In OK1, there was a considerable increase in the area of hotspots between sample seasons 2 and 4, while in OK2 existing hotspots persisted. The area where the most notable increase in clustering occurred was in OK1 on OH4, with wildebeest displaying a strong affinity for open grasslands in OK1 and OK2.

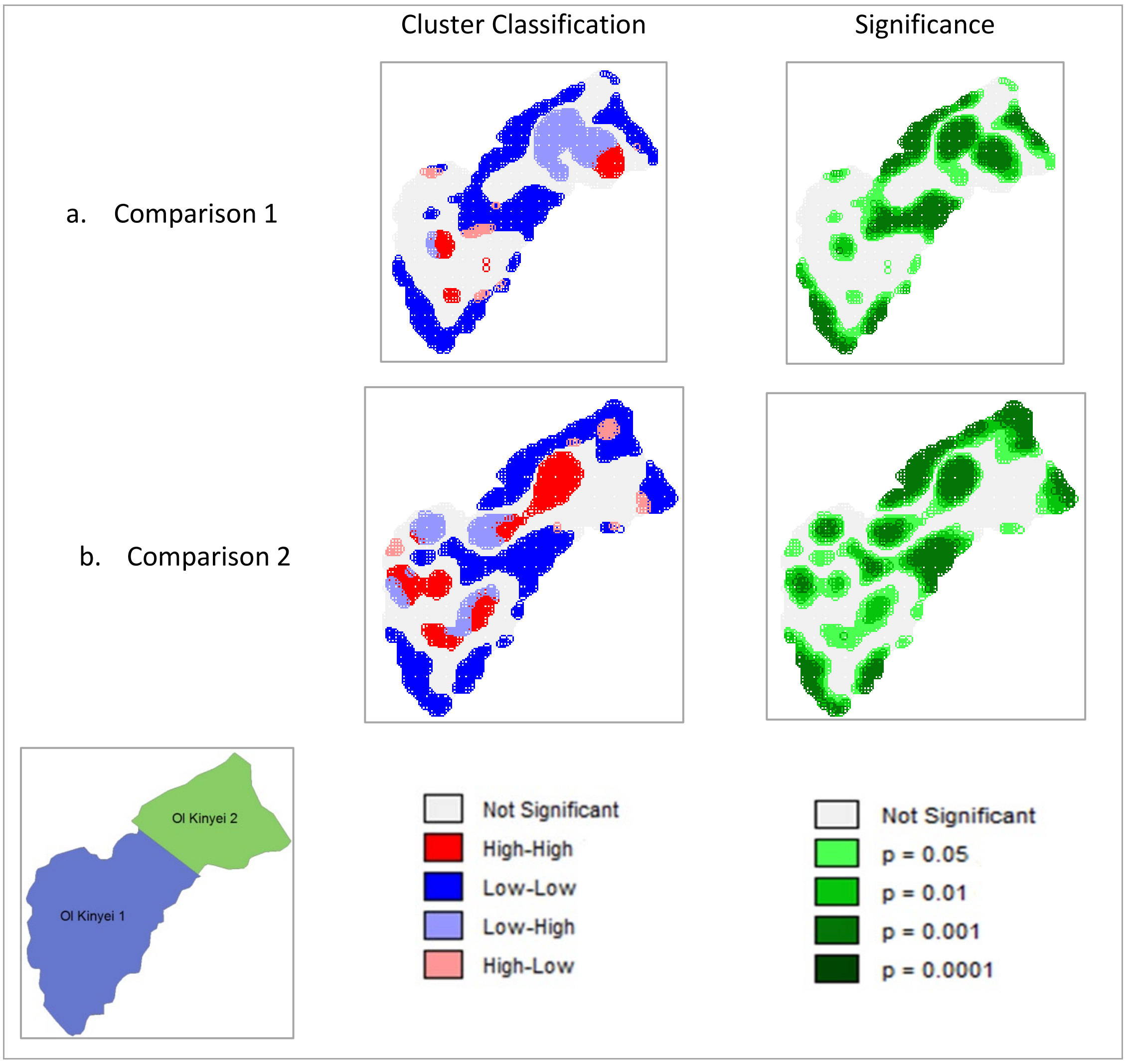
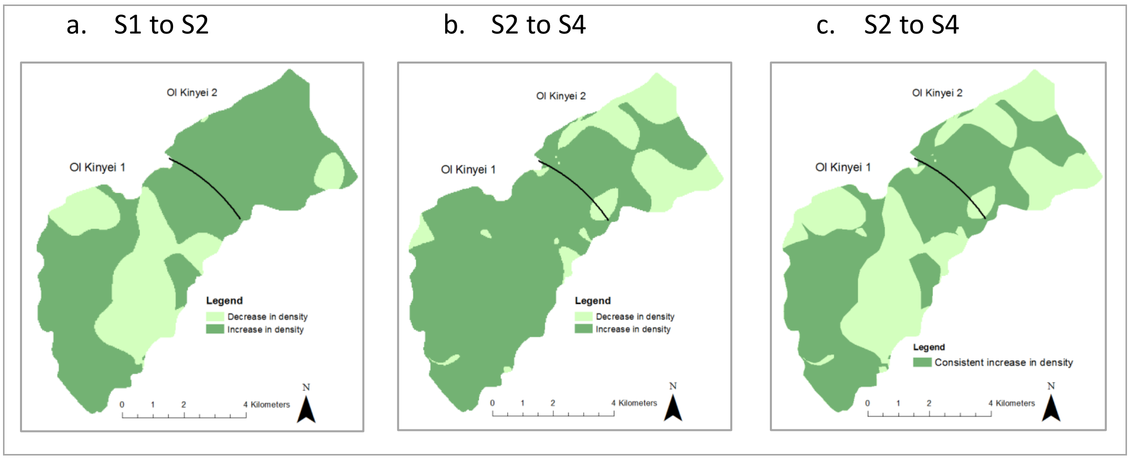


Figure 4.8: Comparison of wildebeest cluster distribution and between sample seasons 1 and 2 (Comparison 1) and sample seasons 2 and 4 (Comparison 2).

4.3.2.4 Spatial distribution of density increases

In OK2 there were increases in the density of wildebeest between sample seasons 1 and 2 with the exception of a small pocket of shrubland in the North/East corner of the conservancy (Figure 4.9.a). Densities increased in most of OK1 between sample seasons 2 and 4. In OK2 there were increases in density in many areas, particularly those directly adjacent to the boundary between OK1 and OK2, but not on OH6 where the density of wildebeest did not increase (Figure 4.9.b). Overall from sample season 1 to 4 wildebeest densities increased in the majority of OK1, while in OK2 increases in density were largely restricted to the Southern section bordering with OK1 (Figure 4.9.c).



a. S1 to S2

b. S2 to S4

c. S2 to S4

Figure 4.9: Areas of density increase of wildebeest between years a) sample season 1 & sample season 2 b) sample season 2 & sample season 4 c) incremental increase from Season 1. Where: Dark green = increase in density; light green = decrease.

4.3.2.5 Habitat use

Wildebeest habitat use was significantly different between classified habitats in three field seasons (Sample season 1, 3 and 4) at the p=0.001 significance level (Appendix 8.5). Results obtained from post-hoc tests revealed similar results to those found for Thompson’s gazelles (Appendix 8.6), with the most marked differences shown between open grasslands and closed habitats (Appendix 8.7).

4.3.2.6 Habitat selectivity within hotspots

Selectivity analysis in clustering hotspots revealed that in season 1 and 3 wildebeest selected open grassland, but this was not replicated in seasons 2 and 4 (Table 4.4). In season 2, wildebeest did not demonstrate selectivity (or avoidance) towards any habitat (Table 4.4), this correlated with findings for habitat use across the whole conservancy. In season 3 wildebeest avoided habitats with closed canopies (woodland, hill slope and riparian forest) as well as the semi-closed acacia shrubland. By season 4, wildebeest showed no selectivity but avoided hill slope and riparian forest (Table 4.4).

Table 4.4: Habitat selection of wildebeest within areas of high use (hotspots) calculated with Jacob's correction (J) of Ivlev's electivity index in each sampling season.

Habitat	Sample Season 1	Sample Season 2	Sample Season 3	Sample Season 4
Open Grassland	0.729	0.07	0.683	0.463
Shrubland (Acacia)	-0.468	-0.108	-0.525	-0.115
Shrubland (Croton)	-0.35	-0.055	-0.245	-0.313
Acacia woodland	-0.804	-0.012	-0.649	-0.444
Riparian Forest	-0.985	0.451	-0.924	-0.812
Hill slope	-0.555	-0.061	-0.509	-0.535

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

4.3.2.7 Summary – Wildebeest

Wildebeest hotspots were concentrated in OK1 during the first sample season in 2012. However, by the corresponding field season in 2013 significant hotspots had developed in OK2, in addition to three small areas of clustering in OK1. In sample season 3, the majority of clusters were located in both OK1 and on the border between OK1 and OK2. By the final sample season in 2014 the clustering was more widespread over OK1 and OK2. Overall there was a significant amount of fluctuation in both the location and size of wildebeest hotspots, with the overall increase in density in wildebeest between 2012 and 2014 restricted to the southern section of OK1 and the area around the boundary of OK1 and OK2.

Habitat use was found to be significantly different in sample seasons 1, 3 and 4 with wildebeest using open grassland more than other habitats. In sample season 2, there was no differential use between habitats. Similarly there was no selectivity towards specific habitat in identified hotspots in sample season 2. In sample seasons 1 and 3 they selected open grassland and avoided woodland, riparian forest and hill slope habitats. The patterns of wildebeest distribution and habitat use and selection were less defined than those found for Thompson's gazelles, indicating that wildebeest are less selective and fluctuate more in range as a result of graze availability, rather than as a consequence of the structure of habitats.

4.3.3 Zebra

4.3.3.1 Clustering classification and coverage

The results of the Global Moran’s Index (I) indicated that zebra were not distributed in a random manner in relation to one another (Table 4.5). In all four seasons the largest proportion of Ol Kinyei Conservancy was classified as having non-significant clustering; sample season 2 had the highest value (%=56.39) followed by season 4 (%=55.28) while sample seasons 1 and 3 scored between 49.97% and 52.43 respectively (Table 4.5).

Table 4.5: Cluster analysis of zebra distribution over four sampling seasons. Classification and significance at individual points (Local Moran’s Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	4.14	3.7155	3.6518		11.507	0.988981	Strong positive
	L-L	0	16.561	22.463		39.023		
	NS				49.47	49.469		
2	H-H	4.445	3.5351	4.1279		12.108	0.986308	Strong positive
	L-L	10.97	9.8434	10.69		31.499		
	NS				56.39	56.393		
3	H-H	5.872	5.662	8.0404		19.575	0.98703	Strong positive
	L-L	10.8	10.103	7.0932		27.994		
					52.43	52.431		
4	H-H	5.21	3.6912	4.8513		13.752	0.986419	Strong positive
	L-L	10.1	11.833	9.0276		30.964		
	NS				55.28	55.284		
Bivariate Global Moran's	Comparison 1: 2012 vs 2013						0.162844	Weak Positive
	Comparison 2: 2012 vs 2014						0.144416	Weak Positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

Between sample seasons 1 and 4, the area of coldspots decreased by 8% while the total area of hotspots increased throughout the four seasons from 11.5% in sample season 1 to 13.75% in sample season 4 (Table 4.5).

4.3.3.2 Spatial distribution of clustering

The cluster distribution patterns of zebra in Ol Kinyei Conservancy changed significantly throughout the four sampling seasons. In sampling season 1 there were no clusters of high density values in OK2, as very few zebra were sighted in the emerging conservancy at the time (Figure 4.10.a).

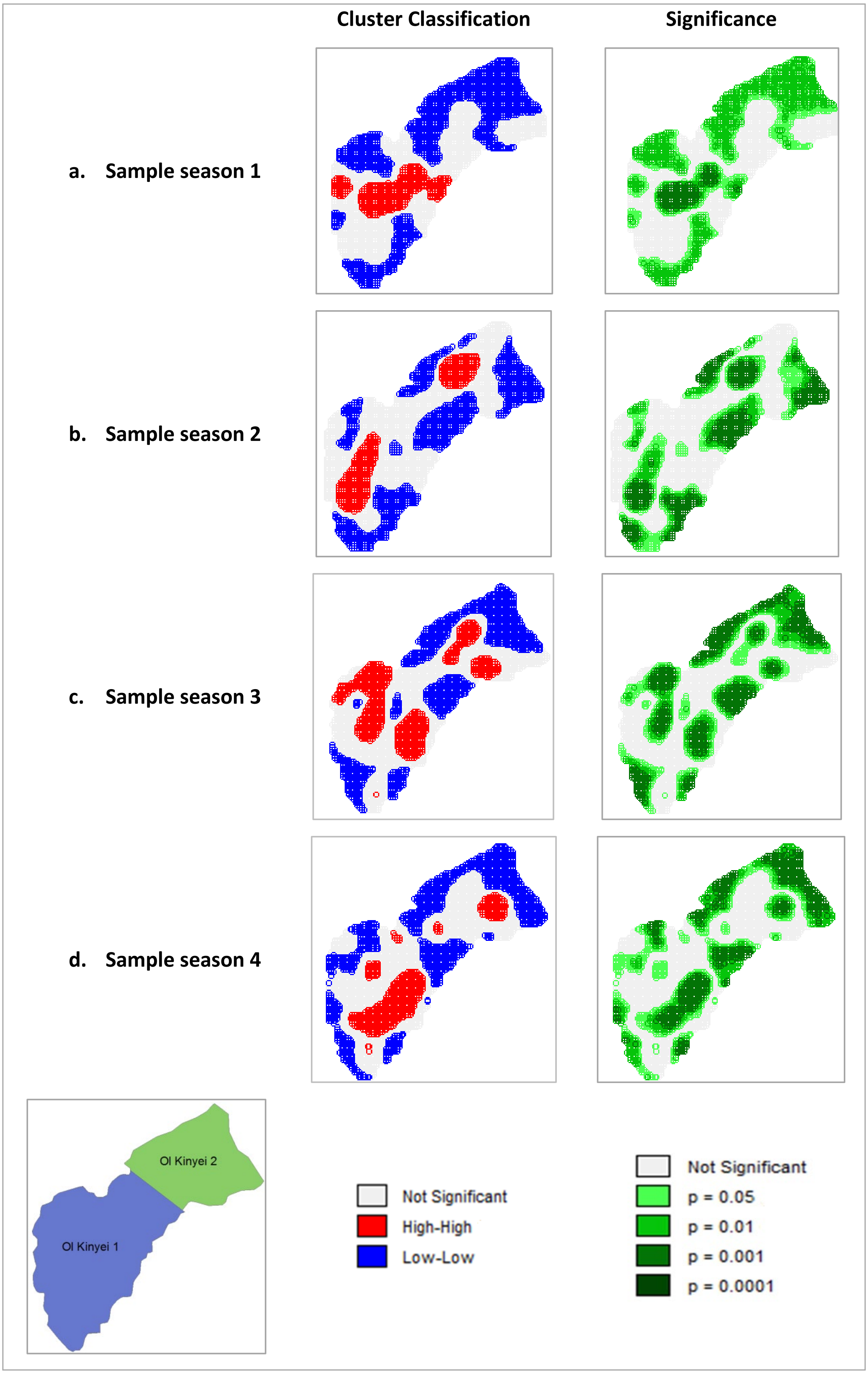


Figure 4.10: Cluster distributions of zebra in sample seasons in Ol Kinyei Conservancy

Conversely in OK1 zebra were present in concentrated (p=0.001) numbers in the partially closed habitat located north of OH1 and 2 (Figure 4.10.a), with another hotspot located on the Western boundary of OK1, where there is a crossing point over a river.

In sample season 2, the area of high levels of zebra clustering in OK1 moved westward onto OH2 away from the partially closed habitat which the hotspot covered in season 1. In sample season 3, two small hotspots were located in OK2 on OH5 and 6 (Figure 4.10.c) while in OK1, one large hotspot was found on OH3 and on the more closed habitats directly around OH3. A further hotspot was also located in OK1 on OH1 which had previously been classified as non-significant (Figure 4.10.c). In sample season 4, the most significant hotspot was located in OK1 on OH2 and the shrublands around it (Figure 4.10.d), adding to several other smaller hotspots also found in OK1. In OK2 there were two hotspots, one located towards the western edge of OH6 and another on the part of OH4 which extends into OH4 (Figure 4.10.d).

4.3.3.3 Clustering comparisons between sample seasons

There was no discernible correlation between distribution of clusters found between sample seasons 1 and 2 (I=0.16; Table 4.5). Similarly, the correlation between the distribution of zebra clusters between sample seasons 2 and 4 was very low (I=0.14; Table 4.5). In OK2 one area was identified where there was an increase in clustering between sample season 1 and 2 (Figure 4.11.a: Low-High). In OK1, there was a large area where clustering increased significantly on OH1, yet there was also a segment where clustering decreased in an area of shrubland in the centre of the conservancy (Figure 4.11.a). There were further increases in clustering in OK1 between sample seasons 2 and 4, particularly on OH1 (Figure 4.11.b) while in OK2, a new cluster developed and overall zebra showed low levels of significant clustering in OK2 (Figure 4.11.b).

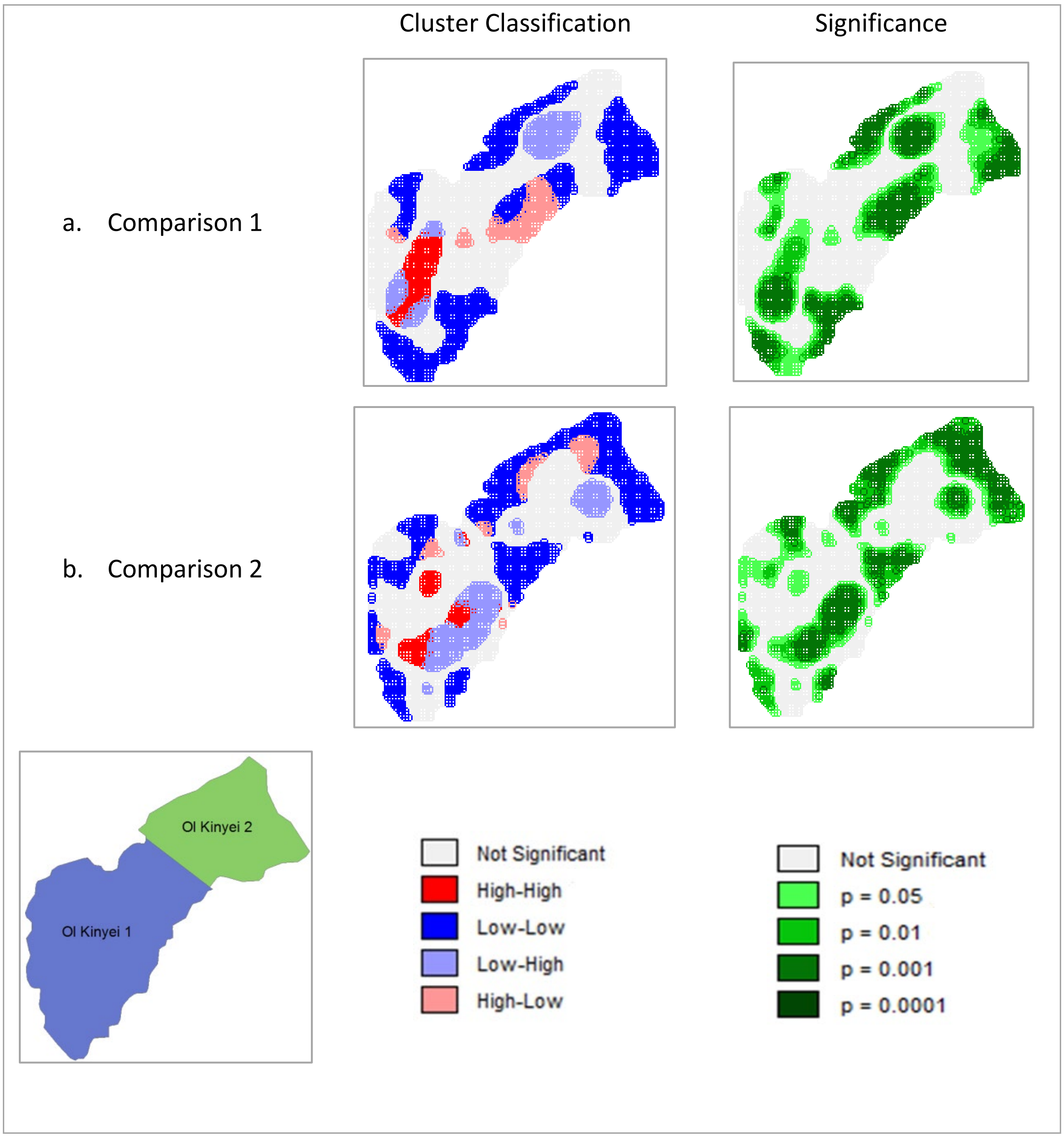


Figure 4.11: Comparison of zebra cluster distribution and between sample seasons 1 and 2 (Comparison 1) and sample seasons 2 and 4 (Comparison 2).

4.3.3.4 Spatial distribution of density increases

Between sample seasons 1 and 2, zebra increased in density in large tracts of OK2. In OK1 they increased in the north and south but not in the centre of the conservancy (Figure 4.12.a). They also increased in density over the majority of OK1 and OK2 between sample seasons 2 and 4 (Figure 4.12.b). Overall, between sample seasons 1 and 4 zebra had increased significantly in density over OK2 and a large proportion of OK1 (Figure 4.12.c).

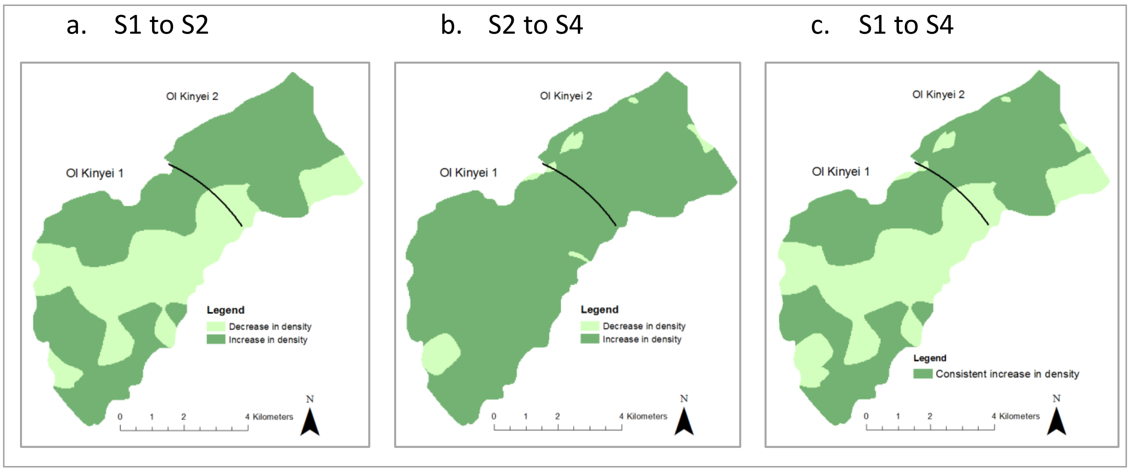


Figure 4.12: Areas of density increase of zebra between years a) sample season 1 & sample season 2 b) sample season 2 & sample season 4 c) incremental increase from Season 1. Where: Dark green = increase in density; light green = decrease.

4.3.3.5 Habitat use

In sample seasons 1 and 2 there was no significant difference in habitat use by zebra (Appendix 8.5) indicating that the habitats available across the whole conservancy were being used proportionally to their availability. In sample seasons 3 and 4, there was a significant difference (Appendix 8.5), with post-hoc tests revealing that zebra were utilising open grassland significantly more than most other habitats, with the exception of riparian forest (Appendix 8.8).

4.3.3.6 Habitat selectivity in hotspots

In the areas identified as hotspots, zebra did not display any selectivity towards a particular habitat (Table 4.6).

Table 4.6: Habitat selection of zebra within areas of high use (hotspots) calculated with Jacob's correction (J) of Ivlev's electivity index in each sampling season.

Habitat	Sample Season 1	Sample Season 2	Sample Season 3	Sample Season 4
Open Grassland	0.192	0.123	0.499	0.49
Shrubland (Acacia)	0.085	-0.057	-0.365	-0.286
Shrubland (Croton)	-0.141	-0.021	-0.211	-0.267
Acacia woodland	-0.415	-0.056	-0.387	-0.436
Riparian Forest	-0.396	-0.326	-0.106	-0.677
Hill slope	0.166	-0.19	-0.278	-0.099

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

4.3.3.7 Summary – Zebra

In sample season 1, shortly after OK2 was established as a conservancy, the majority was classified as a coldspot with no significant hotspots of zebras. By the following sample season there were hotspots in both OK1 and OK2, indicating that zebra had begun to utilise the newly available conservancy area within the space of a year. In sample season 3, both OK1 and OK2 maintained hotspots of significant sizes, however by sample season 4 the amount of clustering in OK2 had decreased leaving a large cluster in the centre of OK1.

Overall zebra densities increased over most of Ol Kinyei Conservancy, apart from a strip of hill slope and shrubland running through the middle of OK1. The habitat classification map reveals that densities did not increase in the areas in which the landscape is more rugged i.e. those portions of the landscape covered by hill slope, shrublands and woodland.

Zebra did not show any differential habitat use in the two first field seasons, but did in the last two. In sample seasons 3 and 4, open grassland was more used than other habitats. Interestingly, when investigating habitat selectivity in areas of high clustering, the results revealed that zebra did not demonstrate preference or avoidance for any habitat.

4.3.4 Topi

4.3.4.1 Clustering classification and coverage

Over the four field seasons there was a strong positive autocorrelation in the distribution of topi (Table 4.7) which indicates that they were not distributed in a random manner in relation to one another. In all four seasons the larger proportion of Ol Kinyei Conservancy was classified as having non-significant clustering, increasing from 58.36% in sample season 1 to 62.42% in sample season 4 (Table 4.7). In all four sample seasons hotspots (H-H) represented the smaller portion of the conservancy (≈11%), with a degree in variation in percentage of the conservancy classified as a hotspot. Sample seasons 2 and 3 had the highest values at 12.15% and 16.69% respectively, while sample season 4 had the lowest of all four season at 7.61%. Coldspots covered approximately 34% of the conservancy, and remained stable averaging 32.2% (Table 4.7).

Table 4.7: Cluster analysis of topi distribution over four sampling seasons. Classification and significance at individual points (Local Moran's Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	2.87	2.44	3.31		8.62	0.987691	Strong positive
	L-L	10.22	11.44	11.36		33.02		
	NS				58.36	58.36		
2	H-H	4.65	3.42	4.08		12.15	0.984716	Strong positive
	L-L	9.99	10.03	13.18		33.21		
	NS				54.65	54.65		
3	H-H	6.57	5.37	4.74		16.69	0.980035	Strong positive
	L-L	10.56	12.45	9.62		32.63		
	NS				50.68	50.68		
4	H-H	2.90	1.75	2.97		7.61	0.986096	Strong positive
	L-L	9.65	11.02	9.30		29.97		
	NS				62.42	62.42		
Bivariate Global Moran's		Comparison 1: 2012 vs 2013					0.4425	Positive
		Comparison 2: 2012 vs 2014					0.710949	Strong positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

4.3.4.2 Spatial distribution of clustering

Over the course of the four sample seasons there was a degree of variation in the distribution of hotspots, coldspots and non-significant clustering (Figure 4.13). The distribution of topi in sample season 1 in areas of shrubland and woodland in the south of OK1 were classified as non-significant indicating that topi utilise these areas, but not in high densities (Figure 4.13.a). Large parts of OK2 had clusters of low values in sample season 1, with the exception of some non-significant clustering located between OH5 and OH6 (Figure 4.13.a). In OK 1, there was one cluster of high density values, located in partially closed habitats located in the centre of the conservancy, with another smaller and statistically less significant (p=0.05) hotspot on OH2 in OK1 (Figure 4.13.a).

In sample season 2, Topi were aggregated in significant clusters in two parts of OK1 (Figure: 4.13.b), these areas were similar to those found the previous year (Figure: 4.13.a). In OK2, a significant hotspot of high values developed in OH5, additionally parts of OK2 were classified as "non-significant" which in the previous year had been classified as coldspots (Figure: 4.13.a)

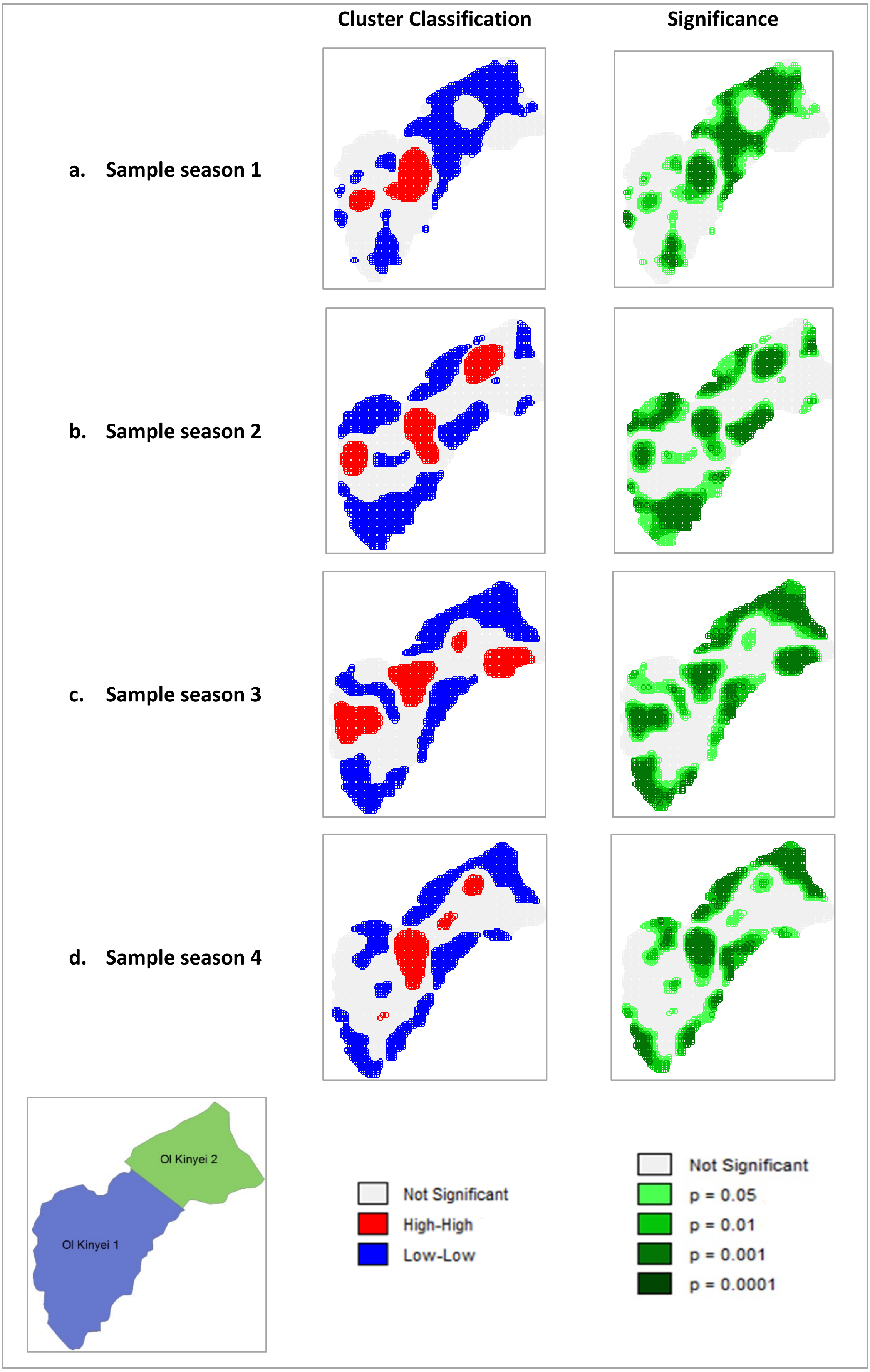


Figure 4.13: Cluster distributions of topi in sample seasons in Ol Kinyei Conservancy

In sample season 3, clusters of high values were found on OH2 and OH4 (Figure 4.2) and the surrounding shrubland in OK1 (Figure: 4.13.c). In OK2 two hotspots were identified, one on OH6 and another smaller less significant one ($p=0.05$) between OH5 and OH4. The number of hotspots in sample season 4 had decreased to one area in OK1 on OH4 and two areas in OK2 on OH4 and OH5 (Figure 4.13.d).

4.3.4.3 Clustering comparisons between sample seasons

There was a correlation between the clustering in season 1 and in season 2 ($I=0.44$) with a strong correlation found between sample seasons 2 and 4 ($I= 0.71$; Table 4.7).

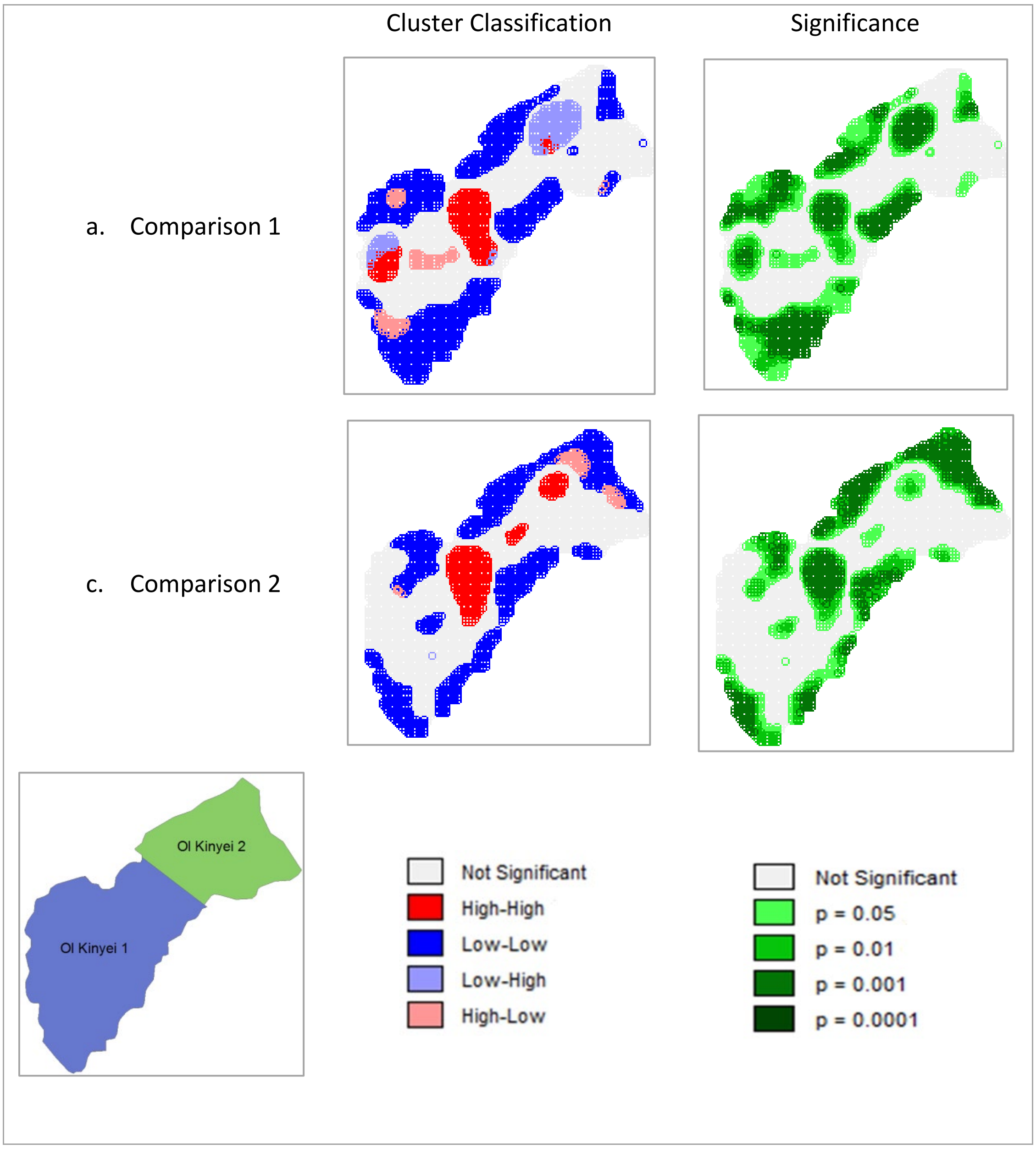


Figure 4.14: Comparison of topi cluster distribution and between sample seasons 1 and 2 (Comparison 1) and sample seasons 2 and 4 (Comparison 2).

Between sample seasons 1 and 2, there were two areas where the clustering of high values increased significantly, one in OK1 on OH2 along its western edge, the other in a large area of OK2 on OH5 (Figure 4.14.a). In the centre of OK1, a small area was identified as having significantly lower numbers in sample season 2 than in sample season 1 (Figure 4.14.a: High-Low). There were no areas where clustering increased significantly between sample season 2 and 4 (Figure 4.14.b). Several small areas were identified as having significantly lower values than the previous year, particularly in OK2 (Figure 4.14.b).

4.3.4.4 Spatial distribution of density increases

Densities increased in most parts of Ol Kinyei Conservancy between sample seasons 1 and 2. OK1 densities increased in the north, and in some parts in the south (Figure 4.18.a). Between sample seasons 2 and 4 densities increased across the whole conservancy apart from along the northern boundary and on OH2 (Figure 4.15.b). Overall between sample seasons 1 and 4, topi densities increased most consistently in most of OK2 and the northern section of OK1 (Figure 4.15.c).

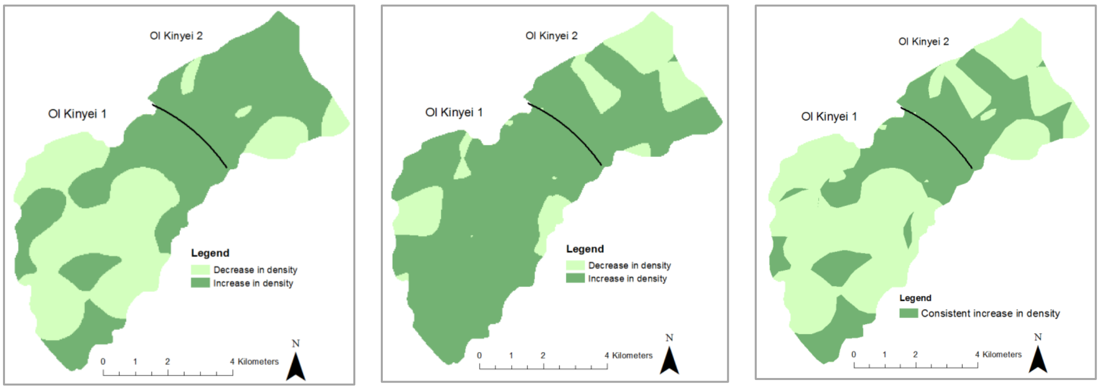

a. S1 to S2 b. S2 to S4 c. S1 to S4

Figure 4.15: Areas of density increase of topi between years a) sample season 1 & sample season 2 b) sample season 2 & sample season 4 c) incremental increase from Season 1. Where: Dark green = increase in density; light green = decrease.

4.3.4.5 Habitat use

In sample seasons 1 and 2 there was no significant difference in habitat use by Topi (Appendix 8.5) suggesting that the habitats available across the whole conservancy were being used proportionally to their availability. In sample seasons 3 and 4, there was a significant difference (Appendix 8.5) and post hoc tests revealed that in sample season 3 topi were utilising open grassland significantly more than the croton dominated shrublands, acacia woodlands and hill slope (Appendix 8.8). In sample season 4 the disparity in habitat use lay between open grassland and hill slope, while all other habitats were used in proportion to their availability (Appendix 8.8). These results suggest that although topi do not consistently use certain habitat more than others, the overall conservancy landscape structure and habitat composition is attractive to them.

4.3.4.6 Habitat selectivity in hotspots

Topi showed a strong preference to open grassland in all four sampling seasons (Table 4.8), and no preference (or avoidance) of shrublands was detected, indicating that these areas were used, but not intensively. Closed habitats such as woodlands, riparian forest and hill slope were all avoided (Table 4.8).

Table 4.8: Habitat selection of topi within areas of high use (hotspots) calculated with Jacob's correction (J) of Ivlev's electivity index in each sampling season

Habitat	Sample Season 1	Sample Season 2	Sample Season 3	Sample Season 4
Open Grassland	0.752	0.641	0.672	0.693
Shrubland (Acacia)	-0.469	-0.385	-0.439	-0.382
Shrubland (Croton)	-0.475	-0.345	-0.373	-0.496
Acacia woodland	-0.754	-0.575	-0.582	-0.649
Riparian Forest	-0.987	-0.946	-0.952	-0.972
Hill slope	-0.864	-0.661	-0.728	-0.776

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

4.3.4.7 Summary – Topi

In sample season 1, there were no significant clustering hotspots of topi in OK2, the majority of the area was classified as a coldspot, indicating that topi were not occupying OK2 in significant numbers. In OK1, there were two areas classified as a hotspot, with a large proportion of the remainder of OK1 classified as having non-significant clustering. By sample season 2, topi were found in significant clusters in both OK1 and OK2 and the coverage of coldspots had reduced considerably to be replaced by non-significant clustering. Similar patterns of clustering were revealed for the subsequent two sample seasons, with large clusters in both parts of the conservancy and the amount of non-significant clustering increasing.

At the conservancy level, topi did not use the habitats classified in Ol Kinyei Conservancy differentially in the two first sample seasons. Pairwise tests revealed that in sample season 3, topi were however utilising areas of open grassland significantly more than the areas classified as shrublands. In sample season 4, the post hoc tests indicated that topi used open grassland more than hill slope. When investigating habitat selectivity within areas identified as clustering hotspots, results indicated that topi were selecting open grasslands, avoiding woodlands, riparian forest and hill slope consistently in all four seasons and demonstrated no selectivity, or avoidance, towards shrublands.

4.4 Discussion

4.4.1 Thompson's gazelles

Thompson's gazelles are highly selective of short grass swards. Large aggregations of Thompson's gazelles are therefore most likely to be found in areas where other grazers (wildebeest and zebra) have already fed creating short grazing lawns. The presence of significant clustering in OK2 shortly after its conversion from communal grazing land for livestock to conservancy can likely be explained by the combination of short swards left as a result of intensive livestock grazing and a lack of predators due to historical human disturbance. Between sample seasons 2 and 4 there were few differences identified in the distributions of Thompson's gazelles, suggesting that by then the population in the conservancy had stabilised and was utilising the whole conservancy.

Population estimates calculated for Thompson's gazelles (Chapter 3) indicated that there was a significant increase in population size between sample seasons 1 and 2, the most marked increases in population estimates occurred in OK2 where the population size was estimated to have increased from approximately 750 to just under 1,200 individuals. These increases are reflected in the distributions of the Thompson's gazelles with the development of three hotspots in OK2 in sample season 2. When considered in tandem with the increasing densities in OK1, the positive response in terms of occupancy of OK2 by Thompson's gazelles is likely to be a result of movement from OK1 to minimise competition for resources that would have resulted from high Thompson's gazelle densities. In addition, Thompson's gazelles are migrant species. The upsurge in population estimates in sample season 2 in both OK1 and OK2 could be linked to the fact that the migrant population returned to the Serengeti later than they did in the previous and subsequent year (pers.obvs).

The distributions of Thompson's gazelles remained relatively stable in the subsequent two sample seasons (3 & 4); however the population estimates calculated suggest that Thompson's gazelles reduced in numbers to closely match the estimates obtained for sample season 1. Interestingly in sample season 3, there was no significant difference in the population estimates between OK1 and OK2, while there was a significant difference in estimates between the three sample seasons that took place in October/November. This indicates that in February/ March, after the short rainy season, resources in OK2 were sufficient to support similar numbers of Thompson's gazelles as OK1, while in the drier seasons (October/November) OK1 consistently held higher numbers of Thompson's gazelles, which suggests that OK1 is more suitable at this stage than OK2 in its ability to support high levels of Thompson's gazelles. These findings are likely related to habitat use and selectivity. Thompson's gazelles were using open grasslands significantly more than the other habitats described in the conservancy, at both the landscape scale and within areas classified as hotspots (Figure 4.10; Table 4.6). Thompson's gazelles also showed a strong preference to open grassland in all four sampling seasons (Table 4.6) with no preference (or avoidance) of shrublands detected, indicating that these areas are used, but not intensively. Closed habitats such as woodlands and riparian forest were avoided as well as hill slope. OK1 is an established wildlife conservancy, and a larger proportion of the areas is composed of open grasslands than OK2 (Figure 4.1), it is therefore not surprising that OK1 held higher densities of Thompson's gazelles than OK2, particularly in the drier seasons.

4.4.2 Wildebeest

In sample season 1, the distribution of wildebeest was similar to the distribution of Thompson's gazelles in both OK1 and OK2. In season 2, their distribution also increased significantly in OK2 (Figure 4.14), which also corresponds to results obtained from the population estimates calculated (Chapter 3). Between sample seasons 1 and 2 the overall population estimates for wildebeest in Ol Kinyei Conservancy increased from approximately 800 to 2,500 individuals. OK2 estimates (Chapter 3) indicated that occupancy had increased from just over 200 individual in sample season 1 to over 1,000 a year later These increases were evident in the distribution patterns of wildebeest, with the development of significant hotspots in OK2. Conversely, in OK1 only three small areas were classified as hotspots in sample season 2, the rest was classified as non- significant. Despite population estimates (Chapter 3) suggesting that the overall density of individuals in OK1 remained considerably higher in OK1 than in OK2, these findings indicate that wildebeest were distributing themselves in a more random and dispersed manner and were not concentrated in aggregations. Similar to the results found for both Thompson's gazelles and zebra, wildebeest are migrants, so it is probable that the estimate for sample season 2 encompasses the migrant population as well as the resident population, due to a later departure date that year (pers. obvs). Similarly the more dispersed distributions described in sample season 2 are likely to be explained by the presence of migrant individuals, which would be composed of less cohesive social groups and would not be predisposed to be aggregated in highly concentrated clusters.

Medium bodied species such as wildebeest are less selective than smaller bodied species and therefore more likely to distribute themselves evenly between habitats (Cromsigt *et al.,* 2009). Their dispersal away from the grazing lawns suggests that resources were not restricted to the large open grasslands, but also available in the herbaceous layer of shrub lands and woodlands. Similarly to Thompson's gazelles, population estimates generated for wildebeest indicated that there were considerably higher numbers of individuals in sample season 3 than in any of the other sample seasons, but the distribution analyses revealed that wildebeest were still largely concentrated in high density clusters in OK1. This constriction of cluster distributions to OK1 as opposed to OK2 is likely a response to changes in resource availability and increased levels of livestock disturbance in OK2 (pers. obvs). Although population estimates decreased between sample seasons 3 and 4, distributions in the final sample season were more widespread across both OK1 and OK2, reinforcing the theory that the shift away from OK2 in season 3 was a seasonal response to resource availability and disturbance.

Wildebeest habitat use was significantly different between habitats in three field seasons (Season 1, 3 & 4), with results revealing similar distribution patterns to those found for Thompson's gazelles. In sample season 2, there was no significant difference in the habitat use of wildebeest, suggesting a widespread distribution over all habitats. Again, this may indicate that forage at this time was of a similar quality in the open areas when compared to the more vegetated habitats. The results reveal that patterns of wildebeest distribution and habitat use and selection were less constricted to specific habitats than Thompson's gazelles, confirming that they are less selective and fluctuate more in range. In addition, the results indicated that they are more accommodating of environmental changes and are more adaptable to occupying habitats with more cover and associated lower levels of vigilance.

4.4.3 Zebra

Zebra are bulk feeders which, like wildebeest, are more highly dependent on high biomass intake but not particularly selective in terms of palatability or forage quality. Zebra are one of the pioneer grazing species in the African savannah that move into areas ahead of more selective feeders to feed on tall and flowering grasses (Shorrocks, 2007). They are also highly adaptable and can also survive on grazing lawns with short grass swards and on the herbaceous layer in more closed habitats if necessary. In sample season 1, zebra were distributed throughout most of OK and interestingly, in most of the areas of open habitats their distributions were indicated as being evenly spread and not clustered. Zebra were therefore utilising a large proportion of OK1, but were still evenly distributed across habitats rather than aggregated in high density clusters. In sample season 1, there were no hotspots in OK2 and the majority of the area was classified as a coldspot, indicating that zebras were avoiding this area, the findings supported by the population estimates generated (Chapter 3) which proposed that the population size of zebra in OK2 was as low as 50 individuals. The avoidance of OK2 was almost certainly due to historical human disturbance and a lack of resources (long swards) as a consequence of long-term intensive livestock grazing. By season two, zebra had started to utilise part of OK2 in numbers up to 400 (Chapter 3), this expansion likely to be a result of competitive release resulting from the exclusion of livestock (particularly cattle) from the area.

Zebra numbers increased dramatically between sample seasons 1 and 2 in Ol Kinyei Conservancy (Chapter 3, Figure 3.2). However the amount of clustering decreased, indicating that the distribution of zebra was more evenly spread across the conservancy, because resources were not limited. In sample season 3, hotspots were more numerous in both OK1 and OK2 and large proportions of non-significant clustering were also present in both areas. The population size of zebra increased considerably in sample season 3 (Chapter 3) as did the amount of hotspots, indicating that high densities resulted in more widespread areas of hotspots and non-significant clustering to accommodate these elevated densities. By sample season 4, zebra distributions were equally spread over most of OK1 and OK2, with population estimates indicating a reduction in numbers from sample season 3, but still remaining higher than estimates from sample season 1. The fact that significant hotspots remained in OK2 despite lower population estimates suggests that zebra populations were stabilising in that part of the conservancy, rather than being pushed out as a result of elevated levels of competition in OK1.

Results revealed that in the initial two sample seasons, zebra were utilising the habitat proportionally to their availability. In sample season 3 and 4, zebra were utilising open grasslands significantly more than other habitats, probably as a result of an increase in the amount and quality of resources (Figure 4.26). When investigating habitat selectivity in areas of high clustering, the results revealed that zebra did not demonstrate preference or avoidance of any habitat. This suggests that zebra distributions are not determined by variable levels of canopy cover, but rather by the amount of herbaceous biomass available.

4.4.4 Topi

Topi demonstrated similar fluctuations in distribution and clustering to zebra. The patterns observed for both zebra and topi were dependent on the availability of long swards of grass. Topi also utilised OK2 from sample season 2 onwards, though interestingly topi clusters were mainly found in open to closed ecotonal areas, indicating that a degree of vegetative cover is an important factor for this species. Topi are highly selective feeding primarily on new growth of more palatable grasses and long grass. In sample season 1, large parts of OK1 were classified as having non-significant clustering, indicating that topi were distributed evenly across most of that part of the conservancy. As a result of the feeding ecology of topi, competition with other species for palatable short swards is likely to be high. However, because topi are considerably larger than Thompson's gazelles they are less vulnerable to predation, they are more accepting of higher levels of canopy cover and consequently can utilise the areas that Thompson's gazelles would avoid. Topi distribution patterns remained similar throughout the sampling seasons, indicating that topi began to utilise OK2 shortly after the removal of livestock from the area and remained there in stable numbers. These findings are supported by resulted obtained from population estimates (Chapter 3) which describe a considerable increase in numbers between sample season 1 and 2 (estimates could not be calculated for sample season 1 due to insufficient sightings). Population estimates yielded for subsequent sample seasons showed that topi numbers increased in sample season 3 in a similar (but less pronounced) way as the other grazers and reduced in sample season 4, but still remained higher than in sample season 1 and 2.

Topi habitat use across the conservancy was found to be evenly spread over all habitats in the first two seasons, indicating that suitable forage was found in all habitats at that time. In season 4, topi avoided hill slope, probably as a response to increased predation from a lion pride that now utilise that area as their core territory. In areas identified as significant clusters, topi demonstrated avoidance of woodlands, riparian forest and hill slope and selectivity towards open grassland. These findings show that although topi are adaptable to most habitats and levels of woody vegetation density, they tend to be aggregated in open areas where the opportunities for vigilance against predators are elevated.

5. Conclusions

Over the three years of study the distributions of all grazing species were found to have increased substantially in OK2, approximately a year after it was established as a wildlife conservancy. Despite expected minor fluctuations the distributions of all four grazing species persisted in OK2, suggesting that populations were beginning to establish themselves in the new conservancy area. The fluctuations described in OK1 are likely to be natural responses to changes in the environment, and most importantly changes in the availability of resources as a result of seasonality and habitat recovery. Overall, wild ungulate distributions and densities increased between sample seasons 1 and 4 in both OK1 and OK2. Population results obtained for sample season 2 indicate that there had been a significant escalation in the population sizes of all four species. The creation of OK2 and the resulting decrease in the utilisation of the area by domestic livestock will have resulted in competitive release which would account for the surge in occupancy by wild ungulates in the conservancy in the year after the creation of OK2. This rapid colonisation is most likely attributed to several factors; migration from OK1, from surrounding areas which are still used as community grazing land and increased reproductive fitness. However, the high densities found in the conservancy in sample season 2, would not be sustainable long term, with the results from sample season 4 demonstrating that even though the populations sizes of grazers were lower, they were more evenly distributed between OK1 and OK2, indicating that ungulate populations in the conservancy were stabilising. Additionally, variations in migration timings could still influence results from data collected in October/November, where ungulates return to the Serengeti at a later date than expected.

Patterns of habitat use and selectivity in areas of high clustering highlighted the importance of habitat heterogeneity in small conservation areas. From the results obtained in Ol Kinyei Conservancy it was evident that the four study species utilised the resources available quite differently. Thompson's gazelles were restricted by body size and vulnerability to predation to occupy only large open space where short, palatable new grass growth is available. Larger bodied grazers such as wildebeest and topi, utilised the open grassland more than other habitats, but were more adaptable to utilising other habitats with more vegetative cover. Zebra did not consistently demonstrate selectivity towards any particular habitat, other than a slight preference for open grasslands. These findings correspond to the ecological theory of resource partitioning, whereby larger bodied species use a larger proportion of a landscape as a result a higher tolerance for low quality resources, and are more tolerant to the increased risk of predation. As a consequence they should be more evenly distributed across the landscape than smaller bodied species (Bell, 1971; Jarman, 1974; Gordon & Illius, 1996; Cromsigt *et al.,* 2009). Resource partitioning is heavily dependent on the availability of a variety of habitats in protected areas and spatial heterogeneity has been proposed as a vital component to consider in the allocation of small protected areas to ensure the persistence of complex species assemblages and providing resistance to temporal variations in resource availability (Fryxell *et al.,* 2005; Cromsigt *et al.,* 2009). Furthermore, several studies have proposed the 'heterogeneity paradigm' in savannah systems, whereby spatial heterogeneity of habitats is imperative to maintain high levels of species richness and abundance particularly in small reserves (Du Toit & Cumming, 1999; Owen-Smith, 2004; Cromsigt *et al.,* 2009).

The fact that all species had begun to utilise the areas so rapidly is not only positive for the wildlife itself but also for potential investors in future conservancies. Investors are heavily reliant on being able to provide optimum wildlife viewing experiences for eco-tourists. Where herbivore populations are quick to populate new conservancies, predators are expected to mirror that trend with the establishment of new territories. One year is a short time for re-wilding yet these results indicate when we situate new conservancy areas adjacent to existing wildlife "reservoirs", in combination with appropriate management, significant increases in both numbers and distribution can be achieved in a short period of time.

More long term monitoring of ungulate species in Ol Kinyei Conservancy would provide a detailed insight to population stability and fluctuations and provide a deeper understanding of changes that occur from climatic variations and the resultant yearly shifts in the timing of the wildebeest, zebra and Thompson's gazelle migrations

In conclusion small wildlife conservancies, such as Ol Kinyei Conservancy, in the GME are providing suitable refugia for grazing ungulates among the pastoral dispersal lands located around the MMNR. The rapid colonisation of OK2 by all grazing species, and the demonstrated diversity of habitat use between feeding guilds and body size, indicate that the spatial heterogeneity found in Ol Kinyei Conservancy is able to maintain a representative assemblage of savannah grazers in significant abundance. Longer term monitoring of these species in Ol Kinyei Conservancy would provide more detailed information on the stability of the populations in the conservancy and provide more detailed descriptions of temporal fluctuations in abundance and patterns of habitat use and selectivity.

Chapter 5

Mixed feeder and browser distribution and habitat use in response to conservancy expansion

5.1 Introduction

The expansion of Ol Kinyei conservancy provided the unique opportunity to identify and quantify the immediate and longer term changes that take place in an emerging protected area in the savannah environment. Additionally insights into the patterns of habitat use in mixed species assemblages are important to understand optimum vegetation composition required in small protected areas in the GME. Here, the distribution of two savannah mixed feeders (Grant's gazelles and impala), and one browser (giraffe) are investigated in Ol Kinyei Conservancy to determine the extent to which these species utilise the conservancy.

In savannahs mixed ungulate assemblages are composed of a variety of species that belong to diverse feeding guilds. A large proportion and the most abundant ungulates are grazers, however a selection of savannah ungulate species are classed as mixed feeders while others are browsers (Hofmann & Stewart, 1972; Owen-Smith & Novellie, 1982; McNaughton, 1984; Owen-Smith, 2004). Browsers feed exclusively on woody vegetation (shrubs or trees) and mixed feeders feed on both grass and woody vegetation depending on the season and habitat (Pérez-Barbería *et al.,* 2001). When forage is not readily available or has become more fibrous and less nutritious (Fritz & Duncan, 1994; Olff *et al*., 2002; Bhola *et al*., 2012) mixed feeders adjust their feeding behaviour and habitat selection to browse in shrublands or woodlands. As a result of the trade-off between the acquisition of optimum resources and maximising vigilance from predators, small bodied ungulates are expected to occupy areas of open grassland where forage is readily available and the lack of woody vegetation affords increased vigilance opportunities. However, browsing species are expected to occupy more vegetated areas in order to fulfil nutritional needs. In addition, Riginos & Grace (2008) found that giraffes utilised open habitats more than densely vegetated areas indicating that habitat preference for browsing herbivores in the savannah environment also appears to be driven by visibility rather than browse availability.

Aims

- Describe the spatial distribution patterns of mixed feeders and browsers and describe how numerical uplifts in population sizes (see chapter 3) manifested themselves in the spatial distribution of grazing ungulates in the newly extended conservancy.
- Investigate habitat use and selectivity of mixed feeders and browsers.

5.2 Methods

5.2.1 Study species

Habitat use and distribution of Grant's gazelles, impala and giraffes (Table 5.1) were investigated using distribution data obtained from game transects and land cover data from satellite imagery classification data (see chapter 6) over four sampling seasons.

To assess mixed feeder and browser distributions, habitat use and selectivity, the methods used were identical to those used for grazers in Chapter 4.

Table 5.1: Study species: Mixed feeders and browsers

Species	Common Name	IUCN status	Body Mass (Kg)	Dietary guild	Water dependence	Dispersion pattern
Giraffa camelopardalis	Maasai Giraffe	LC	450-1930	Browser	High	Resident
Gazella granti	Grant's gazelle	LC	38 - 81.5	Mixed feeder	High	Migratory*
Aepyceros melampus	Impala	LC	45 - 60	Mixed feeder	High	Resident

Abbreviations: LC – Least concern *Are also present in established resident population outside the migration season. Adapted from Estes (1991), & IUCN (2015)

5.3 Results

5.3.1 Grant’s gazelles

5.3.1.1 Clustering classification and coverage

In all four sample seasons there was a strong positive autocorrelation in the distribution of Grant’s gazelles (Global Moran’s Index: Table 5.2) indicating that they were not distributed in a random manner in relation to one another. The largest proportion of Ol Kinyei Conservancy was classified as having non-significant clustering throughout the course of the study, with values ranging from 46.65% of the conservancy in the first sample season to 54.12.38% in the final sample season, with the highest value in sample season 3 at 57.89% (Table 5.2).

Table 5.2: Cluster analysis of Grant’s gazelle distribution over four sampling seasons. Classification and significance at individual points (Local Moran’s Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy s a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	6.87	4.47	5.61		16.95	0.986779	Strong positive
	L-L	10.48	12.98	12.94		36.40		
	NS				46.65	46.65		
2	H-H	5.97	6.45	7.57		19.99	0.985456	Strong positive
	L-L	10.47	9.56	7.73		27.76		
	NS				52.25	52.25		
3	H-H	4.95	3.88	4.53		13.37	0.985507	Strong positive
	L-L	10.71	9.15	8.88		28.74		
	NS				57.89	57.89		
4	H-H	4.54	4.14	5.02		13.69	0.9892	Strong positive
	L-L	10.08	9.09	13.02		32.19		
	NS				54.12	54.12		
Bivariate Global Moran's		Comparison 1: 2012 vs 2013					0.219458	Weak positive
		Comparison 2: 2012 vs 2014					0.477691	Positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

In all four sample seasons hotspots (H-H) represented the smaller portion of the conservancy (≈16%). Between sample season 1 and 4 there was a decrease in the area of hotspots from 16.95% to 13.69% in response to the increase in non-significant clustering (Table 5.2). The area covered by coldspots decreased over the course of the study from 36.40% to 32.19% (Table 5.2).

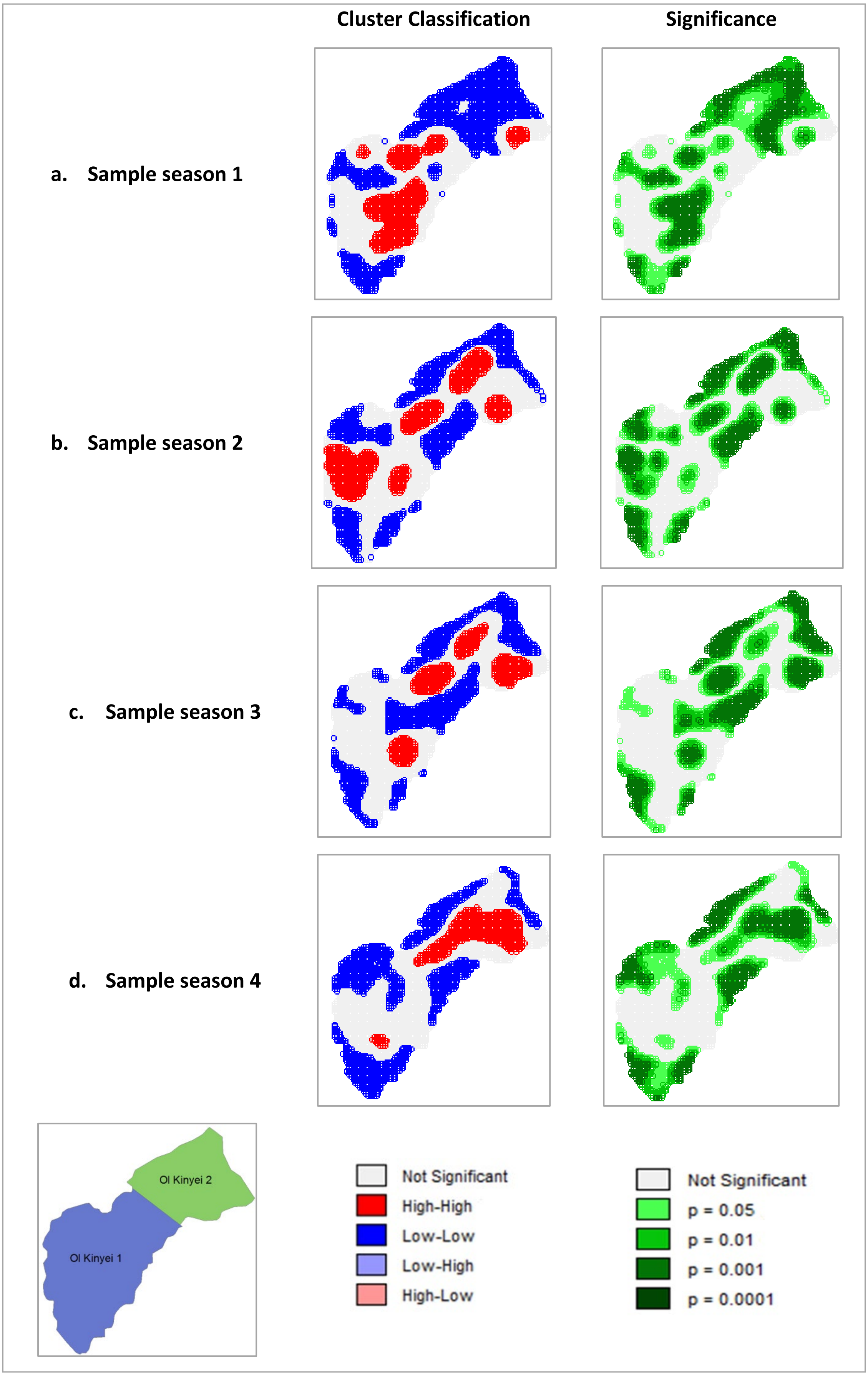
5.3.1.2 Clustering spatial distribution

In sample season 1, Grant’s gazelle hotspots were concentrated in OK1 in both open habitats and partially closed habitats, while the majority of OK2 was classified as a coldspot in season 1, apart from one area along the eastern boundary (Figure 5.1.a).

In sample season 2, overall the area covered by coldspots reduced significantly in OK2, with three significant hotspots and a large proportion of the remaining area classified as non-significant (Figure 5.1.b). In OK1 a hotspot from the previous year remained on OH1 in addition to a second on OH2. The hotspot on OH1 had reduced considerably in size compared to the previous season, with a large proportion replaced by non-significant clustering (Figure 5.1.b).

In sample season 3, only one significant hotspot remained in OK1 in OH1, while in OK2 three were located in the main areas of open grassland (OH 4, 5 and 6) and the shrublands that surround these areas (Figure 5.1.c). A large proportion OK1 was classified as non-significant, indicating that Grant’s gazelles were distributed evenly in that part of the conservancy (Figure 5.1.c).

In sample season 4, Grant’s gazelles were mostly clustered in OK2 over one large area (Figure 5.1.d). In OK1 one small hotspot remained, with a large proportion of OK1 showing non-significant clustering, with a marked increase in coldspot distribution (Figure 5.1.d).



a. Sample season 1

b. Sample season 2

c. Sample season 3

d. Sample season 4

Figure 5.1: Cluster distributions of Grant's gazelles in sample seasons in Ol Kinyei conservancy.

5.3.1.3 Clustering comparisons between sample seasons

There was a weak correlation in the distribution of clusters in sample seasons 1 and 2 (I=0.219458; Table 5.2). The main differences in distribution and size of clusters were located in OK2, where significant increases in clustering occurred (Figure 5.2.a). However, there were also several areas, mainly in partially closed habitats, where clustering decreased (Figure 5.2.a).

There was a positive correlation in cluster patterns in sample seasons 2 and 4, which indicated that the difference between sample seasons 2 and 4 was not as pronounced as between sample season 1 and 2 (Table 5.2). Between sample seasons 2 and 4 there were few areas where there was an increase in clustering in OK1, consequently a large proportion of OK1 remained classified as non-significant (Figure 5.2.b).

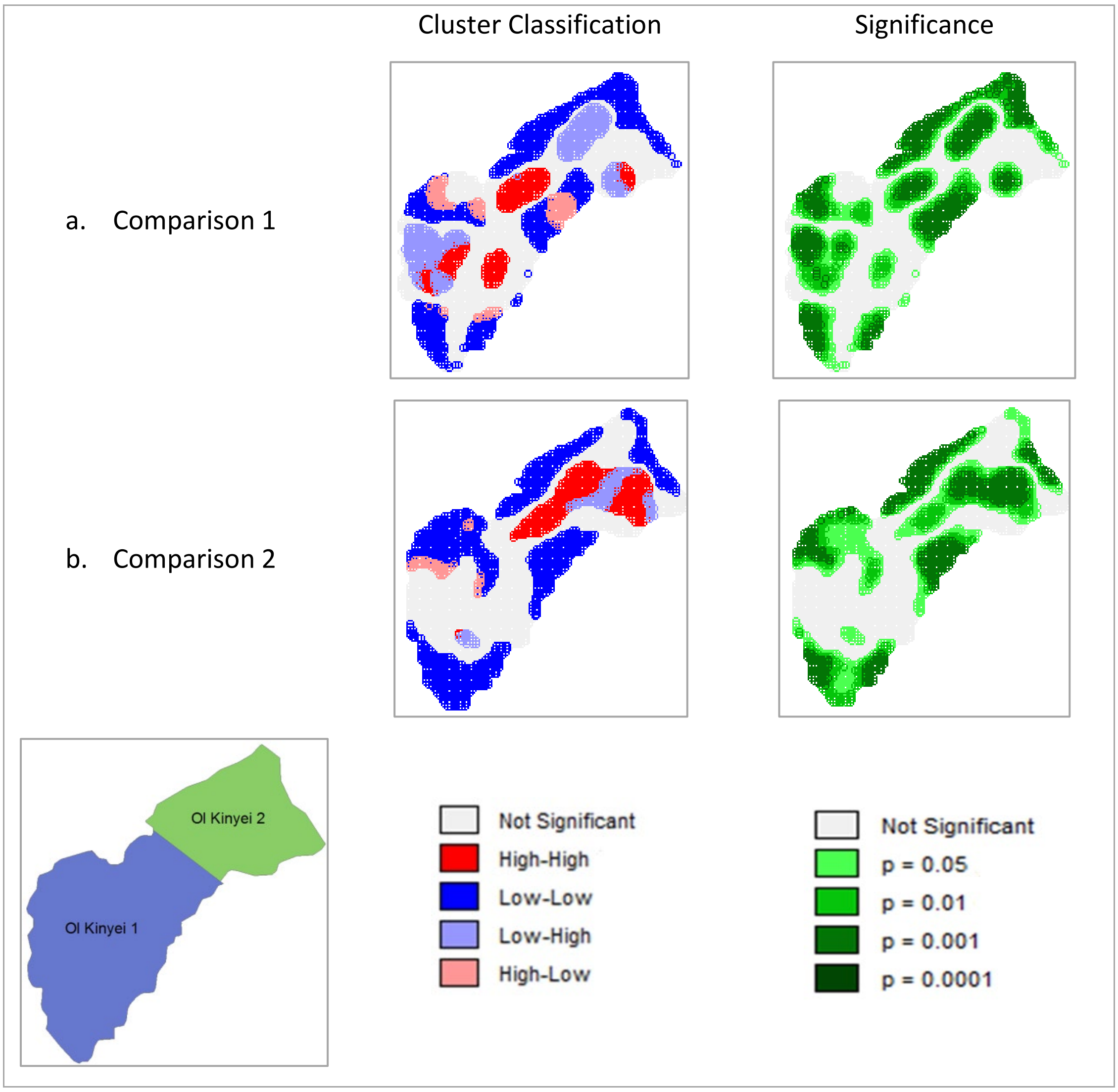
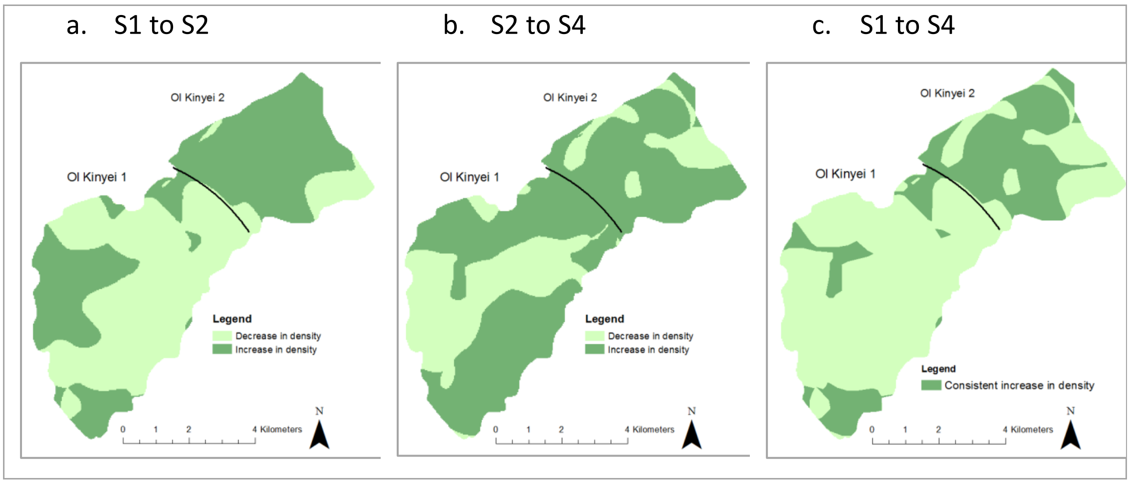


Figure 5.2: Comparison of Grant's gazelles cluster distribution between sample seasons 1 and 2 (Comparison 1); and sample seasons 2 and 4 (Comparison 2).

5.3.1.4 Spatial distribution of density increases

Between sample seasons 1 and 2, Grant's gazelle densities increased in most of OK2. In OK1 they mainly increased along the western boundary and in the southern tip (Figure 5.3.a). Grant's gazelle densities continued to increase in most of OK1 and 2 between sample seasons 2 and 4 with the exception of a corridor running over OH2 and in the shrubland located between OH1 and OH4 in OK1 (Figure 5.3.b). Overall, between sample seasons 1 and 4 there was an increase in density over most of OK2, while conversely there was no increase in density over most of OK1 (Figure 5.3.c).



a. S1 to S2

b. S2 to S4

c. S1 to S4

Figure 5.3: Areas of density increase of Grant's gazelle between years a) season 1 & season 2 b) season 2 & season 4 c) incremental increase from Season 1 to season 4. Where: Dark green = increase in density; light green = decrease.

5.3.1.5 Habitat use

To determine whether Grant' gazelles were using certain habitats more than others, ANOVA and post hoc Tukey tests were conducted on density and habitat classification data in R (R Development Core Team 2008). There was no clear pattern of habitat use throughout the three sample seasons with results indicating that Grant's gazelles were utilising certain habitats disproportionately to others in three of the four sampling seasons: 1 ($F_{1,5}$ = 29.99, p <2^{-16}), 2 ($F_{1,5}$ = 4.078, p =0.00117) and 3 ($F_{1,5}$ = 13.04, p = 3.44^{-12}) (Appendix 9.4). Post hoc pairwise analysis revealed that Grant's gazelles utilised open grasslands in significantly higher densities than all other habitats in sample seasons 1 and 3 (Appendix 9.3). In sample season 2, Grant's gazelles utilised open grasslands more than croton shrublands and Acacia woodlands, whilst in sample season 4 habitats were not used differentially (Appendix 9.5).

5.3.1.6 Habitat selectivity in hotspots

Habitat selectivity was analysed by determining proportional use of each habitat within the hotspots identified in the distribution analysis. The habitat selectivity displayed by Grant's gazelles varied considerably between sample seasons (Table 5.3). In sample season 1, there was selectivity towards open grassland, avoidance of acacia woodlands and riparian forest while shrublands and hill slope were neither avoided nor used preferentially. In sample season 3, Grant's gazelles demonstrated selectivity towards open grassland, with only riparian forest avoided. In sample seasons 2 and 4 Grant's gazelles did not display any preference or avoidance for any habitat (Figure 5.3).

Table 5.3: Habitat selection of Grant's gazelles within areas of high use (hotspots) calculated with Jacob's correction J of Ivlev's selectivity index I in each sampling season

Sampling season	Sample season 1	Sample season 2	Sample season 3	Sample season 4
Open Grassland	0.695	0.328	0.535	0.001
Shrubland (Acacia)	-0.396	-0.156	-0.378	-0.049
Shrubland (Croton)	-0.475	-0.162	-0.208	-0.034
Acacia woodland	-0.735	-0.26	-0.41	0.031
Riparian Forest	-0.818	-0.134	-0.787	0.356
Hill slope	-0.401	-0.189	-0.383	-0.024

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

5.3.1.7 Summary – Grant's gazelles

At the inception of the project, Grant's gazelles were well established throughout OK1 but not in OK2. By sample season 2, Grant's gazelles had established themselves over much of OK2, with three significant aggregation areas identified. Any coldspots that remained were located around the boundary of the conservancy. OK1 retained several areas of significant aggregations, although the actual locations of these areas moved to the western edge of the conservancy. In sample season 3, most of the significant clustering occurred in OK2, while the majority of OK1 was classified as non-significant. By sample season 4, clustering in OK1 had reduced significantly and coldspots had increased, conversely in OK2 a hotspot had developed that covered most of the area.

Between sample seasons 1 and 2, Grant's gazelle densities increased in OK2, while in OK1 the increase in density was more limited. Between sample seasons 2 and 4, the increase in density was more evenly spread between OK1 and OK2. There was a consistent increase in density from sample seasons 1 to 4 in the majority of OK2, while in OK1 the main increase occurred between sample seasons 2 and 4.

Overall, results reveal that Grant's gazelles were utilising open grasslands significantly more than they were all other habitats available in Ol Kinyei conservancy.

5.3.2 Impala

5.3.2.1 Clustering classification and coverage

High levels of clustering of impala were found for all four sample seasons (Table 5.4). In all four sample seasons a large proportion of Ol Kinyei Conservancy was classified as having non-significant clustering, with values increasing consistently from 51.86% in sample season 1 to 58.14% in sample season 4 (Table 5.4). The amount of area classified as hotspots varied between all sample seasons, with the highest in sample season 3 at 17.65%, decreasing to 10.31% in sample season 4. Coldspots averaged around 30% in sample seasons 1, 3 and 4 but were highest in sample season 2 at 36.10% (Table 5.4).

Table 5.4: Cluster analysis of impala distribution over four sampling seasons. Classification and significance at individual points (Local Moran's Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	5.90	5.58	5.29		16.76	0.989264	Strong positive
	L-L	10.76	11.31	9.31		31.38		
	NS				51.86	51.86		
2	H-H	3.54	4.34	3.96		11.83	0.987244	Strong positive
	L-L	8.76	10.73	16.61		36.10		
	NS				52.07	52.07		
3	H-H	6.00	5.83	5.81		17.65	0.986811	Strong positive
	L-L	10.47	8.67	9.86		29.00		
	NS				53.36	53.36		
4	H-H	4.10	2.08	4.14		10.31	0.989294	Strong positive
	L-L	10.19	10.10	11.26		31.55		
	NS				58.14	58.14		
Bivariate Global Moran's	Comparison 1: 2012 vs 2013						0.130528	Weak Positive
	Comparison 2: 2012 vs 2014						0.564857	Positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

5.3.2.2 Spatial distribution of clustering

In sample season 1 impala hotspots were all located in OK1, particularly in partially closed habitats, while in OK2 large areas in the north were classified as coldspots with the remainder classified non-significant (Figure 5.4.a).

By sample season 2, one hotspot remained in OK1 and two large hotspots had developed in OK2 located on both open areas and partially closed areas (Figure 5.4.b). With the development of hotspots in OK2, the size and extent of coldspots decreased considerably. Areas that had been classified as non-significant in sample season 1 had also reduced in size. In sample season 3, there were several hotspots in OK1, mainly located on the partially closed habitats, with a large proportion of the remainder of OK1 classified as non-significant (Figure 5.4.c). In OK2, a large hotspot spanned the centre, with coldspots distributed around the western and northern boundary (Figure 5.4.c).

In sample season 4, a large hotspot in OK2 remained, but a coldspot had developed which bisected the conservancy along the boundary between OK1 and OK2. In OK1 only two small areas were classified as hotspots resulting in a large proportion of OK1 being classified as non-significant (Figure 5.4.d).

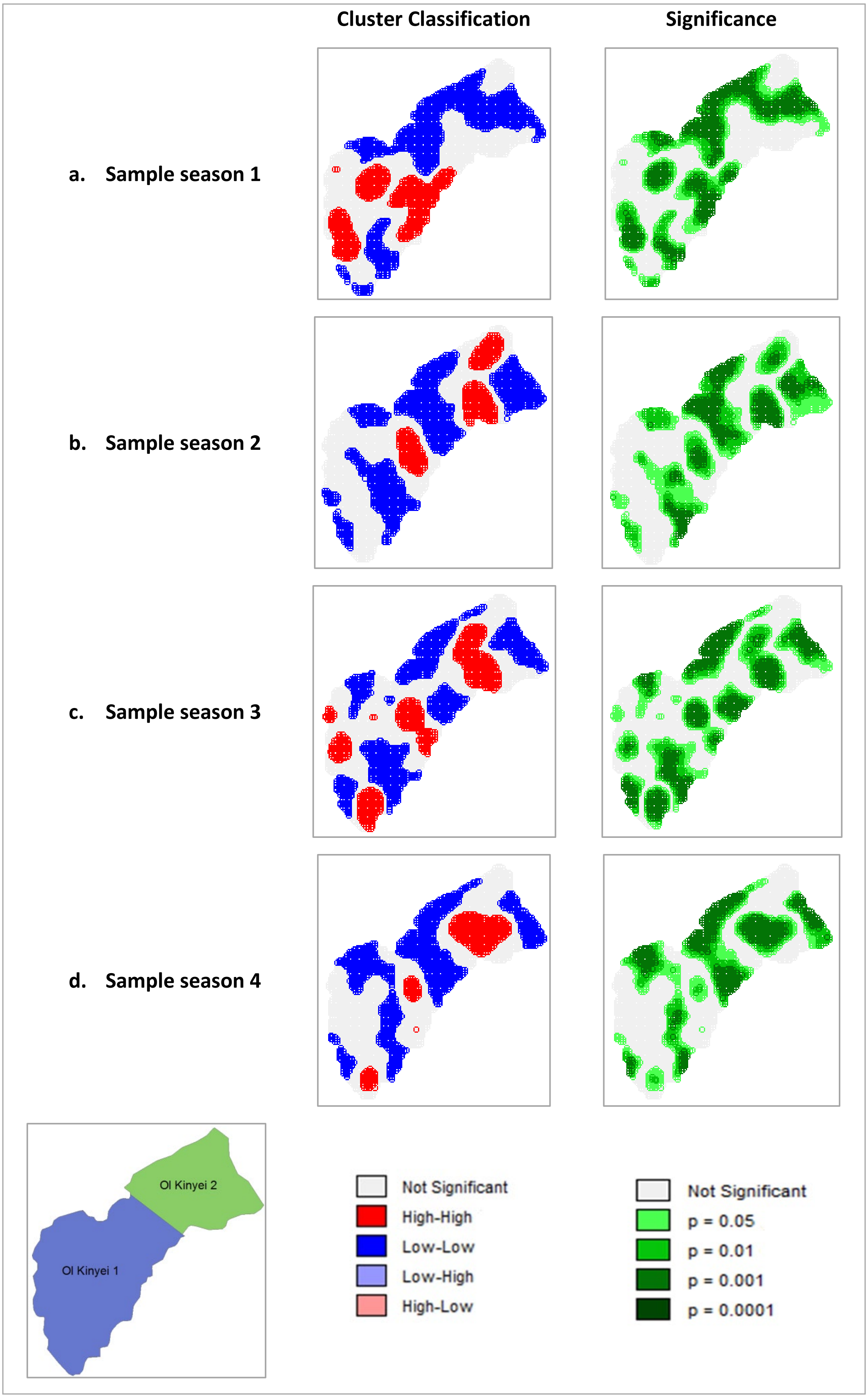


Figure 5.4: Cluster distributions of impala in sample seasons in Ol Kinyei conservancy

5.3.2.3 Clustering comparisons between sample seasons

There was a slight correlation between the distribution of clustering in sample seasons 1 and 2, with more significant correlation between sample seasons 2 and 4 (Table 5.4).

In season 2, two new significant clusters were present in OK2, while in OK1 there were several areas which had lower levels of clustering than in sample season 1 (Figure 5.5.a). In sample season 4, an existing hotspot in OK2 had expanded, while in OK1 a small area of high clustering had developed in the southern tip of the conservancy (Figure 5.5.b).

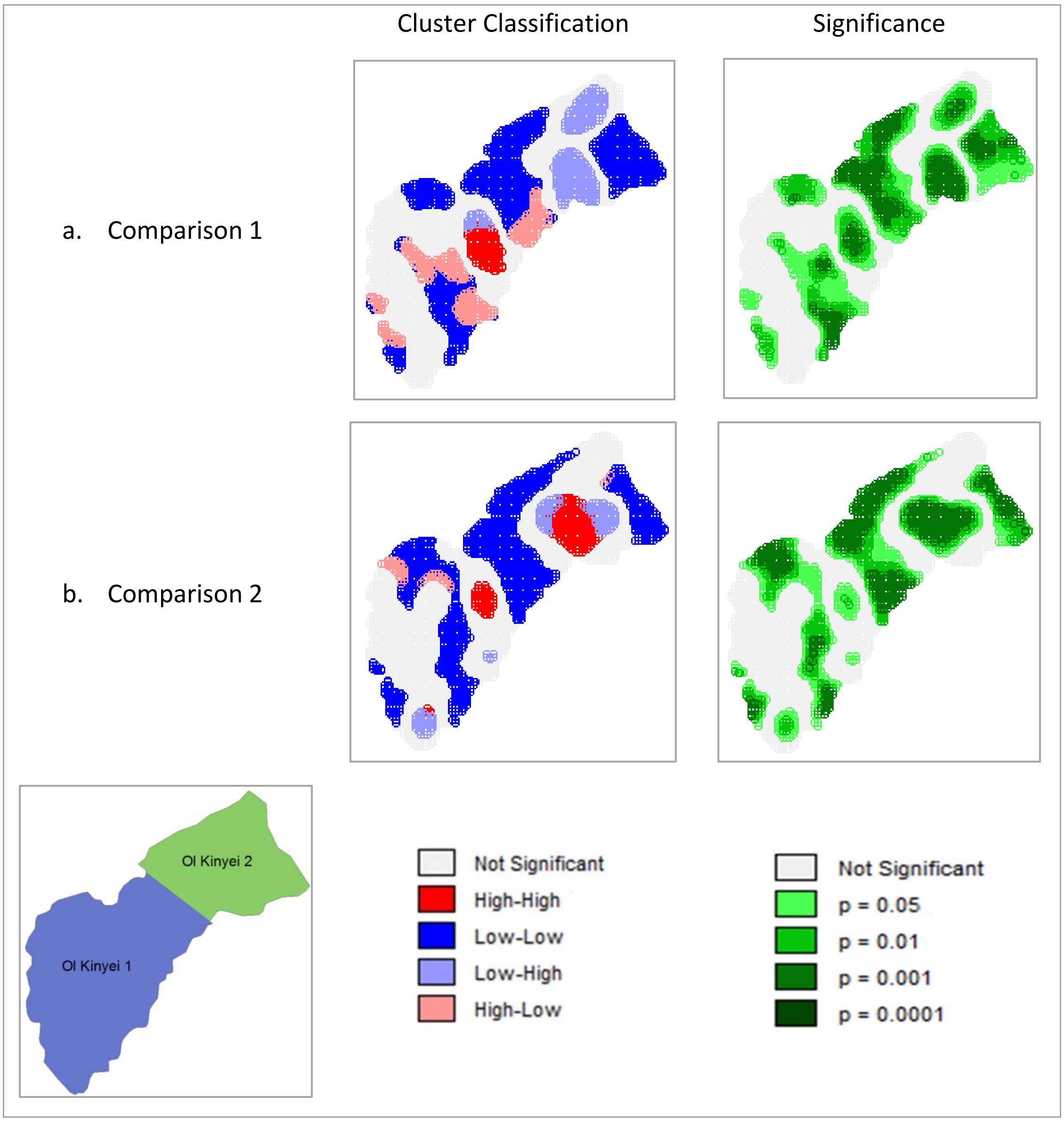


Figure 5.5: Comparison of impala cluster distribution; between sample seasons 1 and 2 (Comparison 1); and sample seasons 2 and 4 (Comparison 2).

5.3.2.4 Spatial distribution of density increases

Between sample seasons 1 and 2, impala density increased in most of OK2, but in OK1 increases were restricted to the western edge and southern tip (Figure 5.6.a). Between sample seasons 2 and 4 there were increases in density in a larger proportion of OK1, while in OK2 increases were more dispersed (Figure 5.6.b). Overall, between sample seasons 1 and 4 there was a more widespread increase in density in OK2 than in OK1 (Figure 5.6.c).

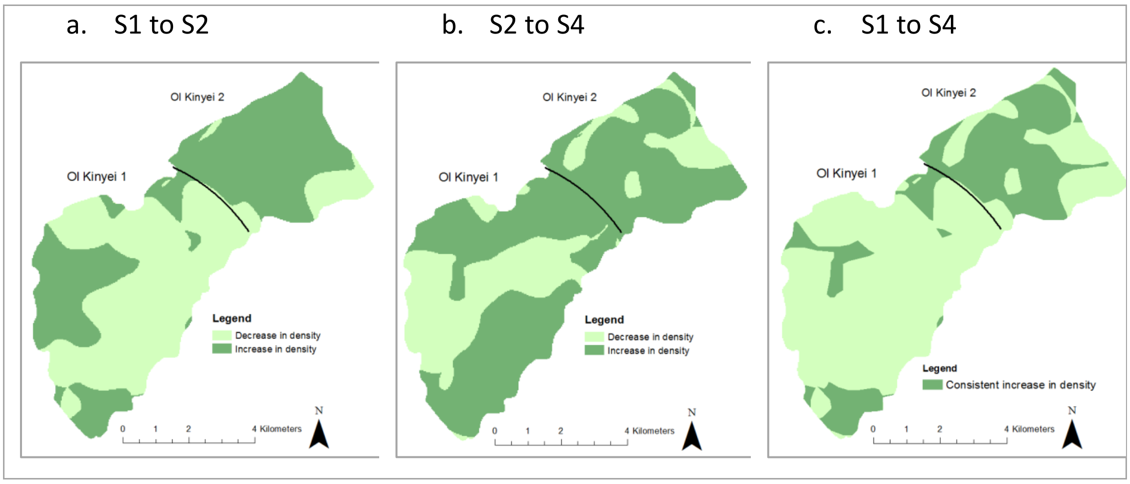

a. S1 to S2 b. S2 to S4 c. S1 to S4

Figure 5.6: Areas of density increase of impala between years a) season 1 & season 2 b) season 2 & season 4 c) incremental increase from Season 1 to season 4. Where: Dark green = increase in density; light green = decrease.

5.3.2.5 Habitat use

Impala did not use the habitats available in Ol Kinyei conservancy differentially in sample seasons 1 and 3 (Appendix 9.4) indicating that habitats were utilised proportional to their availability within the conservancy. Habitat use was significantly different in sample season 2 ($F_{1,5}$ =5.817, p = 2.79^{-05}) and sample season 4 ($F_{1,5}$ =3.325, p =0.00561). Pairwise analysis revealed that impala were utilising areas of acacia woodland more than other habitats in sample season 2, while in sample season 4 they utilised the acacia shrublands more than other habitats (Appendix 9.6).

5.3.2.6 Habitat selectivity in hotspots

Results from analyses conducted on habitat selectivity within areas of high use, or clusters, revealed that impala did not consistently avoid any particular habitat over the four years (Table 5.5).

Table 5.5: Habitat selection of impala within areas of high use (hotspots) calculated with Jacob's correction J of Ivlev's selectivity index I in each sampling season

Sampling season	Sample season 1	Sample season 2	Sample season 3	Sample season 4
Open Grassland	0.168	-0.355	-0.106	-0.171
Shrubland (Acacia)	0.002	0.168	0.106	0.004
Shrubland (Croton)	-0.061	0.081	0.048	0.056
Acacia woodland	-0.221	0.128	0.01	0.109
Riparian Forest	-0.115	0.586	0.318	0.5
Hill slope	-0.056	0.026	-0.159	0.055

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

There was no selectivity demonstrated towards open grassland, shrubland, woodland or hill slope, but in sample seasons 2 and 4 impala were selecting riparian forest over all other habitats.

5.3.2.7 Summary - Impala

Results for impala revealed significant levels of clustering in all four field seasons. In sample season 1 the significant clustering was limited to OK1, while OK2 largely consisted of non-significant clustering and coldspots. Although the distribution and size of clusters did not vary significantly between sample seasons 2 and 4, there was however a significant difference between sample seasons 1 and 2. In sample season 2, impala had begun to utilise OK2, this was evident from the development of two large hotspots in areas which had in previous season's been classified as coldspots or as non-significant. In OK1, large areas were classified as coldspots and as non-significant, only one area (in hill slope) was identified as a hotspot. In sample season 3, some significant hotspots were located in OK1 and the amount of non-significant clustering had increased. In OK2 a similar hotspot to the one in sample season 2 was identified and the non-significant classification became more widespread. In sample season 4 the majority of significant clustering was in OK2, while in OK1 the largest proportion of the area was classified as non-significant.

Between sample season 1 and season 2, there was an increase in impala density over most of OK2, while in OK1 increases were more fragmented. Between sample seasons 2 and 4, the increases in density were more widespread throughout the whole conservancy. Overall between sample seasons 1 and 4 there was a more uniform increase in density in OK2 than in OK1.

The habitat use of impala in sample seasons 1 and 3 demonstrated that they occupied all habitats proportional to their availability but there was differential habitat use in sample seasons 2 and 4. In sample season 2 acacia woodland was used significantly more than other habitats and in sample season 4, acacia shrublands were used more than other habitats. There was no selectivity demonstrated towards open grassland, shrublands, woodlands or hill slope, however in sample seasons 2 and 4 impala were selecting riparian forest over all other habitats.

5.3.3 Giraffe

5.3.3.1 Clustering classification and coverage

Whilst significant levels of clustering of giraffe were found in all four sample seasons, in agreement with results from all other species, the largest proportion of the conservancy was classified as non-significant averaging 53% (Table 5.6). The area covered by hotspots increased between seasons 1 and 4 by approximately 6%, while the amount of coldspots was highest in sample season 2 at 37.51% and reduced to 32.04% by sample season 4. (Table 5.6)

Table 5.6: Cluster analysis of giraffe distribution over four sampling seasons. Classification and significance at individual points (Local Moran's Index) as a percentage of each class in the conservancy and, strength of clustering across the conservancy as a whole (Global Moran Index).

Season	Local Moran's Index (p-values) (% of conservancy)						Global Moran Index	Auto-correlation relationship
	Classification	0.001	0.01	0.05	NS	Total		
1	H-H	2.83	2.27	3.97		9.07	0.986385	Strong positive
	L-L	9.45	11.15	10.02		30.62		
	NS				60.31	60.31		
2	H-H	3.38	3.76	6.74		13.88	0.98622	Strong positive
	L-L	0.06	26.13	11.32		37.51		
	NS				48.60	48.60		
3	H-H	4.67	4.39	6.16		15.22	0.988567	Strong positive
	L-L	8.28	9.55	12.83		30.66		
	NS				54.12	54.12		
4	H-H	4.73	5.55	4.73		15.01	0.983514	Strong positive
	L-L	8.96	11.75	11.33		32.04		
	NS				52.95	52.95		
Bivariate Global Moran's	Comparison 1: 2012 vs 2013						0.023477	Weak Positive
	Comparison 2: 2012 vs 2014						0.328248	Weak Positive

Where: H-H = Clustering of high density values; L-L = clustering of low density values; NS = non-significant clustering.

5.3.3.2 Spatial distribution of clustering

In sample season 1 there were no high density clusters in OK2, with very few giraffes sighted in the emerging conservancy. As a consequence the majority of OK2 was classified as a coldspot, leaving only a small portion of non-significant clustering (Figure 5.7.a). In OK1, there were several areas that were classified as hotspots in the south of the conservancy in areas of partially closed habitats, but a coldspot was also identified that ran along the entire eastern section of OK1 (Figure 5.7.a).

In sample season 2, there was one hotspot located across the boundary of OK1 and OK2 on OH4 and OH5 and another in the north-western tip of OK2 (Figure 5.7.b). In OK1 several hotspots were identified around the centre, but where in the previous sample season there had been a hotspot in the south of the conservancy, a large coldspot had developed (Figure 5.7.b).

In sample season 3, a significant proportion of OK2 was classified as a hotspot and the amount of non-significant clustering of giraffe had also increased (Figure 5.7.c). In OK1, the most significant hotspot was located in the southern tip of the conservancy with another found in the centre of OK1 (Figure 5.7.c).

In sample season 4, the majority of the significant hotspots were located in the centre of OK2 (Figure 5.7.d). In OK1, one hotspot remained in the southern tip of the conservancy. Overall the area was dominated by coldspots that covered large sections of the centre of OK1, with intermittent areas of non-significant clustering dispersed amongst them (Figure 5.7.d).

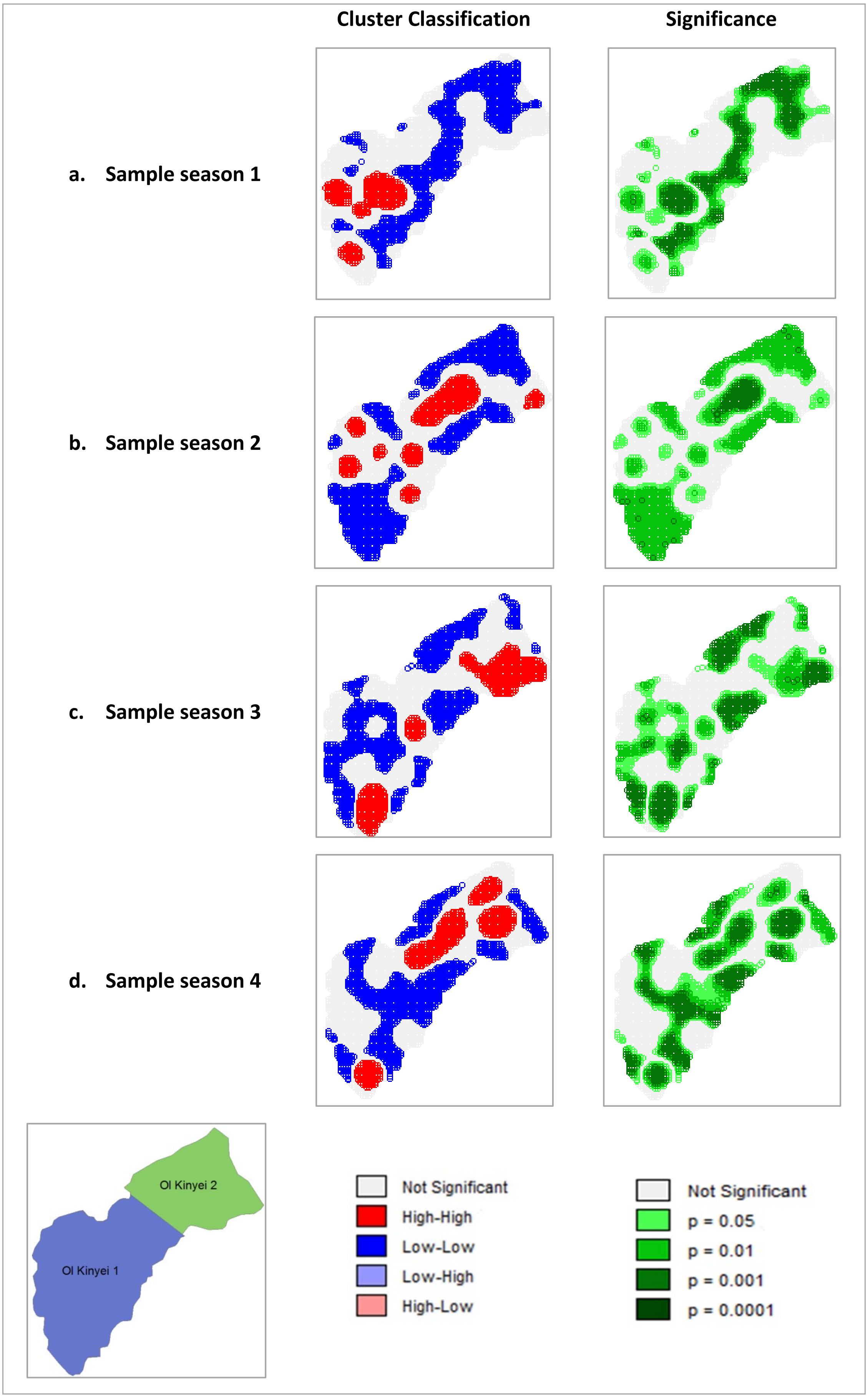


Figure 5.7: Cluster distributions of giraffe in four sample seasons in Ol Kinyei conservancy

5.3.3.3 Clustering comparisons between sample seasons

There was no correlation between clustering patterns in sample seasons 1 and 2 for giraffe, indicating that the pattern of clusters for giraffe was significantly different between the two sample seasons (Table 5.6). The comparison between sample seasons 2 and 4 yielded a slightly higher statistic I=0.328248 suggesting the patterns were more similar.

In sample season 2, there was a large increase in the number of hotspots in OK2, whilst conversely in OK1 there were considerably fewer hotspots (Figure 5.8.a). In sample season 4, two additional hotspots had developed in OK2, creating a large expanse of high density clustering in the centre of the conservancy (Figure 5.8.b). In many parts of OK1 the amount of high density clustering decreased significantly from sample season 2 to sample season 4.

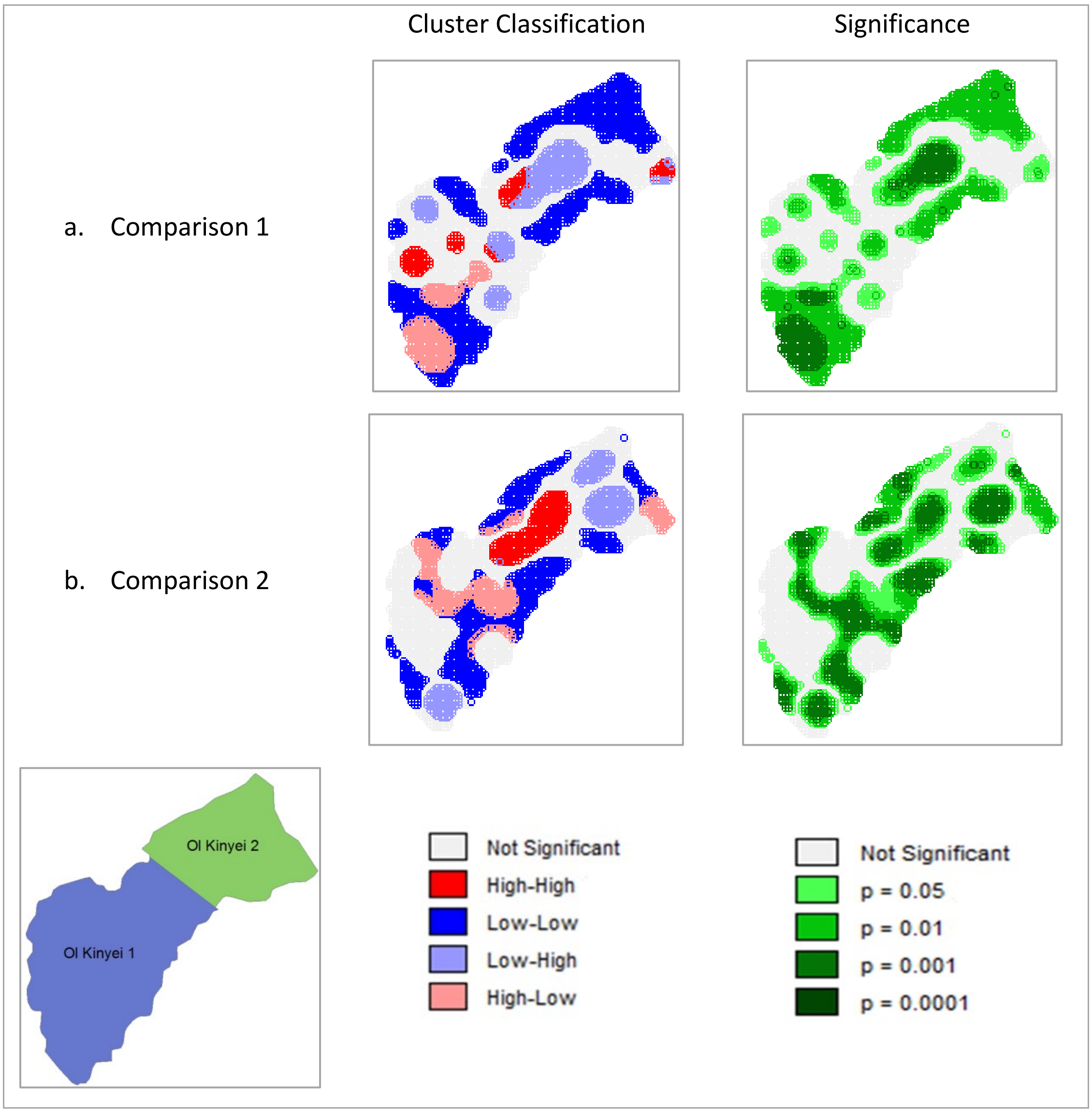


Figure 5.8: Comparison of giraffe cluster distribution between sample seasons 1 and 2 (Comparison 1); and sample seasons 2 and 4 (Comparison 2).

5.3.3.4 Spatial distribution of density increases

Between sample season 1 and 2, giraffe densities increased in most of OK2, while in OK1 increases in density were mainly located along the boundaries (Figure 5.9.a). Between sample seasons 2 and 4, there were increases in density in most of OK2 and over a large proportion of OK1 (Figure 5.9.b). Overall between sample seasons 1 and 4, the most widespread increases in density took place in OK2 (Figure 5.9.c).

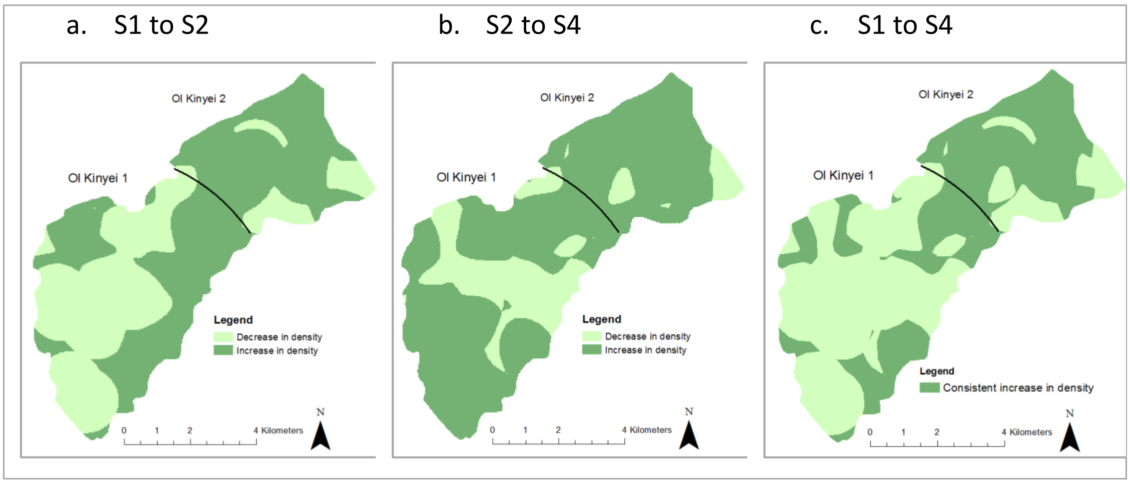


Figure 5.9: Areas of density increase of giraffe between years a) season 1 & season 2 b) season 2 & season 4 c) incremental increase from Season 1 to season 4. Where: Dark green = increase in density; light green = decrease.

5.3.3.5 Habitat use

In sample seasons 1, 3 and 4 there was no significant difference in habitats used by giraffe (Appendix 9.4) indicating that the habitats available across the whole conservancy were being used proportional to their availability. In season 2, there was a significant difference ($F_{1,5}$ =5.817, p =2.79^{-05}) and post hoc tests revealed that giraffe were utilising shrublands, woodlands and hill slope significantly more than open grassland (Appendix 9.7).

5.3.3.6 Habitat selectivity in hotspots

Habitat selectivity analysis conducted in the areas identified as significant aggregations, or hotspots, indicated that giraffe did not use any habitat preferentially in all four field seasons but in sample seasons 1 and 2 giraffe demonstrated avoidance of riparian forest (Table 5.7).

Table 5.7: Habitat selection of giraffes within areas of high use (hotspots) calculated with Jacob's correction J of Ivlev's selectivity index I in each sampling season

Sampling season	Sample season 1	Sample season 2	Sample season 3	Sample season 4
Open Grassland	0.2	0.116	0.149	0.049
Shrubland (Acacia)	0.101	-0.114	-0.107	0.026
Shrubland (Croton)	-0.19	-0.09	0.077	-0.038
Acacia woodland	-0.337	-0.367	-0.055	-0.074
Riparian Forest	-0.667	-0.75	-0.159	-0.187
Hill slope	-0.015	-0.108	-0.184	-0.091

J < -0.5 = avoidance	-0.5 < J > 0.5 = no selectivity	J > 0.5 = selectivity

5.3.3.6 Summary – Giraffe

In sample season 1, significant clustering of giraffes occurred in OK1, while in OK2 no hotspots were identified, indicating that giraffes were not utilising the areas in significant numbers at the time. In sample season 2, the distribution of hotspots had expanded into OK2, with a large area of significant clustering being identified on the boundary of OK1 and OK2. However, in the conservancy as a whole the amount of hotspots and non-significant clustering decreased and coldspots increased in coverage. In sample season 3, the distribution of giraffe was largely concentrated in OK2. Giraffe distributions in sample season 4 were concentrated in OK2 in a combination of hotspots and non-significant clustering. In OK1, the distribution of giraffe was thinly spread over most of the area with the exception of one hotspot in the southern tip of the conservancy.

The distribution of giraffes in the Ol Kinyei conservancy differed significantly between all four field seasons. Initially significant clustering was concentrated on OK1, however by sample season 2 the clustering was more significant on OK2 than in OK1, a pattern that persisted to sample season 4.

The density of giraffes increased in most of OK2 between sample seasons 1 and 2, similarly there were significant increases in OK1. Between season 2 and season 4, giraffe densities increased in most of OK2 and over vast sections of OK1. Overall between sample seasons 1 and 4, the area where most of the incremental increase in giraffe density occurred was OK2.

Giraffe did not display significant levels of differential use of any particular habitat. In sample season 2, there was increased use of more densely vegetated areas (with the exception of riparian forest) over open grasslands. Within areas identified as hotspots, giraffe did not show preference towards any habitat.

5.4 Discussion

All of the study species demonstrated high levels of clustering. This indicates that they are using the conservancy selectively, occupying certain areas in higher densities than others. Mixed feeders such as Grant's gazelles and impala either graze or browse depending on resource availability and were consequently expected to be widely distributed and highly mobile across all habitats, using areas where the highest quality food is available at that time.

5.4.1 Grant's gazelles

Grant's gazelles were evenly distributed in most of OK1 with the exception of areas where they were aggregating in more significant numbers, which were predominantly areas of open grassland and the partially closed shrublands that surround them. Grant's gazelles were using areas of open grassland more than the densely vegetated areas indicating that forage was readily available. When forage is available mixed feeders are expected to utilise open areas more frequently to avoid predation from ambush predators that frequent the more vegetated areas for cover (van Orsdol, 1984). In sample season 1, the clustering was only high in OK2 in one area of open grassland, with the majority of OK2 classified as a cold-spot indicating that Grant's gazelles were not utilising most of OK2 when it became part of Ol Kinyei Conservancy. This is likely to be the result of human disturbance and low quality graze and browse as a result of intensive livestock activity (Riginos & Young, 2007). Mixed feeders in the GME are in direct competition livestock, but particularly with goats which are also mixed feeders, and have been shown to reduce biodiversity and displace wildlife through competitive exclusion (Norton, 1995; Hester *et al.,* 2006). By sample season 2, Grant's gazelles were more widely distributed across the whole conservancy, as their utilisation of OK2 had increased considerably. Conversely, in OK1 the amount of significant hotspots had decreased. This reduction could be the result of migration from OK1 to OK2 by the gazelles. There was little difference in the distribution of clustering of the gazelles between sample seasons 3 and 4 suggesting that the population in the conservancy was stabilising. Over the three years of study Grant's gazelles increased in distribution over most of OK2, these results align themselves to results obtained from population estimates, which indicated a significant increase in Grant's gazelle numbers from sample season 2 to 3. Population estimates for sample season 4 indicated that the number of Grant's gazelles was slightly higher (N= 621) than they had been in sample season 2 (N = 545) but lower than in sample season 3 (N=850) (Chapter 3). In sample seasons 2 and 3, open grassland was still used more intensively than other habitats, particularly woodlands and croton shrublands. Croton shrublands are an important habitat for lions that often use these areas to rest in the daytime (verb. Comm: N. Mogensen). Avoidance of these areas is therefore not surprising for a medium bodied ungulate which would be at high risk of predation in these areas (Houston *et al.,* 1993; Lima, 1998; Ritchie & Olff, 1999; Wilmhurst *et al.,* 1999; Asrenault & Owen-Smith, 2002; Cromsigt & Olff, 2006; Bhola *et al.,* 2012). By sample season 4, Grant's gazelles did not disproportionately utilise any habitat, which indicates that resources were available in all classified habitats yet the increased use of more vegetated areas also suggests that forage may have been less readily available and had been replaced by browse in their feeding behaviour at that time.

5.4.2 Impala

Impala are a highly adaptive species that are less susceptible to human disturbance than other ungulates species (Estes, 1991), however in sample season 1 their distribution and density in OK2 was limited. This was probably a result of competition with goats for food rather than the presence of humans and their habitation. In OK1, impala were aggregated in a large proportion of the area and evenly distributed in most other areas. By sample season 2 they had expanded their distribution in most of OK2 and by sample seasons 3 and 4 they remained distributed over the majority of the conservancy and formed significant aggregations in both OK1 and OK2. The increases in clustering and density (Chapter 3) indicate that the number of impala increased from sample season 1 to 4 and that they were distributing themselves throughout the whole conservancy in response to creation of OK2. There were several areas where the amount of clustering decreased significantly between sample seasons 2 and 4, probably a result of avoidance of closed areas where predator (leopard and lion) occurrence increased. Impala did not demonstrate any differential use of habitat, although in sample seasons 2 and 4, they occupied acacia shrublands more than open grasslands. As mixed feeders, impala are adaptable to feeding in a variety of habitats. Interestingly, within areas of significant aggregation, impala were found to be selecting riparian forest where vegetative cover is high but browse is readily available.

5.4.3 Giraffe

Giraffe are strict browsers highly adapted to feeding from trees; consequently giraffe distributions would be expected to be concentrated in habitats with higher woody vegetation cover. They are however a highly mobile species which are also frequently found on open grasslands and shrublands (Riginos & Grace, 2008). In sample season 1 giraffe distribution was relatively wide spread across OK1, forming significant aggregations in closed habitats. In OK2 there were no significant aggregations and large parts of the area were identified as coldspots. Competition with livestock is not likely to be the cause of this avoidance; human disturbance is the most probable explanation for this pattern. In sample season 2, their distribution had expanded into OK2 to form two hotspots. In OK1 the distribution of significant aggregations were more uniformly spread over the area. In season 4, OK2 contained large and more numerous hotspots than OK1 as woodland cover in OK2 is higher than in OK1, resulting in more widely available browse for giraffe. With the addition of OK2 to the conservancy the amount of optimum habitat for giraffes greatly increased, which has resulted in significant increases in their density (Chapter 3 – Figure 3.4) and expansion of the range within which they are found in significant clusters.

5.5 Conclusions

Over the three years of study there were considerable fluctuations in the spatial distribution of mixed feeders and browsers in Ol Kinyei conservancy. However, similarly to the results obtained for the grazers (Chapter 4), the mixed feeders and browser were found in significant numbers in both OK1 and OK2 by sample season 2 and persisted in both areas to sample season 4 (Figure 3.3). This indicates that impala, Grant's gazelles and giraffe were beginning to establish populations in the newly created part of the conservancy. The cluster analysis supported these findings, whereby the three species were found in significant clusters in OK1 in sample seasons 2, 3 and 4. The establishment of these three species in OK2 and their persistence in OK1, supports the results from the previous chapter that indicate that the habitat composition and heterogeneity in Ol Kinyei Conservancy is proving acceptable as a refugia to the diverse ungulate dietary guilds represented by the most abundant species in the GME. In conclusion, these results further support the concept of wildlife conservancies in the GME, as they demonstrate that wild ungulates will readily utilise the areas made available to them as a result of conservancy creation.

Chapter 6

Habitat composition, distribution and species composition in Ol Kinyei Conservancy

6.1 Introduction

6.1.1 Savannah

Spatial patterns in vegetation type and structure are key to understanding animal distribution and behaviour (Reed *et al.,* 2009) and have been demonstrated to be key to understanding ecosystem processes in savannah environments such as the Serengeti-Mara expanse (Sankaran *et al.,* 2004). Savannahs are geographically widespread, covering an eighth of land surface and over half of the African continent (Werner, 1991 cited in: Scholes & Archer, 1997). Globally savannah habitats are found in temperate, boreal and arid environments. Many of these are types of grassland with varying degrees of tree cover and tree species composition, which have been converted to agricultural farming. Savannahs are classified as a grassland ecosystem interspersed with trees sufficiently widely spaced to maintain an open canopy (Menaut, 1983). A large proportion of the world's savannah grasslands are found in the dry to arid zones, with 68% found in developing countries (Boval & Dixon, 2012). People inhabiting the arid to semi-arid grasslands are predominantly nomadic to semi-nomadic pastoralists who depend heavily on extended pastures to support not only their livelihood but also their cultural values (De Fries & Rosenzweig, 2010; Ayantunde *et al.,* 2011). In areas where climatic conditions and soil quality are not suitable for food crop production, grasslands remain as grazing lands, not only for livestock, but also vast numbers of wild herbivores.

Climate and topography influence the distribution, density and cover of woody versus herbaceous vegetation across landscapes (Sankaran *et al.,* 2004; Reed *et al.,* 2009). Savannahs are described as being ecosystems that consist of a continuous herbaceous understorey across which discrete patches of woody vegetation occur (Talbot & Kesel, 1975; Cole, 1986). Additionally savannahs can be distinguished from grassland, desert and woodland biomes by biotic factors such as climatic variations that result in an alternation of wet and dry periods (Scholes & Archer, 1997). Abiotic and biotic variables have been suggested as being the drivers of savannah structure and species composition, principally mean and annual variability of rainfall, elevation, soil type and texture, intensity of herbivory and net productivity (Belsky, 1990; Scholes & Archer, 1997; Reed *et al.,* 2009; Wessel *et al.,* 2011). Whilst historic and present human activity has undoubtedly influenced savannah structure, identifying trends that anthropogenic activities may have triggered in savannah ecosystems, as opposed to trends resulting from abiotic and biotic factors, are very difficult to differentiate (Scholes & Archer, 1997). Savannahs are a mosaic of continuous herbaceous layer and discrete patches of woody vegetation, this delivers substantial levels of habitat heterogeneity that has been suggested as being partly responsible for the high diversity and abundance of savannah ungulates found in areas such as the Maasai Mara where the savannah ecosystem has largely remained intact (Cromisgt *et al.,* 2009).

6.1.2 Habitat classification

Conventionally, savannahs have been defined by their most dominant lifeform to differentiate the mosaic of vegetative structures. These are often termed as open grasslands, open to closed shrublands, woodlands and thickets (Sharam *et al.,* 2006). Grunblatt *et al.,* (1989) produced a detailed hierarchical approach to vegetation classifications in Kenya, which provided habitat descriptors that could be applied to the myriad of habitats present in sub-Saharan East Africa and that could be applied to different data sources ranging from ground surveys to satellite imagery classification. The system developed allows for differing levels of precision to be employed in order to describe ecosystem characteristics (Reed *et al.,* 2009). In total the hierarchical approach consists of four levels; firstly the primary lifeform (or lack of) is intended to provide an indication of the general structure of the area in addition to information in terms of canopy cover (termed density modifier) (Table 6.1). The second level of classification applies to the secondary lifeform, provided it accounts for more than 20% of the canopy cover and details its' contribution to the total canopy cover. The third level refers to the height of the primary lifeform and the fourth level is a descriptor of specific species that dominate the community in question (Grunblatt *et al.,* 1989). Additionally, another level of detail can be added to describe the environmental condition of the site (Table 6.1).

Table 6.1: Summary of hierarchical vegetation classification scheme as proposed by Grunblatt *et al.,* 1989.

Classification Level	Variable	Terms	Density Modifier	Canopy cover
1	Primary Lifeform	Forest (F) Woodland (W) Shrub (S) Grass (G) Bare (B)		
			Closed	80-100%
			Dense	50-79%
			Open	20-49%
			Sparse	2-19%
2	Secondary Lifeform	Treed Shrubbed Grassed		
			Closed	80-100%
			Dense	50-79%
			Open	20-49%
			Sparse	2-19%
3	Primary lifeform height	Tall	F & W > 10m; S > 6m; G > 1m	
		Low	F & W 6m <x> 10m; S 1m <x>6m; G < 1m	
		Dwarf	F & W <6m; S < 1m; G N/A	
4	Species	Dominant species		

Environmental Conditions: M = Multi-storey; R = Riverine, W = Wet

In the GME the vegetation is a mosaic of habitats ranging from dense woodland/forest through to open grassland. Woodlands are described as more open areas of tree cover, with trees 8-20 meters tall and canopy cover of approximately 40%. The available light reaching the ground layer allows for the establishment of a sparse shrub layer and a ground layer dominated by grasses.

Forests are defined as vegetation of continuous tree cover at least 10m tall with over-lapping canopies (Menaut, 1983). ‘Forest-savannah’ mosaics are highly dynamic ecosystems and support high levels of species richness due to their complex structural dynamics.

Grass and shrub savannahs tend to be situated on the border between semi-arid and woodland savannahs and are drier in climate as a consequence, especially to the north (Shorrocks & Bates, 2015). Tree and shrub savannah describes a continuous herbaceous layer interspersed with trees, the dominant vegetation species in any one of these areas often gives rise to a specific vegetation classification (e,g. Table 6.1)

Eastern Africa is renowned as a centre of genetic diversity of tropical grasses and the centre of greatest diversity of cultivated grass species (Boonman, 1993). The Poaceae form the main vegetation layer, interspersed with a few annuals and perennials, and occasional trees and shrubs, mostly Acacia spp. (Bussman *et al.,* 2006). *Themeda triandra* is one of the most widespread grass species in sub-Saharan Africa. The species is very variable and shows wide adaptation to growth in both the highland regions and the lowland savannahs. In the Mara *T. triandra* constitutes approximately 50% of the grass cover in light to moderate grazed sites, with a severe reduction in presence in areas which have heavy livestock grazing/corral presence. Other grassland species composition throughout the Mara is variable, linked to differing environmental parameters.

Aims

- Describe changes to habitat heterogeneity and vegetation productivity from 5 years prior to conservancy creation to the present day.

- Investigate changes to the herbaceous layer in term of species composition, cover and grass height and compare these between the established wildlife conservancy and the newly designated area (Chapter 6).

6.2 Methods

The composition of different habitats, or land cover was determined using remote sensing data, with changes to the herbaceous layer over three years analysed using data collected in the field.

6.2.1 Study site

Vegetation composition and structure was analysed for Ol Kinyei Conservancy (see Chapter 2.2.1 to 2.2.3 for detailed description). A base map of Ol Kinyei Conservancy was created from ground truthed data, where the main vegetation stands were identified, delimited in the field and incorporated into a GIS (Figure 6.1). These data also provided the training samples required for supervised classification of remotely sensed data.

6.2.2 Land cover

6.2.2.1 Data acquisition

To accurately assess changes to land cover in Ol Kinyei Conservancy, satellite images were used to classify habitats and calculate Normalised Difference Vegetation index (NDVI).

Satellite images dating back to 1999 are freely available from USGS NASA from Landsat 7 at a 30 metre resolution (http://earthexplorer.usgs.gov/). The images selected were taken in October or November in 2014, to represent the final sampling season, another image was selected for 2005, the year OK1 was created and a final image selected for five years prior to the creation of OK1, to provide an indication of the habitat composition when the area was still being utilised for livestock grazing (Table 6.2).

Table 6.2: Remotely sensed images selected from Landsat archive (USGS)

Year	Acquisition Date	Season	Satellite
2000	26th October	5 years pre-season creation OK	Landsat 7 SLC ON
2005	7th October	Creation of OK1	Landsat 7 SLC OFF
2014	1st November	Season 4	Landsat 7 SLC OFF

The images were selected on the basis of minimal cloud cover and being taken at a dates that correspond as closely as possible to the field seasons completed. The images that correspond the GME are from the Landsat path = 169 and row = 061. These images are all georeferenced using the Universal Transverse Mercator (UTM) map projection and the World Geodetic System (WGS) 84 datum.

6.2.2.2 Data preparation

In order to reduce processing time the Landsat images acquired were initially cropped in ArcGIS® to only represent the GME. The images acquired after 2003 when the SLC sensor on the satellite failed required some manipulation to remove the stripes of no data that resulted from the malfunction (see Chapter 2.5.2). The ‘Gapfill function’ was run three times on each of the seven bands of each image in order to replace the no data stripes with interpolated data in ArcGIS® (see Chapter 2.5.3). Finally, band composites of the images were created and cropped to represent the extent of Ol Kinyei Conservancy.

6.2.2.4 NDVI

NDVI was calculated for each satellite image in a GIS, two spectral bands are required; band 4 which is the Near-Infrared (NIR) band and band 3 which is the red band (RED) and calculated thus:

Equation 1

(NIR-RED)/ (NIR+RED)

In order to calculate NDVI the pixel values in the two band layer were converted from integers to float numbers, the ‘float’ function was incorporated into the NDVI equation in the raster calculator in ArcGIS:

Equation 2

float(Band 4-Band 3)/float(Band 4+Band 3)

To enable the visual comparison of the NDVI output of the three images analysed, the symbology of each map was stretched to match the minimum value and maximum values calculated between the three maps. In order to identify areas where NDVI values differed significantly between years spatial autocorrelation was calculated using Anselin’s Local Moran’s Index bivariate analysis (Anselin, 1995) to determine where significant increases and decreases in NDVI occurred (See Chapter 2.3 for detailed description).

6.2.3 Herbaceous Layer

6.2.3.1 Data collection

Herbaceous cover is the most commonly used parameter to determine and describe habitat quality for wild herbivores in the landscape they occupy. Pin frame sampling, or point sampling has long been regarded as the most reliable and non-destructive method of assessing herbaceous frequency (Hughes, 1962; Jonasson, 1983; Bonham, 1989).

Herbaceous layer surveys were conducted in 30 sampling plots that were established using random stratified sampling to ensure that the main habitats identified were sampled. Densely vegetated areas such as riparian forest and areas that were not accessible by vehicle were not included in the sampling process. Ten sampling plots were established in both OK1, OK2 and in areas surrounding the conservancy which were still being utilised as communal grazing by the Maasai (Figure 6.1). The sampling plots outside the conservancy were established to provide more understanding on the difference in herbaceous species composition and grass height between conservancy areas and land heavily grazed by livestock.

The sampling plots were quadrats that measured 50 x 50 m, the random point assignation conducted in ArcGIS provided the co-ordinate of the south-west corner of the quadrat. Once located in the field, the quadrat was marked out by travelling 50m directly north from the initial point to locate the north western corner, from there the north-western corner was located by travelling 50m east and finally the south-eastern corner was located by travelling directly south for the last point. At the each corner of a quadrat the herbaceous vegetation was sampled using a pin-frame. The herbaceous data was collected with a pin frame at each corner of the quadrat, the pin frame was composed of ten pins placed 10cm apart always placed so that it faced directly north from the corner points. In this way 40 data points were recorded per quadrat.

The parameters recorded using the pin frame method were:

- Species (Table 6.3)
- Total height (cm)
- Basal height (cm)
- Touch per pin for each species identified on each of the ten pins
- Evidence of grazing/fire/cutting

All data were recorded and stored with the mobile device using a specifically designed data recording form using Wildknowledge®.

Table 6.3: Description of most abundant species recorded in Ol Kinyei Conservancy 2012 to 2014

Species	Habitat	Palatability	Description
Aristida kenyensis	Dry or eroded soils in bushland	High when young, reduces with maturity	Annual 15-90 cm
Brachiaria brizantha	Grassland and open woodland	High, good leaf/stem ratio	Perennial Up to 120 cm
Chrystopogon aucheri	Dry, rocky slopes, alkaline soils	High, good leaf/stem ratio	Perennial Up to 60 cm
Cynodon Dactylon	Grassland	High when short, reduces with growth	Perennial Up to 90 cm
Eragrotis chloromelas	Grassland	Low	Perennial 40-80 cm
Eragrotis cilianensis	Widespread on poor soils/ alluvial soils	Low	Annual Up to 90 cm
Heteropogon contortus	Open forest, woodland and grassland.	High when short, reduces with growth	Perennial Up to 75 cm
Hyparrhenia filipendula	Grassland and open woodland	High when short, reduces with growth	Perennial Up to 150 cm
Hyparrhenia hirta	Grassland, rocky slopes and open woodland	Low	Perennial Up to 90 cm
Panicum maximum	Grassland and open woodland	High	Perennial 60-200 cm
Pennisetum pupureum	Damp grassland and forest edges	High when short, reduces with growth	Perennial 180-360 cm
Setaria spacelata	Grassland, woodland on clay soils	High when young, reduces with growth	Perennial 45-180 cm
Sporobolus festivus	Grassland and open woodland	High	Perennial 10 - 60 cm
Sporobolus spicatus	Grassland and open woodland	High	Perennial 10-70 cm
Themeda triandra	Grassland, woodland on clay soils	High when young, reduces with growth	Perennial 45-180 cm

Adapted from: FAO Grassland Species profiles, http://www.fao.org/ag/agp/AGPC/doc/Gbase/Default.htm, 02/10/15

6.2.3.2 Data analysis

As a result of conservancy creation and the removal of intensive livestock grazing, the herbaceous layer can be expected to change with less pressure from intensive grazing herbaceous cover is expected to increase, resulting in a reduction of bare ground. Therefore both the percentage of herbaceous cover and bare ground was recorded to create a baseline against which long term monitoring can be established. Additionally the herbaceous layer was studied in more detail and the percentage cover of individual species was investigated across the four sampling seasons, to determine whether vegetation composition changes occurred and to identify changes to the palatability of the grassland in

Ol Kinyei Conservancy over time. As a consequence, total grass height and basal height were compared between sampling seasons for the conservancy as a whole employing both ANOVA and Tukey post hoc tests (R Script: 2). In addition, differences in total grass height and basal height were investigated between sampling blocks, between OK1, OK2 and between the conservancy and community grazing land. Differences in total and basal heights were also tested between species in the four sampling seasons.

6.3 Results

6.3.1 Land cover classifications

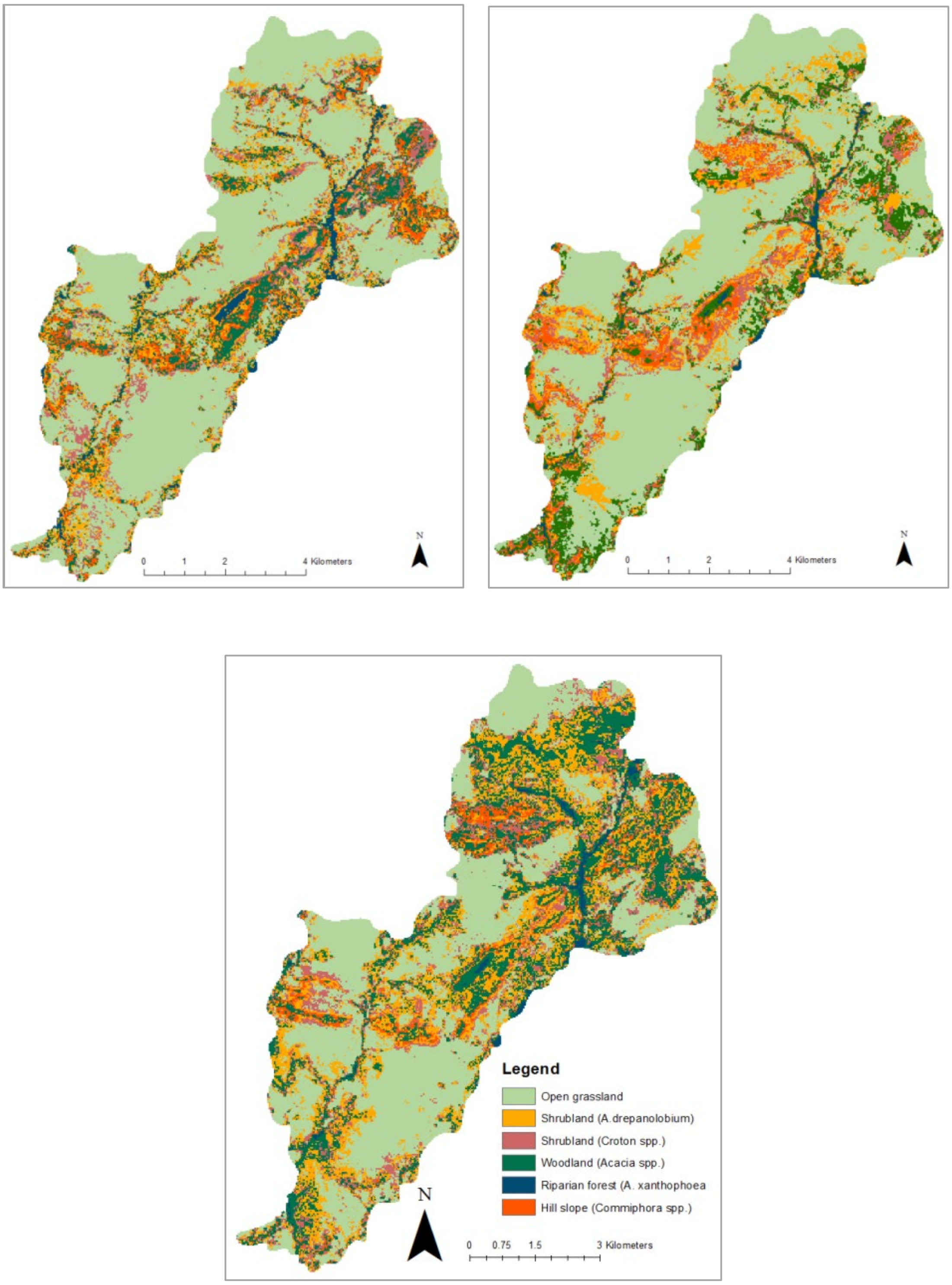
In order to assess changes that occurred to land cover in the study site as a consequence of the establishment of the conservancy, satellite imagery was used to conduct supervised classifications of the area using ground-truthed training samples (Figure 6.1).

The most prevalent habitat classified was open grassland which had the highest coverage in 2005 at 37.87km^2 with a decrease in value to 25.73km^2 in 2014 (Table 6.4). Shrublands and woodlands increased in area between 2000 and 2014, while hill slope decreased in coverage from 4.15km^2 to 2.88km^2 in 2014 (Table 6.4).

Table 6.4: Total area (km^2) of each classified habitat

Habitat	2000	2005	2014
Open grassland	37.39	37.87	25.73
Shrubland (Acacia)	8.00	7.63	13.80
Shrubland (Croton)	5.39	5.05	6.45
Woodland (Acacia)	6.79	7.86	13.68
Riparian forest	1.58	0.82	0.76
Hill slope (Commiphora)	4.15	4.06	2.88

The land cover classifications obtained for the three images varied considerably, indicating that significant changes have taken place to the composition of habitats in the study site since 2000 (Figure 6.1.a) five years prior to the establishment of OK1 in 2005 (Figure 6.1.b). The most noticeable difference was that increase in shrubland habitats in the central and northern areas in the conservancy. By 2014, the last field season, habitat heterogeneity had increased considerably.



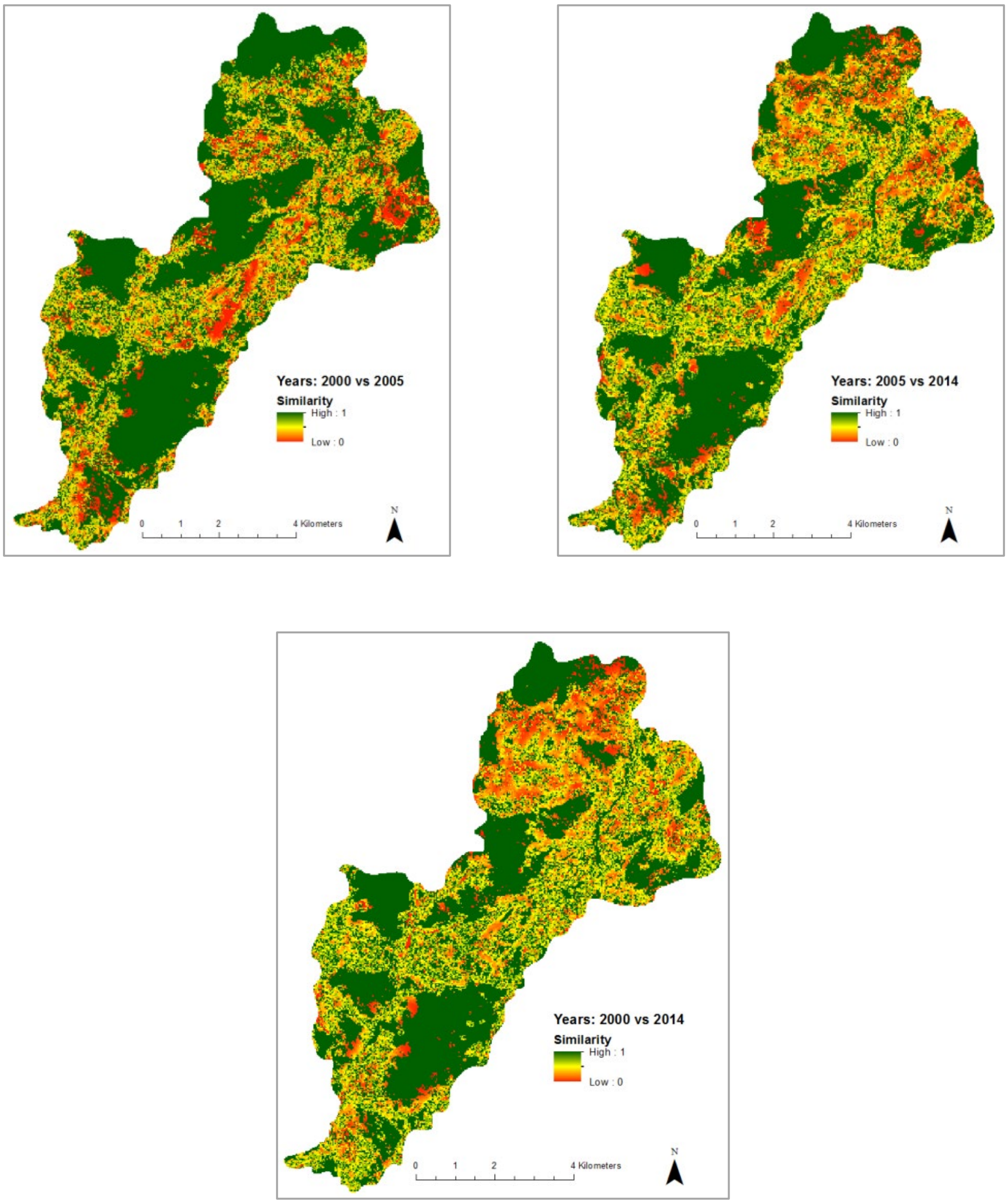
a. 2000

b. 2005

c. 2014

Figure 6.1: Habitat classifications in Ol Kinyei Conservancy of the final year of study (2014), the year of the creation of OK1 (2005) and 5 year prior (2000). Images used all acquired in October/November.

Statistical comparison was conducted to identify and quantify the locations and extent of differences in habitat composition between the three images and revealed a strong match in classification in 68.6% of the conservancy between 2000 and 2014 (Fuzzy kappa statistic = 0.409), between 2000 and the establishment of OK1 the similarity was higher at 75.3% (Fuzzy kappa statistic = 0.472).



a. Comparison 1

b. Comparison 2

c. Comparison 3

Figure 6.2: Comparison of habitat classifications with fuzzy kappa similarity index; Comparison 1 = 2000 to 2005; comparison 2 = 2005 to 2014; comparisons 3 = 2000 to 2014.

Areas where similarity in land cover class was high corresponded strongly with areas classified as open grassland (Figure 6.2 & 6.1), whereas in areas classified as shrublands, woodlands and hill slope there was a pronounced degree of variation between the years.

Further analyses supported these observations in that the percentage similarity in areas identified as open grassland was considerably higher than in other habitats with high values ranging between 75.2% in comparison 1, 59% in comparison 2 and 63% for comparison 3 (Figure 6.3). Similarly, there was a high degree of similarity in areas classified as riparian forest with the highest similarity value from comparison 3 at 70% similarity (Figure 6.3). The areas classified as shrublands woodlands and hill slope have considerably lower similarity values, particularly croton shrublands (Figure 6.3).

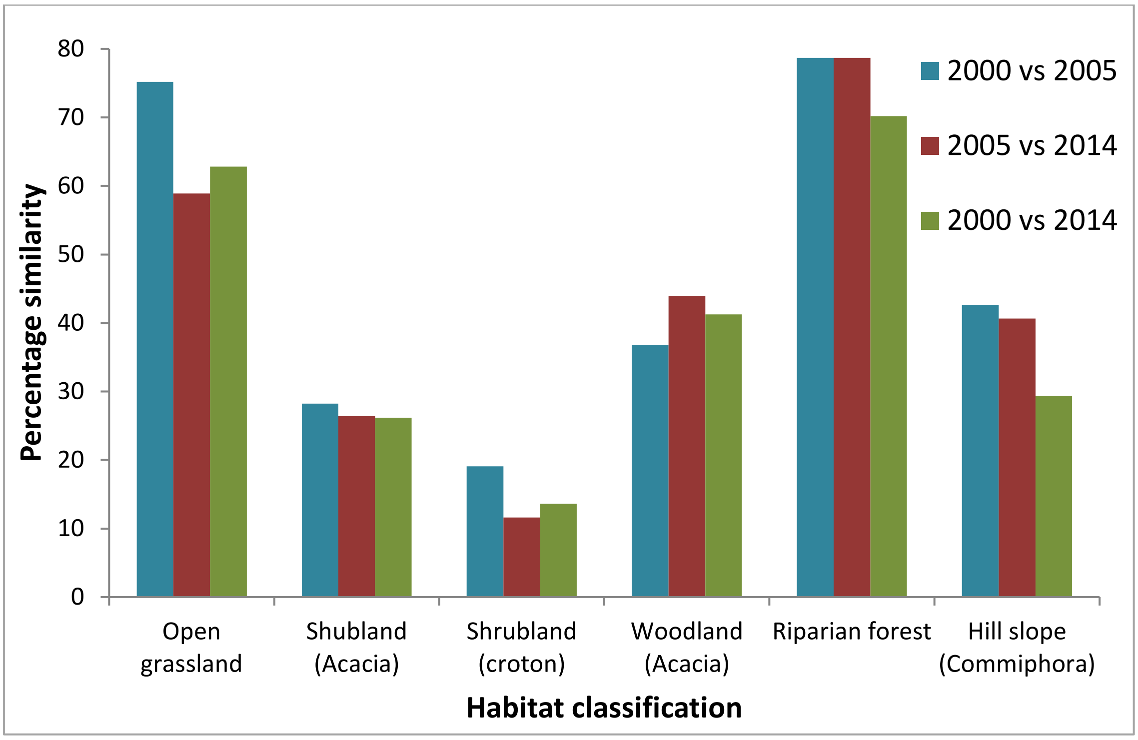


Figure 6.3: Percentage similarity of habitat classifications between 2000 and 2005 (comparison 1); 2005 and 2014 (comparison 2), and 2000 and 2014 (comparison 3).

6.3.2 Productivity - NDVI

To determine whether productivity in terms of photosynthetic activity changed over time in Ol Kinyei Conservancy the NDVI (which ranges from -1 to 1) was calculated from the satellite images used for habitat classification (Appendix 10).

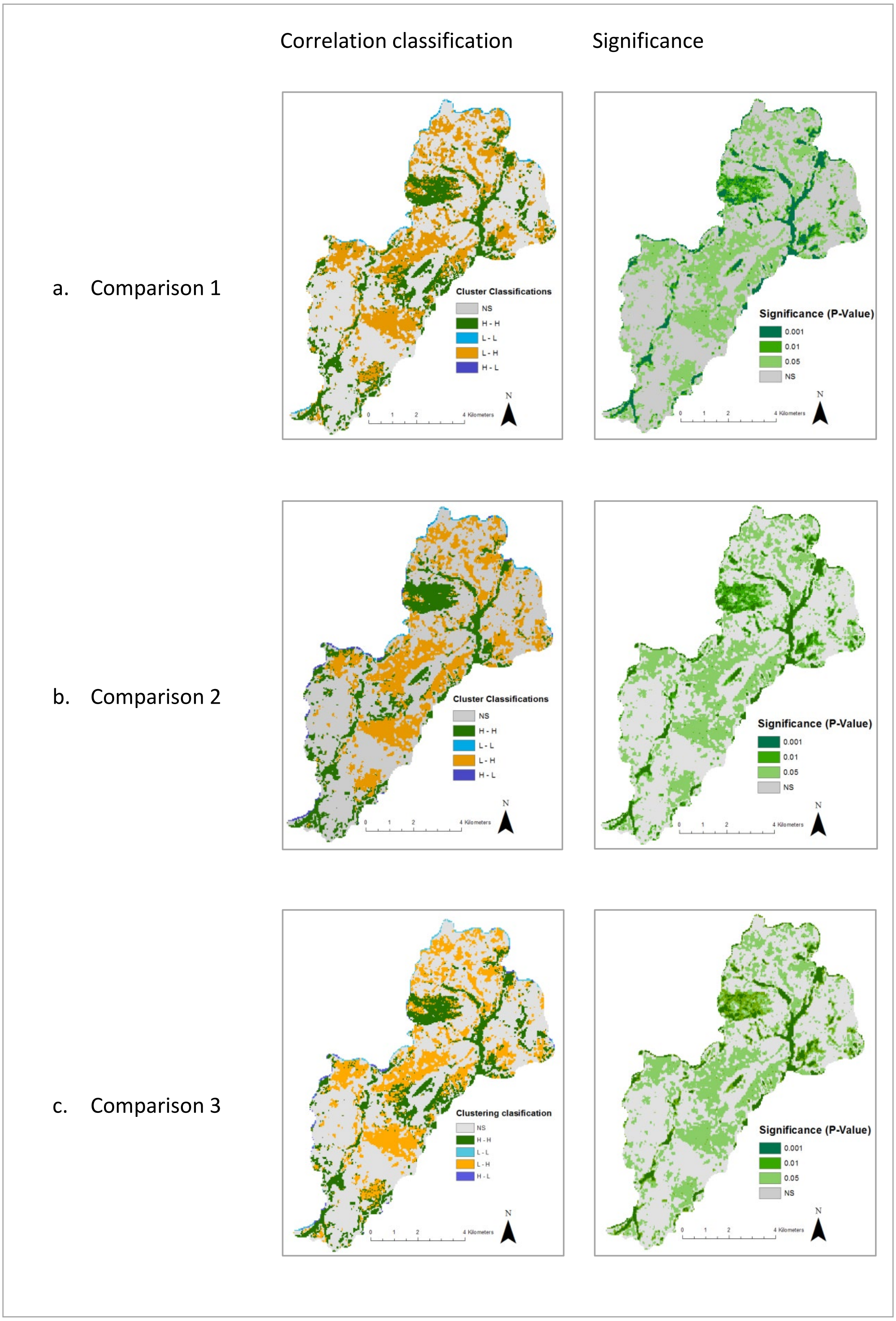


Figure 6.4: Distribution and direction of change in NDVI from comparison 1 (2000 to 2005), comparison 2 (2005 to 2014), and comparison 3 (2000 to 2014).

Overall there was an increase in NDVI across the whole conservancy from 2000 to 2014 (Appendix 10). In the three time frames examined, NDVI was found to be particularly low in areas identified as open grasslands in the habitat classifications. In 2000, NDVI was considerably lower than in the two other years, only reaching a maximum of 0.18, whereas in 2014 the maximum calculated was 0.46.

To identify where the most significant changes occurred to productivity in the conservancy, bivariate local Moran's index was calculated for each comparison and a map output produced, detailing areas where NDVI values increased or decreased significantly between years using Anselin's autocorrelation outputs for verification (Figure 6.4). There was the least correlation between the NDVI map for the year 2000 and 2014 (I= -0.0064) which indicated that there was little similarly between the NDVI values in both maps. Between 2000 and 2005 there was more correlation, although the value was still low (I=0.0297). However between 2005 and 2014 there was a substantial increase in correlation between the two maps (I=0.671), indicating that the NDVI results for 2005 and 2014 were similar, particularly when compared to 2000. Local Moran's indices were used to identify the direction of change, increases or decreases in NDVI and identify where the changes occurred in the (Figure 6.4).

For the three comparisons conducted, in approximately 50% of the conservancy there was no significant change in NDVI, however in all three comparisons there were more areas where there were significant increases in NDVI, most notably in areas of open grassland (Figure 6.4). As would be expected, NDVI remained high in woodlands and riparian forests. Areas where NDVI was low or had decreased were restricted to the north-eastern boundary of the conservancy for all three comparisons.

6.3.3 Herbaceous layer

6.3.3.1 Herbaceous species abundance

As a result of the changes to the grazing management regime that took place in Ol Kinyei Conservancy when it was established, changes to the herbaceous vegetation could be expected. The results revealed that in Ol Kinyei Conservancy as a whole the amount of bare ground reduced throughout the course of the study from 21% in sample season 1 to 18.26% in sample season 4 (Table 6.5). The lowest value (14.25%) for bare ground was calculated in sample season 3 which took place after the short rainy season in February/March as opposed to before it in October/November (Table 6.5). In sample seasons 1 and 4, the amount bare ground was higher in OK1 than in OK2, while there was little difference between OK1 and OK2 in sample season 2 and in sample season 3 there was less bare ground in OK1 than in OK2.

Table 6.5: Mean percentage cover of herbaceous vegetation in OK2, OK1 and OK as a whole in the four sampling seasons

Sampling season	Sampling area	Bare ground	Herbaceous Cover
1	Ol Kinyei 1	25.00	75.00
	Ol Kinyei 2	17.00	80.00
	Ol Kinyei (whole)	21.00	77.50
2	Ol Kinyei 1	16.00	84.00
	Ol Kinyei 2	15.75	84.25
	Ol Kinyei (whole)	15.88	84.13
3	Ol Kinyei 1	13.50	86.50
	Ol Kinyei 2	15.00	85.00
	Ol Kinyei (whole)	14.25	85.75
4	Ol Kinyei 1	19.25	80.75
	Ol Kinyei 2	17.27	82.73
	Ol Kinyei (whole)	18.26	81.74

Among the herbaceous species, *Themeda triandra* was the most abundant in the conservancy, accounting for between 24.9% in sample season 1 to 26.2% in sample season 4, although the higher value for cover was in sample season 2 at 27.2% (Table 6.6). The second most abundant species was *Cynodon dactylon* which represented 16.7% of the herbaceous cover in OK in sample season 1, but had reduced to 12.3% by sample season 4. Other species were present in low abundance, although the majority increased throughout the course of the study. Among the more palatable species, the two *Sporobolus* species increased in abundance as well as *Aristida kenyensis* and *Panicum maximum*. In sample season 1, *C. dactylon* was considerably more abundant in OK2 than it was in OK1 but in sample seasons 2, 3 and 4 the situation reversed and it was more abundant in OK1 than in OK2. *A. kenyensis* and *P. maximum* were also more abundant in OK2 than in OK1 in sample season 1, but in consequent sample seasons their abundance was similar in both OK1 and OK2. Conversely, *T. triandra* was more abundant in OK1 than it was in OK2 in sample season 1 but from sample season 2 onwards it was more abundant in OK2 than in OK1. The Sporobolus species maintained similar levels of cover in OK1 and OK2 throughout the course of the study. The overall increase in cover from most species by sample season 4 and the reduction in the amount of bare ground indicates that the herbaceous vegetation was diversifying way from being *T. triandra* dominated and becoming an increasingly heterogeneous and palatable grassland.

Table 6.6: Percentage cover of herbaceous species in OK1, OK2 and the conservancy as a whole (OK)

	Sample season 1			**Sample season 2**			**Sample season 3**			**Sample season 4**		
Species	**OK1**	**OK2**	**OK**	**OK1**	**OK2**	**OK**	**OK1**	**OK2**	**OK**	**OK1**	**OK2**	**OK**
Aristida kenyensis	2.4	8.8	**5.6**	5.8	5.8	**5.8**	4.7	5.5	**5.1**	7.6	5.5	**6.6**
Brachiaria brizantha	3.6	3.0	**3.3**	3.7	3.2	**3.4**	6.1	3.5	**4.8**	4.4	3.2	**3.8**
Chrystopogon aucheri	2.9	5.2	**4.1**	4.7	4.7	**4.7**	5.1	5.1	**5.1**	4.2	6.4	**5.3**
Cynodon Dactylon	9.7	23.6	**16.7**	17.5	14.5	**16.0**	14.9	10.9	**12.9**	12.9	11.7	**12.3**
Eragrotis chloromelas	1.5	2.5	**2.0**	1.9	2.7	**2.3**	2.0	3.9	**3.0**	2.4	2.7	**2.5**
Eragrotis cilianensis	1.6	1.0	**1.3**	1.6	1.2	**1.4**	2.5	2.4	**2.4**	3.2	2.7	**3.0**
Heteropogon contortus	3.2	3.2	**3.2**	4.3	2.4	**3.3**	4.9	2.1	**3.5**	3.5	4.0	**3.7**
Hyparrhenia filipendula	1.6	0.7	**1.2**	1.1	1.0	**1.1**	1.3	1.4	**1.3**	2.8	1.5	**2.1**
Hyparrhenia hirta	2.7	5.4	**4.1**	2.9	5.1	**4.0**	3.9	5.3	**4.6**	4.6	5.7	**5.2**
Panicum maximum	5.2	7.8	**6.5**	8.4	6.4	**7.4**	8.1	7.7	**7.9**	7.2	9.9	**8.6**
Pennisetum pupureum	2.6	0.5	**1.6**	1.9	1.4	**1.7**	2.4	2.5	**2.4**	2.9	1.5	**2.2**
Setaria spacelata	2.1	0.7	**1.4**	1.9	1.5	**1.7**	2.4	1.3	**1.9**	2.2	1.7	**2.0**
Sporobolus festivus	2.1	2.2	**2.2**	2.9	2.2	**2.5**	4.0	3.5	**3.7**	4.4	3.2	**3.8**
Sporobolus spicatus	1.8	2.5	**2.1**	2.3	2.7	**2.5**	2.1	3.2	**2.7**	2.9	4.0	**3.4**
Themeda triandra	33.4	16.4	**24.9**	24.5	29.9	**27.2**	24.1	27.6	**25.9**	22.8	29.5	**26.2**

6.3.3.2 Grass height

6.3.3.2.1 Between sampling seasons

To determine whether there was a difference in grass height between sampling seasons and between sampling blocks, ANOVA's were conducted in R (Script 2). There was a significant difference in total grass height between sample seasons ($F_{1,3}$=159.65, p <2^{-16}), and post hoc Tukey tests revealed that in sample season 3 the total grass height was significantly higher than it was in sample season 1, while in sample season 4, it was significantly shorter than in the three other sample seasons (Appendix 11.1). There was no significant difference in the total grass height between sample season 1 and 2 and between sample seasons 2 and 3.

There was also a significant difference in basal height between all sample seasons (($F_{1,3}$=126.2, p <2^{-16}) and post hoc test revealed that in sample season 2 the basal height of the grass was significantly higher than it was in sample season 1. In addition, the basal height in sample season 3 was consistently higher than it was in all other sample seasons, and in sample season 4 if was significantly shorter (Appendix 11.2).

6.3.3.2.2 Between sampling blocks

There was no significant difference in the total grass height between OK1 and OK2 but there was a significant difference between sampling block 3, located outside the conservancy on community grazing directly adjacent to Ol Kinyei Conservancy ($F_{1,2}$= 52.75; P<2^{-16}) . In sampling block 3 the total grass height was significantly lower than it was in both OK1 and OK2 (Appendix 11.3).

The basal height was significantly different between n sampling blocks ($F_{1,2}$=30.08; p= 1.09^{-13}) and post hoc tests revealed that basal height was significantly lower outside the conservancy areas in sampling block 3 than it was inside the conservancy area in OK1 and OK2 (Appendix 11.4) indicating that there was significantly less palatable foliage available outside the conservancy area than there is inside

6.3.3.2.3 Between species

The total grass height of species was found to be significantly different ($F_{1,18}$ = 29.81, p <2^{16}), post hoc tests revealed that the differences were limited to certain species, most specifically *C. dactylon* which had a mean total and basal height which was higher than some other species (Table 6.7 & Appendix 11.5).

Table 6.7: Post hoc Tukey significant results (P-values) to determine level of significance in total and basal height between *Cynodon dactylon* and other herbaceous species

Species	***Cynodon dactylon***		
	Total height	**Basal height**	**Significance**
Aristida kenyensis	4.37E-05		***
Heteropogon contortus	0.004701		**
Panicum maximum	0.000195		***
Sporobulus spicatus		0.016693	*
Themeda triandra	0.000001	0.000131	***

6.5 Discussion

Savannahs are a mosaic of continuous herbaceous layer and discrete patches of woody vegetation which contribute to the high levels of habitat heterogeneity which subsequently influence the diversity and abundance of savannah ungulates typically found in these ecosystems (Cromisgt *et al.,* 2009).

The habitats classified in Ol Kinyei Conservancy differed considerably in the three time frames investigated. Overall, habitat heterogeneity in the conservancy increased. Five years prior to the conservancy establishment the habitats were relatively homogenous, yet by 2014, (the final year of study) habitat heterogeneity had increased. In particular, the amount of open grassland decreased, being replaced by acacia and croton shrublands. Woodlands also increased in cover between 2000 and 2014, while hill slope and riparian forest decreased in cover, with this attributed to reduced browsing pressure from domestic livestock (goats in particular). Intensive livestock grazing has frequently been linked to shrub encroachment in sub-Saharan Africa (Scholes & Archer, 1997; Asner *et al.,* 2009; Roques *et al.,* 2001; Cabral *et al.,* 2003; Sankaran *et al.,* 2008) and portrayed as a negative trend as it results in a decrease in palatable herbaceous vegetation and an increase in unpalatable woody vegetation (Scholes and Walker, 1993). In Ol Kinyei Conservancy, the significant increases in ungulate numbers (Chapters: 3, 4 & 5) contradict these hypotheses, as when viewed in tandem with increased habitat heterogeneity (much of which can be attributed to shrub encroachment), ungulate population increases did occur. It would appear that the shrub encroachment increased the diversity of resources to ungulate populations, which decreased inter-specific competition, particularly for mixed feeders.

Decreases in riparian forest are most likely the result of increased destruction from the increasing elephant population. Areas originally classified as open grasslands (in 2000) were where the least significant changes to land cover occurred. Riparian forest also had strong level of similarity between 2000 and 2015 despite the overall decrease in coverage. Productivity, calculated using NDVI, increased throughout the study, with the disparity between the maximum NDVI in 2000 and 2014 considerable, indicating that the vegetation in Ol Kinyei by 2014 was 'healthier' than it had been in 2000. Between 2005 and 2014 there were also increases in NDVI, though not as pronounced as between 2000 and 2005. Increases in productivity indicate that the photosynthetic rate of plants has increased which in turn suggests that increased foliage is available for species that depend on forage and browse. Significant increase in NDVI occurred primarily on open grasslands, which is encouraging as it indicated that the amount and quality of forage has increased since the establishment of Ol Kinyei Conservancy. Importantly, increased habitat heterogeneity and productivity, indicate that the vegetation in Ol Kinyei is diversifying to provide a wider range of resources for the different herbivore feeding guilds typically found in savannah environments.

Changes to the herbaceous layer in Ol Kinyei over the course of the three years of study indicated that the amount of bare ground decreased. This was mirrored with an increase in the cover of herbaceous species. However, there were fluctuations in the amount of bare ground, for example the second year of study (2013) was found to have the lowest cover of bare ground. These findings are closely aligned to climatic variations between years as well as changes in grazing pressure. This changing species composition affected the overall palatability of the forage available to herbivores as the most abundant species found included *T. triandra*, a typical savannah species which is highly palatable when kept short, and *C. dactylon* and *Sporobolus* species which are also highly palatable (FAO, 2015). At the species level, *C. dactylon* was found to have a significant higher total and basal height than other species. *C. dactylon* becomes very stoloniferous when allowed to grow; this renders part of the usually palatable plant highly unattractive to grazers.

Grass height is an important driver in ungulate abundance and distribution. Smaller bodied ungulates are reliant on access to short, high quality forage (Demment & Van Soest, 1985; Owen-Smith, 1988; Bhola *et al.,* 2012). Results revealed that grass height (total and basal) was lowest in the final year of study. This indicated that although overall herbaceous cover increased, the above ground biomass available was lower. The basal part of the plant represents the main body where most of the palatable foliage is found, total height represents the tallest (and therefore oldest) swards on the plants, which are more likely to have decreased levels of palatability (more fibrous). Grass height in the community grazing lands directly adjacent to the conservancy were significantly lower than inside the conservancy indicating that there is a difference in forage availability in areas with intensive livestock grazing as compared to the areas set aside for wild ungulates. Within the conservancy, the grass height was not significantly different between Ol Kinyei 1, an area that has had conservancy status since 2005 and Ol Kinyei 2, which was established in 2012, this indicates that the grazing pressure from wild ungulates is similar in both section of the conservancy.

6.6 Conclusions

With maturity, the habitat heterogeneity and productivity of Ol Kinyei Conservancy increased and when considered in tandem with increased ungulate populations, results suggest that the removal of livestock grazing has allowed the vegetation to begin to recover and regenerate. Additionally the species composition of the herbaceous layer reflected the high diversity of grass species commonly associated with savannah grasslands, whilst the short pasture that has been maintained by the wild ungulates increases the conservancy's attractiveness to small and medium herbivores that represent a large proportion of herbivore biomass in savannah environments. Importantly, these findings suggest that key vegetation types in wildlife conservancies are responding positively to the management strategies, particularly in areas that have historically been intensively grazed and degraded by livestock.

Chapter 7

Site selection tool for the identification of suitable areas for additional wildlife conservancy creation in the GME

7.1 Introduction

7.1.1 Background

With the establishment of several pioneer conservancies over the last 10 years, private land owners have witnessed the advantages experienced by communities that own land in conservancies. This has led to an increase in community interest and subsequently areas being proposed as wildlife conservancies. While this is a positive development, the process of creating a wildlife conservancy requires careful planning in terms of location, accessibility to wildlife and potential revenue from tourism. Proximity to human settlements and intensive agriculture are important factors that need to be taken into consideration, as well as the overall attractiveness of an area to wildlife.

7.1.2 Model building

Species distribution modelling is extensively used in the field of ecological research and conservation management (Elith & Leathwick, 2009), it can be applied to understanding biological and ecological processes at varying spatial scales in relation to environmental and geographical properties (Mac Nally, 2000) or to predict possible or future species' distributions across a landscape as a result of management strategies, changes in resource availability or climate change (Elith & Leathwick, 2009). The influence that environmental and geographical parameters have on species can be ranked in a hierarchical manner in terms of effect each parameter has on distribution (Cushman & McGarigal, 2002; Pearson & Dawson, 2003), commonly this is achieved from observational distribution data and identification and quantification of the influence of environmental parameters on the patterns observed. The selection of environmental variables (or independent variable) should be made by inferring on existing knowledge of species distributions (dependable variable), their ecology and characteristics of their environment.

7.1.3.3 Model building process

To assess the ecological viability of Ol Kinyei Conservancy, selected as a 'model conservancy' in the GME, empirical evidence was collected over a three year period on ungulate distributions and vegetation cover (Figure 7.1). These data, combined with remotely sensed data extracted from satellite images provided information on the likely processes that drive ungulate distributions in a conservancy setting in the GME. Ungulate distribution for the seven most abundant species covering three major feeding guilds; grazers (Chapter 4), mixed feeders and browsers (Chapter 5) in the conservancy (Table 1.3) were determined using kernel density estimation. Habitat use and selectivity analysis was also conducted to determine which habitats were most important to each species. Habitat classification was conducted using supervised classification of satellite imagery and verified from ground truthed data (Figure 7.1). Additionally further environmental parameters were derived from satellite imagery to incorporate elevation, terrain texture (Relative Topographic Position), aspect, distance from features (permanent water sources, existing conservancies and permanent settlements) and NDVI (Figure 7.1). A suitability model was subsequently produced for the ungulate populations in the greater GME, by identifying the parameters that were consistently significant in the distribution patterns for the species. This model therefore identifies areas in the Greater GME where the environmental and geographical conditions are optimal for the assemblage of ungulate species identified as most abundant in existing conservancies. Consequently the areas identified by the tool should be considered as a priority should additional wildlife conservancies be proposed in the GME.

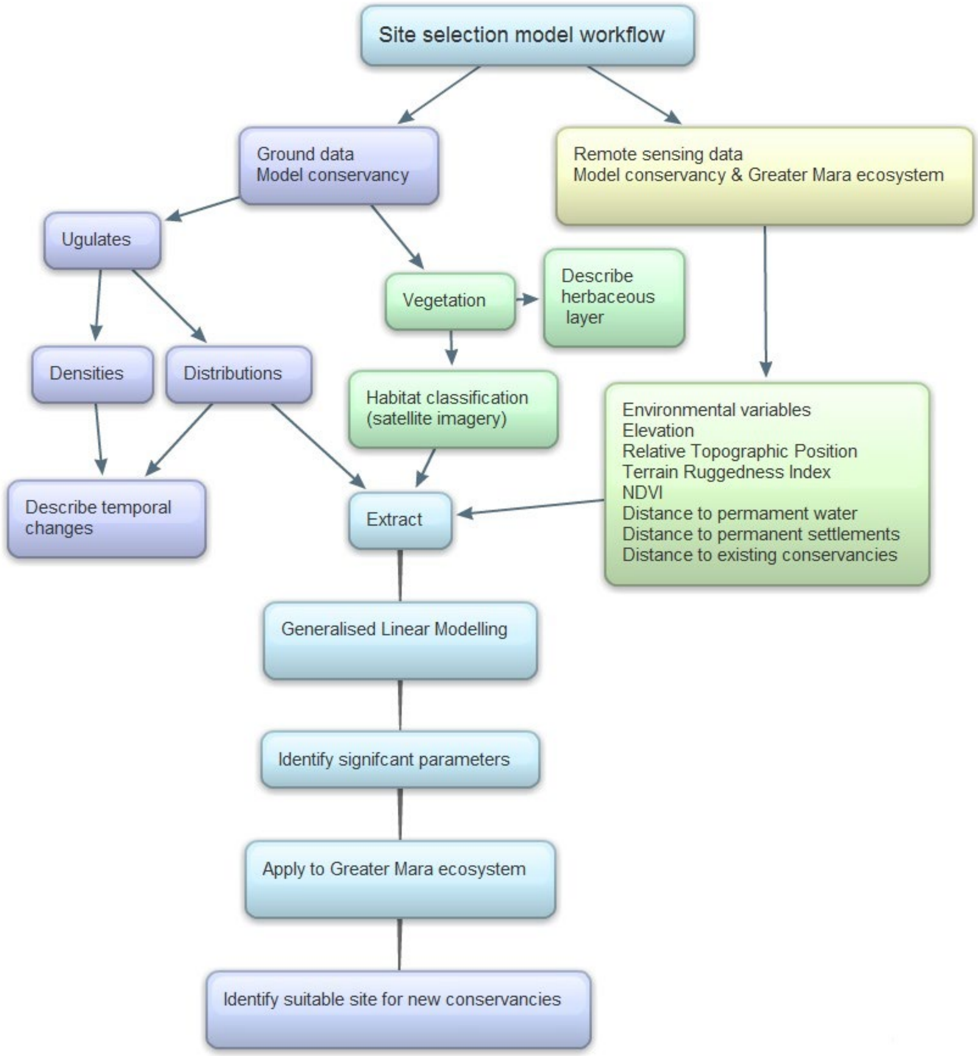


Figure 7.1: Conceptual workflow of model building process for a site selectivity tool to identify potential areas for future conservancy creation in the Greater GME.

Aim

- Develop a tool to identify areas suitable for future conservancy creation in the GME by incorporating the empirical evidence collected on wild ungulate abundance and distribution to identify landscape optimum characteristics incorporated via a modelling approach in a GIS.

7.2 Methods

To identify areas in the Greater GME that are suitable for future conservancy creation, a suitability model was constructed building on data acquired from Ol Kinyei Conservancy which was selected as a model conservancy in the ecosystem as a consequence of the length of establishment and the high densities of wildlife present there (Chapter 3). Currently a network of established conservancies currently exists to the North of the MMNR (Figure 7.2), results obtained from investigation of ungulate response to conservancy creation (Chapters 4 and 5) suggested that the presence of existing conservancy areas in close proximity resulted in a rapid uplift to ungulate.

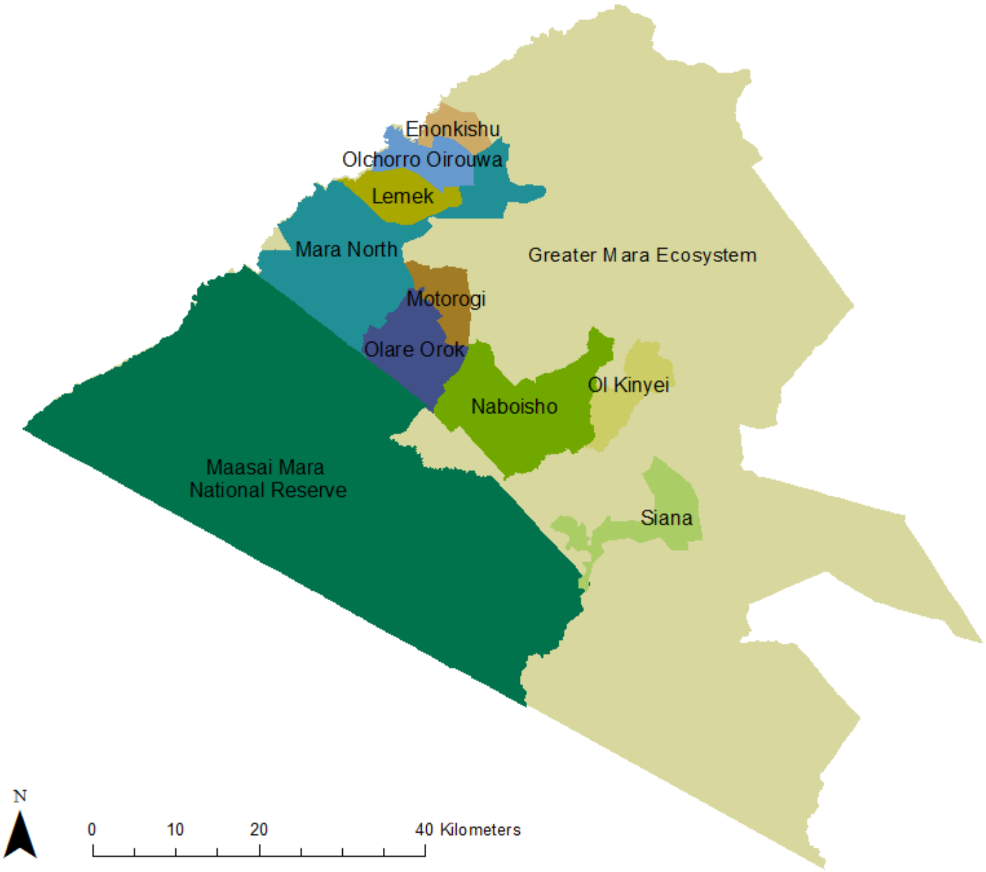
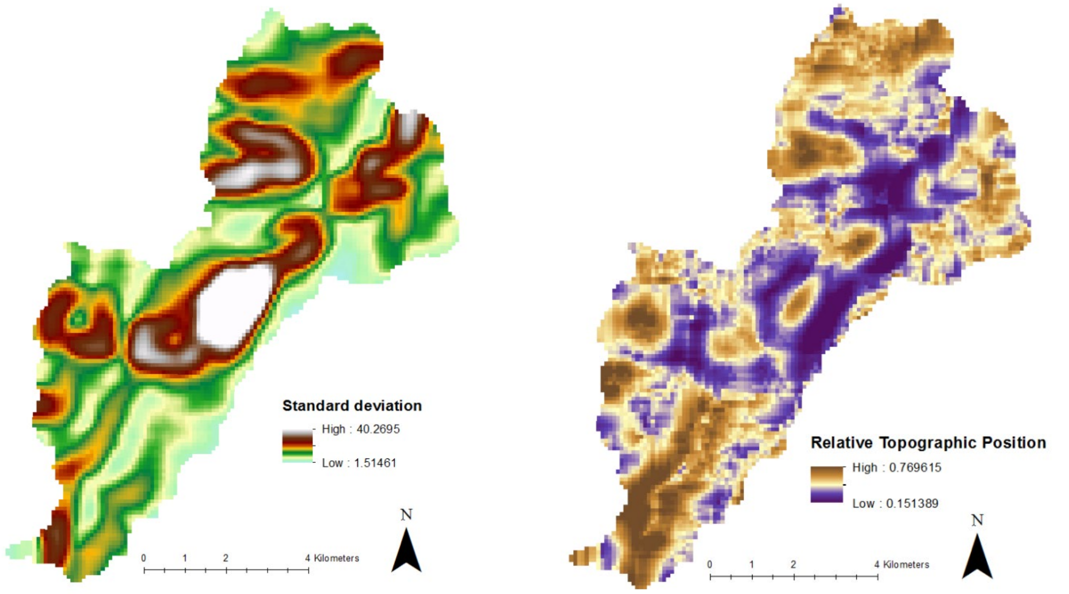


Figure 7.2: GME and existing conservation areas: Maasai Mara National reserve and Wildlife Conservancies

Ungulates were selected as indicator species (Table 3.3), as they represent the principal prey base for carnivores, many of which are declining severely in numbers in Kenya (Goldman, 2010). Wild ungulates also act good indicators of rangeland health, as they rely heavily on the availability of palatable grasses. To determine which environmental variables were significant in determining ungulate distribution and densities in Ol Kinyei Conservancy data were extracted from the kernel density estimation conducted (Chapters 4 & 5) for all study species over a grid of points constructed at 250m intervals. Additionally environmental parameters were also extracted for the points, these included: habitat classification (Chapter 6 - Figure 6.3.c), elevation (Figure 7.2.a), RTP (Figure 7.3.b), TRI (Figure 7.3.c), aspect (Figure 7.3.d) and distance to permanent water and NDVI (Appendix 10.1).

a. Elevation

b. Relative Topographic Position (RTP)



c. Terrain Ruggedness Index (TRI)

d. Aspect

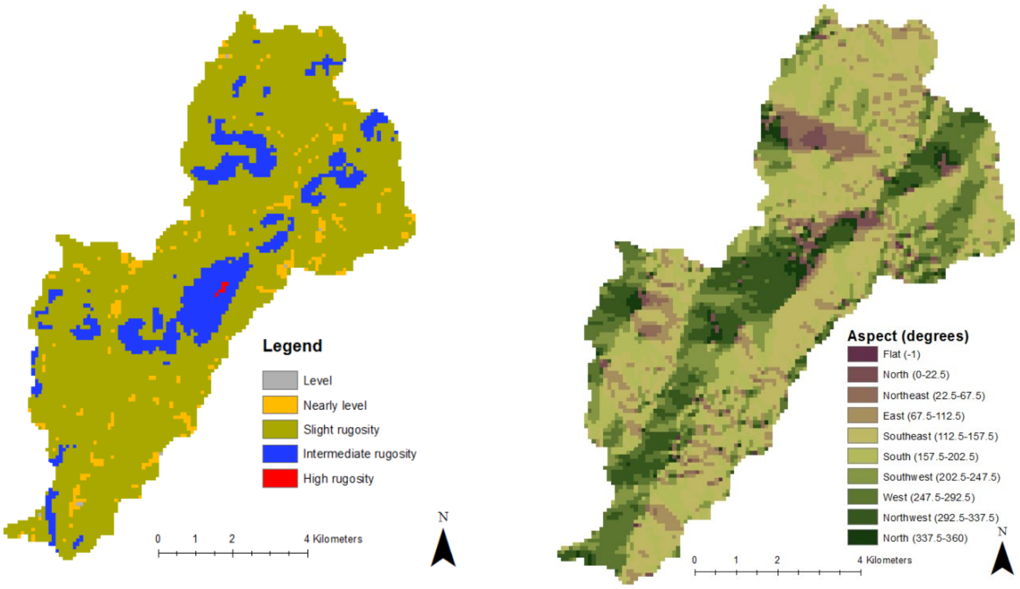


Figure 7.3: Environmental parameters derived from digital elevation data acquired from USGS.

The relationship between the environmental parameters and ungulate density were investigated using GLM's (Appendix: 12) in R (R Core Team (2013); Script 3). Categorical data - habitat classification and aspect - were ranked by influence on ungulate densities. The environmental layers in ArcGIS® were reclassified to represent fuzzy membership where a value of 0 represents a negative effect on density while a value of 1 represents a positive effect. Fuzzy overlay was conducted for each species incorporating the parameters found to be significant in explaining patterns of density (see Chapter 2.6.2).

To produce a suitability model for the ungulate populations in the greater GME, the parameters that were consistently significant across species were identified and incorporated to the suitability model, produced using a fuzzy overlay function (Chapter 2.6.2).

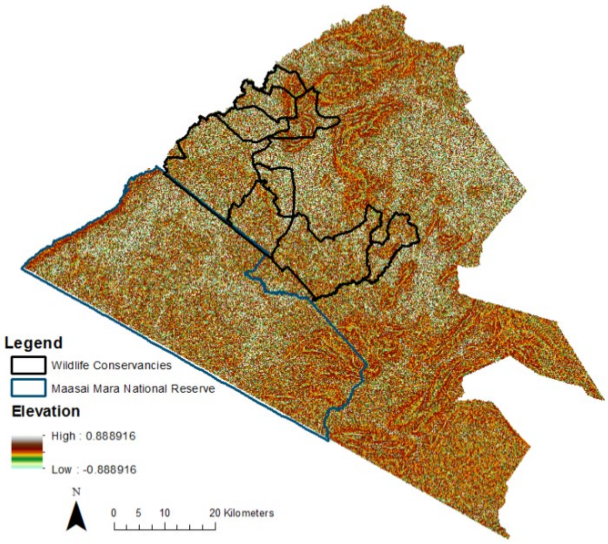


Figure 7.4.a: Elevation data derived from digital elevation models acquired from USGS for the Greater GME,

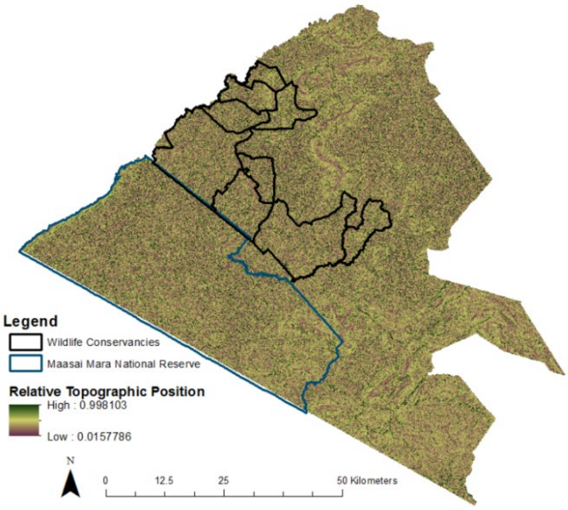


Figure 7.4.b: Relative topographic position derived from digital elevation models acquired from USGS for the Greater GME,

Distance from existing conservancies (Figure 7.4.a) and permanent settlements (Data from: ILRI & DSRS) (Figure 7.4.b) were included as additional parameters in addition to RTP and elevation, the hypothesis being that areas close to existing conservancies and far from permanent settlements were more suitable for new wildlife conservancy site.

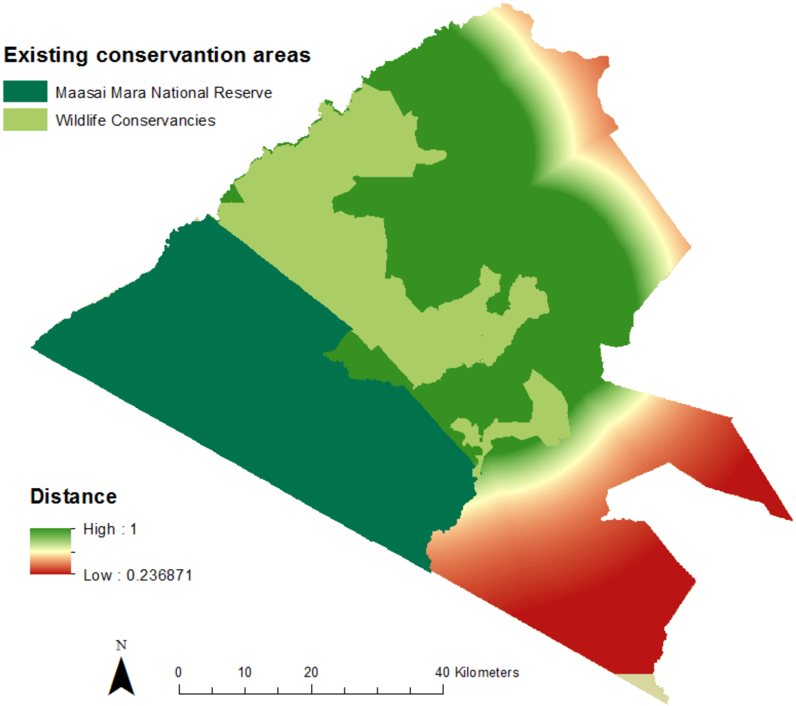


Figure 7.5: Distance from existing conservancies (1= close and 0 = far)

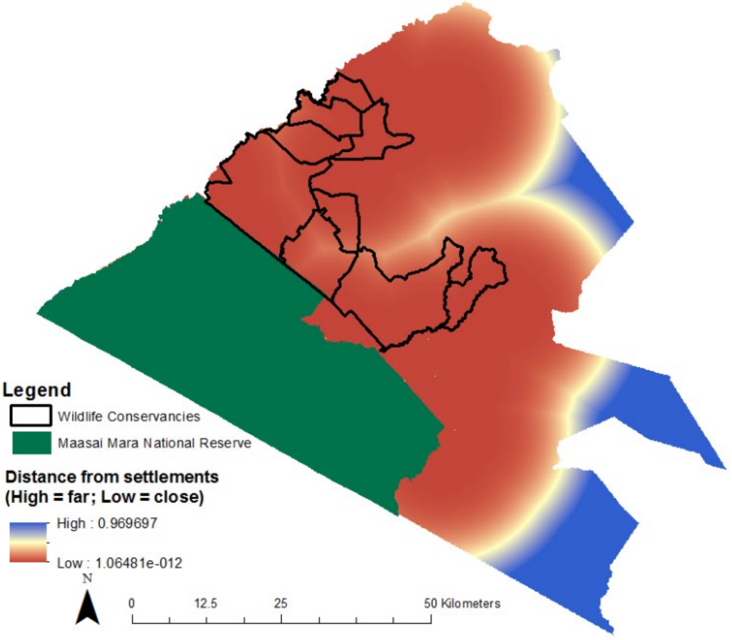


Figure 7.6: Distance from permanent settlements

Outputs from the suitability model were extrapolated and represented in a final suitability map restricted by only selecting those parameter and trends that applied to the majority of ungulate species considered in the study, subsequently conducting fuzzy overlay analysis, reclassifications and extrapolation to give an indication of high suitability values. Classifications were categorised in term of suitability and connectivity using aggregation and neighbourhood tools in ArcGIS® and three categories were identified; high suitability and high connectivity with other patches of high suitability, high suitability with low connectivity and patches of medium suitability.

To provide an understanding of the abundance of ungulates that could be expected in new conservancies prospective population estimates In areas identified as high suitability and connectivity were calculated using the population densities calculated in Ol Kinyei Conservancy (Chapter 3) for three time frames; one year after conservancy creation (Sample season 2 in OK2); three years after conservancy creation (sample season 4 in OK2) and 9 years after conservancy creation (Sample season 4 in OK1).

7.3 Results & Discussion

7.3.1 Species specific suitability models

Elevation and RTP were the most significant parameters to explain variations in density for most of the ungulate species considered in the study (Table 7.1). Elevation had a negative influence of the densities of all species, apart from topi, which indicates that densities for most species were higher at lower elevations while topi densities were not significantly influenced by elevation. RTP which is an indicator of terrain texture also contributed significantly in explaining variations in densities for most of the study species (Table 7.1).

Table 7.1: Model parameter outputs from generalised linear models assessing influence of environmental parameters on ungulate densities.

Species	Elevation	RTP	NDVI	Distance from water	Aspect	Habitat
Thompson's gazelle	Negative ***	NS	NS	Positive ***	NS	Positive ***
Wildebeest	Negative ***	Negative **	NS	Positive ***	Positive ***	Positive ***
Zebra	Negative ***	NS	Negative **	Positive ***	NS	Positive ***
Topi	NS	Negative ***	Negative **	Positive ***	Positive ***	NS
Grant's Gazelle	Negative ***	Negative ***	NS	NS	Positive ***	Positive ***
Impala	Negative ***	Negative **	NS	Positive ***	Positive ***	Positive ***
Giraffe	Negative **	Negative **	NS	Positive ***	NS	NS

***= p<0.001;**= p<0.01; NS= Non-significant; Positive = Density increased with increase in parameter; Negative = Density decreased with increase in parameter

Only Thompson's gazelle and zebra distributions were not influenced significantly by RTP. All other study species' density distributions were linked to RTP in a negative relationship, where densities decreased with increased RTP, or ruggedness (Table 7.1). Where elevation and RTP are low the landscape is relatively flat and therefore represents open savannahs or woodlands. Conversely in more rugged areas, the vegetation is more likely to be composed of shrublands, particularly Commiphora dominated hill slopes which most species either actively avoided or showed little preference towards in the habitat use and selectivity analyses (Chapters 4 &5). Consequently it is not surprising that the majority of species distributions demonstrated negative relationships to increased elevation and/or RTP.

Distance from water was significant for all species except Grant's gazelles, yet interestingly the relationship was positive which indicates that densities increased with increased distance from permanent water sources (Table 7.1). This pattern is likely to be a response to vegetative structure which tends to be denser in close proximity to water (Ogutu *et al.,* 2010) which would deter many ungulate species due to high risk of predation in these areas. NDVI, which is an indicator of vegetation productivity, was only a significant explanatory parameter for two species; zebra and topi (Table 7.1), and the relationship was negative for both species where their densities decreased with increased productivity. This pattern is a result of increased vegetative cover in areas with high NDVI, which are most likely to be in areas with higher levels of moisture, such as areas neighbouring permanent water sources. Aspect and habitat are both categorical parameters. Habitat was identified as being an important explanatory parameter for most species apart from topi and giraffe, while aspect was significant for all except Thompson's gazelles, zebra and giraffe (Table 7.1). Habitat classifications were ranked in order of preference in accordance to the coefficients calculated from the GLM's. For all species open grassland was the most 'suitable' habitat, while other habitat rankings varied between species (Appendix 6).

Within Ol Kinyei Conservancy, large areas were found to have favourable conditions for all species combined, particularly the areas located in the central strip of the conservancy that runs from the central part of OK2 to the western boundary of OK1 (Figure 7.7).

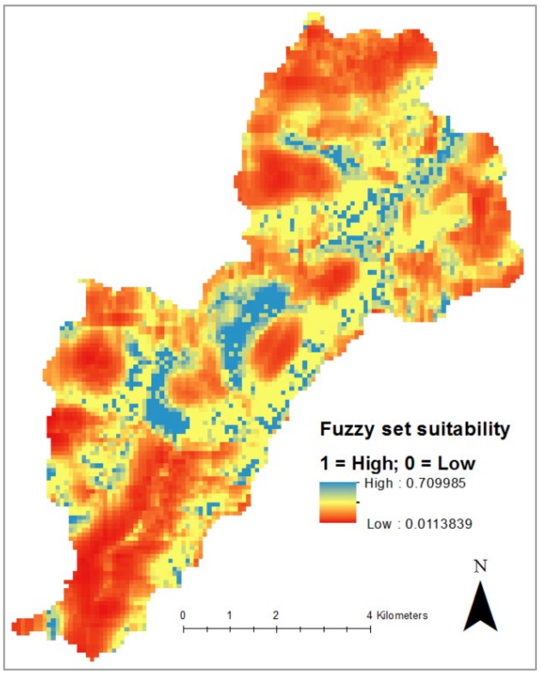
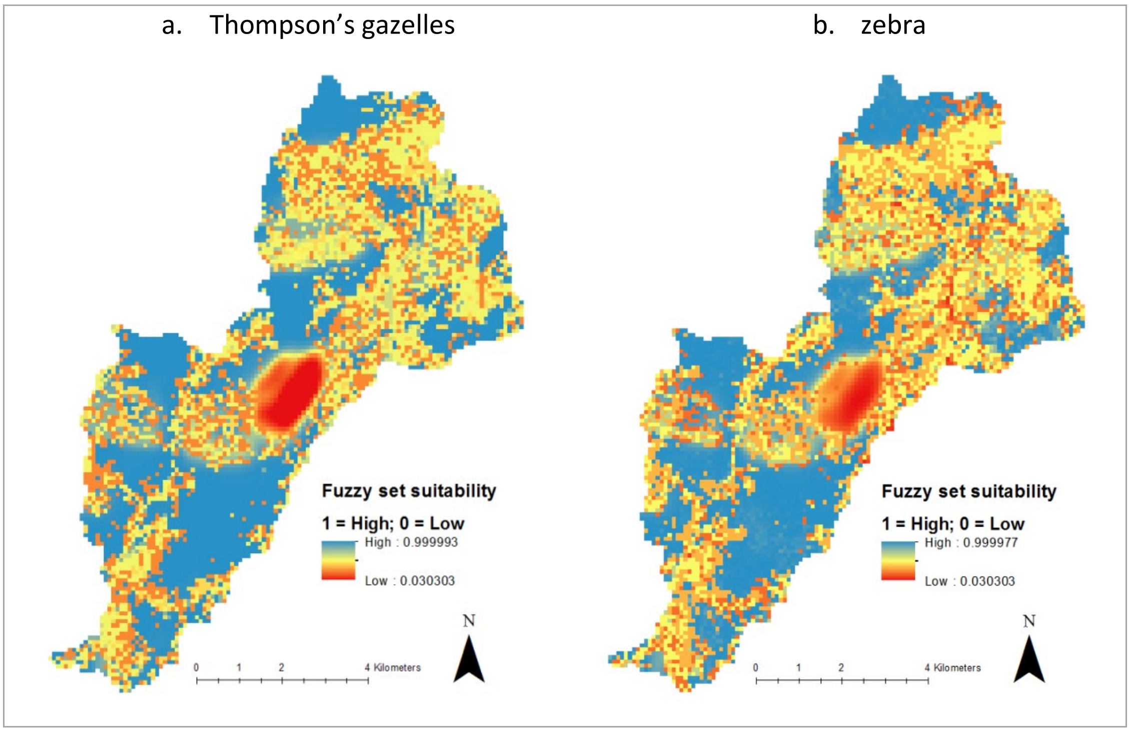


Figure 7.7: Range suitability all study species

Fuzzy overlay analysis revealed that large areas of open habitat are present and highly suitable for Thompson's gazelles and zebra (Figure 7.8) these areas are representative of the large open grasslands identified in the habitat classifications conducted in chapter 6 (Figure 6.3.c) and correspond with results from habitat selection and use from Chapter 4. Of all the study species Thompson's gazelles and zebra were the most dependent on the availability of large open tracts of grasslands where predator vigilance is high and forage readily available.

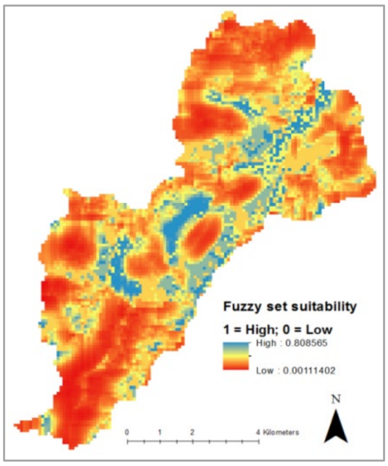

a. Thompson's gazelles

b. zebra

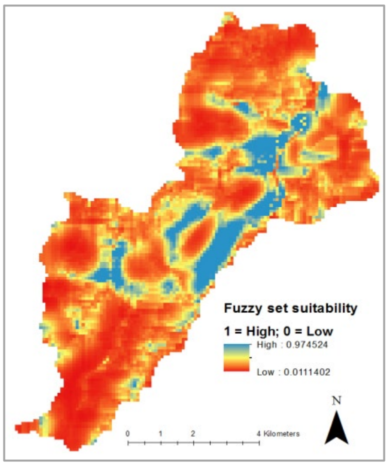
Figure 7.8: Fuzzy overlay suitability models for Thompson's gazelles, and zebra in Ol Kinyei Conservancy, incorporating significant environmental parameter from GLM outputs (1 = highly suitable; 0 = Not suitable)

Suitability model for all other species (wildebeest, topi, Grant's gazelles, impala and giraffe) yielded similar outputs, with the majority of highly suitable areas were on areas that were less rugged (Figure 7.9). In particular, an area in the centre of the conservancy was identified as not suitable for all species, this is a hill (Oloibormurt) which is significantly larger than other hills in the conservancy.

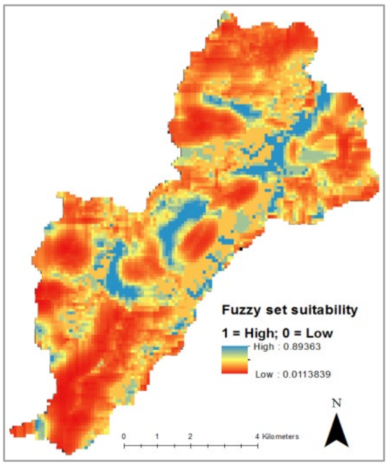
a. Wildebeest



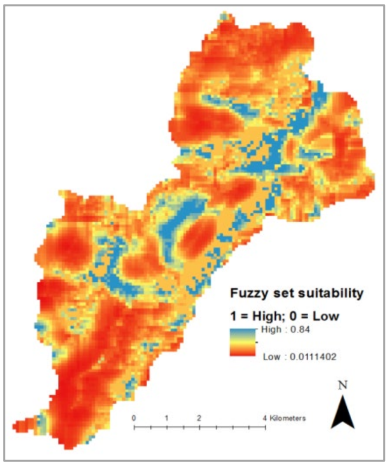
b. Topi



c. Grant's gazelle



d. Impala



e. Giraffe

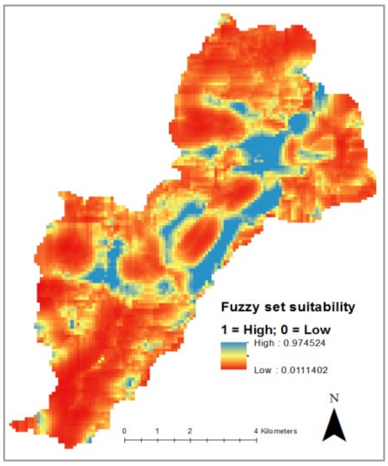


Figure 7.9: Fuzzy overlay suitability models for wildebeest, topi, Grant's gazelles, impala and giraffe in Ol Kinyei Conservancy, incorporating significant environmental parameter from GLM outputs (1 = highly suitable; 0 = Not suitable)

It is evident that large, steep hills are not suitable to the savannah species considered here, however the areas directly adjacent to significant slopes were those selected as favourable.

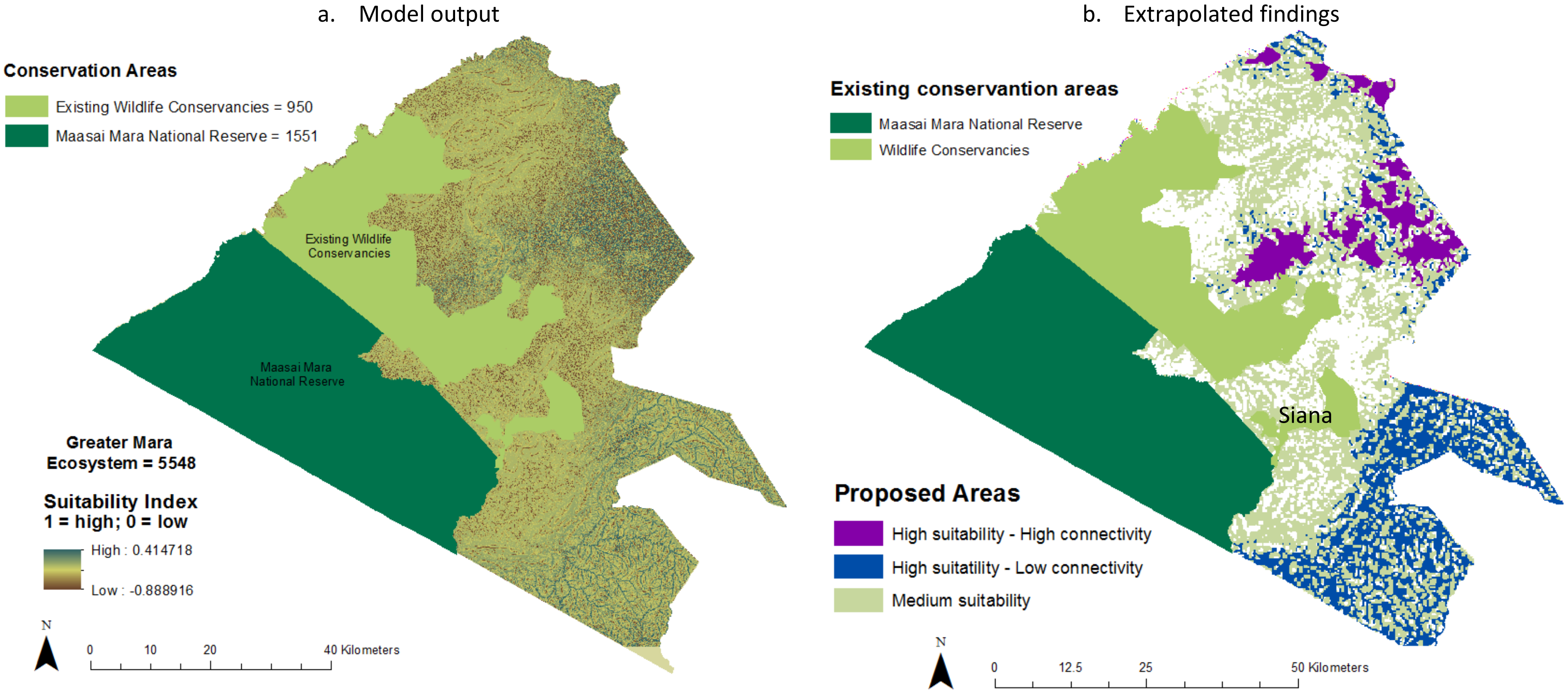
This pattern surprisingly applied to all feeding guilds considered; wildebeest and topi which are strict grazers, impala and Grant's gazelles which are mixed feeders, and giraffe which are strict browsers. The areas identified as suitable for these species had high levels of habitat heterogeneity (Figure 6.3.c) which would accommodate the different feeding guilds the species represent and minimise competition between species for resources.

7.3.2 Site selection tool

In order to identify areas that are suitable for future wildlife conservancy creation in the Greater GME, parameters identified as important in explaining ungulate species distribution were selected and incorporated into a suitability model that was applied to cover the extent of the Greater GME. Although habitat classification was a significant explanatory variable for most species, unfortunately no adequate baseline map for the extent of the GME is currently available. This meant that as Ol Kinyei is not entirely representative of all habitats and terrains present in the ecosystem not all habitats were identified in the ground truthing exercise to allow for accurate supervised classification of habitat in the Greater GME. Distance from permanent water was also excluded, on the basis that the trends identified were more likely to be a response to vegetative cover than water availability, and therefore if the negative effect of water were incorporated, the output would not be representative of actual responses to the presence of water sources.

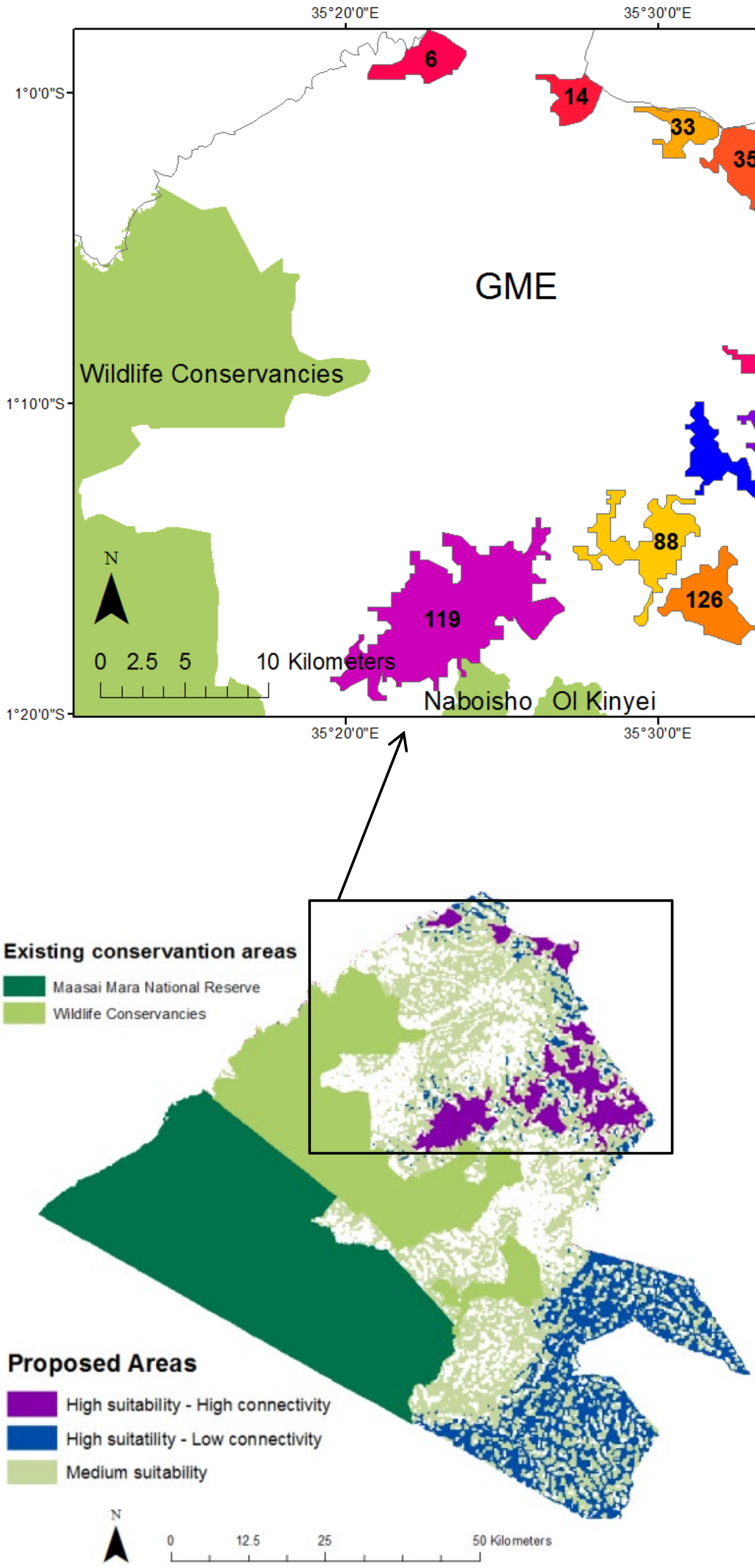
The results from the site selection tool identified several proposed areas for future conservancy designation which are suitable in terms of the abiotic and biotic conditions present (Figure 7.10). The model output, represented here in map format, depicts areas (dark hue; Figure 7.10.a) which should be considered most suitable for future wildlife conservancy creation. These areas are largely limited to the northeast and southeast corner of the Greater GME, and further with extrapolation these suitable areas were classified to represent areas that were closely connected and identified as highly suitable by the model. Interestingly, all such areas were located in the north-eastern sections of the GME (Figure 7.10.b & Figure 7.11).

Other classifications included areas with high suitability but that were poorly connected to other areas of high suitability, these areas were primarily located in the southeast of the GME, while areas of medium suitability were concentrated in the north of GME and between MMNR, Siana conservancy and the south-east area identified as highly suitable with low connectivity (Figure 7.10.b).


a. Model output

b. Extrapolated findings

Figure 7.10: Wildlife conservancy site suitability model for most abundant wild ungulates in the GME based on findings from Ol Kinyei Conservancy, considered here as a 'Model' wildlife conservancy in the GME. Proposed locations for future conservancy designations are classified in three categories: High suitability and connectivity; high suitability and low connectivity; medium suitability.



Area (km²)

6 = 9.2

14 = 6.8

33 = 7.2

35 = 11.6

59 = 11.0

73 = 7.7

74 = 34.8

88 = 18.4

107 = 42.1

119 = 63.6

226 = 14.6

Figure 7.11: Location and size (km²) of proposed conservancy areas identified to have high suitability and connectivity in the north-eastern part of GME

The north-east of the GME represents a tract of land which is currently under increased pressure from agricultural expansion and urban development, yet it also represents a critical wildlife corridor along which the Loita migration extends. The establishment of additional wildlife conservancies in this part of the GME would therefore provide vital rangeland for migrating wildlife and resident populations which are being constricted from the north as a result of increased disturbance from increased human activity and habitat loss and fragmentation. This area has a significant proportion as low lying terrain that will be dominated by open grasslands, shrublands and patches of Acacia woodland. The habitat composition of this area is therefore likely to be highly suitable for those species that are heavily reliant on access to large areas of open grassland and the Ecotonal habitats found surrounding them, such as the grazers considered in this study. The 11 areas identified with high suitability and connectivity varied considerably in size, however many of the smaller patches have the potential to be linked by areas identified as medium suitability to cover larger expanses as the areas between them were predominantly identified as 'medium suitability' which suggest that no physical or major anthropogenic barriers separate them (See 33 & 35; 88 & 126; 74 & 107 in Figure 7.11). Keeping in mind the results obtained from ungulate responses to conservancy creation (Chapter 4 & 5) that postulated that the rapid colonisation of the newly designated areas but ungulates was dependent on the close proximity of an adjacent, mature conservancy the area connected to Naboisho (N=119; Figure 7.11) has the potential to become a successful prospect for both investors and as a refuge for wildlife. In addition, the size of this area of high suitability is only marginally smaller than Ol Kinyei Conservancy (74 km²), which as demonstrated in the study contributes successfully as a conservancy area. The mosaic of proposed areas of conservancy areas presented here, would not only provide wildlife in the GME with a considerably extended range within protected areas but would also spread the financial benefits of wildlife tourism to parts of the GME that have so far been far removed from the conservancy movement and any financial benefit from the MMNR.

The south-eastern corner of the GME is sparsely populated and has an undulating terrain which provides high levels of habitat heterogeneity. The terrain in this part of GEM is considerably more rugged than in the North of GME which is more evenly elevated, which suggests that there will be a greater mosaic of habitats in this area. The amount of hill slope type habitats will be higher; it is also highly likely that habitat patches will be smaller than in the north of GME, as a result of the increased variation in topography and physical properties of the landscape. Species such as impala, giraffe and grant's gazelles have been demonstrated in this research as having high dependence heterogeneity will likely thrive in this area. This heterogeneity would explain the mosaic of suitability classifications obtained from the model (Figure 7.10.b) whereby the elevated portions of the landscape would have low suitability but the more evenly elevated portions would meet the suitability requirements. Although the outputs from the site selection model are not as clearly defined for this part of The GME, further investigation into habitat cover, water availability and current wildlife occupancy could be incorporated into the model to produce more defined areas that would be suitable for future conservancy creation. This is of particular importance because all wildlife conservancies in the GME are currently concentrated to the north of the MMNR, therefore the creation of additional wildlife conservancies in this area would be highly beneficial as they would create important refuges for wildlife in areas that are located at some distance from both the MMNR and/or the existing network of well-established wildlife conservancies. As such they would form the basis of an additional network of wildlife conservancies in close proximity to the GME's newest conservancy, "Siana". The extent of medium suitability is also encouraging, particularly in the identification of wildlife corridors between existing and areas that could potentially be designated as wildlife conservancies and in the protection of migratory routes.

7.3.3 Predicted ungulate population sizes

In the assessment of Ol Kinyei wildlife conservancy, population estimates were generated for seven wild ungulate species selected as indicators of ecological viability (Chapter 3). With the expansion of Ol Kinyei Conservancy the opportunity arose to identity trends in ungulate numbers as a result of conservancy creation. To provide an understanding of ungulate numbers that future investors and conservancy managers could expect should the areas identified in this study be considered as potential locations, the population estimates obtained in Ol Kinyei Conservancy were applied to the proposed areas (Table 7.2). The results were presented on three time frames; after one year of designation (Sample season 2 in OK2), after three years of designation (sample season 4 in OK2), and after 9 years of conservancy designation (sample season 4 in OK1) (Table 7.2).

Table 7.2: Predicted ungulate population sizes for sites proposed for future conservancy designation. Population size predictions are presented for 1, 3 and 9 years after creation presented and were based on population estimates generated for Ol Kinyei Conservancy, used in the study as a model conservancy in the GME 1, 3 and 9 years after creation.

Proposed conservancy areas	Age of conservancy	Predicted Ungulate Population size						
		Thompson's gazelle	Wildebeest	Impala	Zebra	Grant's gazelle	Giraffe	Topi
119 (63.64 km²)	1 Year	2112	1872	1160	720	358	106	134
	3 Years	1563	1421	1217	629	356	261	379
	9 Years	1559	1276	1032	516	527	202	295
107 (42.18 km²)	1 Year	1399	1241	769	477	237	70	89
	3 Years	1036	942	807	417	236	173	252
	9 Years	1087	796	599	286	482	103	150
74 (34.83 km²)	1 Year	1156	1025	635	394	196	58	74
	3 Years	855	778	666	344	195	143	208
	9 Years	898	657	495	236	398	85	124
88 (18.42 km²)	1 Year	611	542	336	208	104	31	39
	3 Years	452	411	352	182	103	76	110
	9 Years	475	348	262	125	211	45	65
226 (14.66 km²)	1 Year	486	431	267	166	82	24	31
	3 Years	360	327	280	145	82	60	87
	9 Years	359	294	238	119	122	47	68
Average 6 - 73 (9 km²)	1 Year	297	263	163	101	50	15	19
	3 Years	220	200	171	88	50	37	53
	9 Years	219	179	145	73	74	28	41

7.4 Conclusions

The model identified several locations as suitable for future wildlife conservancy creation in the GME. These areas represent the extent of potential locations for future wildlife conservancies, it is not being suggested here that these areas should be designated as conservancy areas in their entirety, but that additional conservancy areas should be identified using supplementary finer scale analyses within these areas, particularly the areas classified as ‘medium suitability’. This would be achieved by the creation of a detailed land cover map produced from large scale ground-truthing of habitat composition, which would enabled the inclusion of habitat type, demonstrated in this study to be highly influential in defining ungulate spatial distribution, as a parameter in site selection models. The resulting finer scale analyses enabled by the creation of the map would also enable more species specific analyses to be conducted, which could be implemented to provide protection for those species which are more threatened by the anthropogenic pressures currently affecting the GME. Finer scale analyses would also need to incorporate anthropogenic factors such as the locations of small scale community settlements and the grazing requirements of the Maasai herders and their livestock in and neighbouring the areas identified for suitable for conservancy designation. These additions to the site selection model would produce a more refined output, and would identify areas that of a manageable in size than those identified in this study from both a financial point of view for potential investors, but also from the land owner’s point of view in terms of the quantity of land they are willing to ‘hand-over’ to wildlife.

Conclusions

Background

Habitat loss, contraction and fragmentation have been suggested as prevalent causes in the decrease of wildlife numbers in areas that historically sustained large numbers, such as the rangelands of the GME (Sinclair *et al.,* 1995; Fryxell *et al.,* 2005; Ogutu *et al.,* 2009; Ogutu *et al.,* 2010; Ogutu *et al.,* 2011). Increases in human population size, a shift from semi-nomadic pastoral to increasingly sedentary lifestyles and a movement from communal to private tenure in the GME (Lamprey & Reid, 2004) have resulted in increased habitat loss, competition with livestock and hunting. These factors combined have resulted in marked wildlife population declines (Ottichilo *et al.,* 2000; Shackleton *et al.,* 2002; Ogutu *et al.,* 2011). Specifically, wild ungulate numbers have declined by two thirds or more in both the MMNR and the adjacent pastoral lands between 1977 and 2009 (Ogutu *et al.,* 2011). Tourism is prolific in the areas around the MMNR and although this industry is advantageous economically to the area, it has further restricted wildlife movement as a result of the growth of settlements and trading posts at the gates and along the edge of MMNR (Thompson & Homewood, 2002; Lamprey & Reid, 2004). To address these conservation management issues, wildlife conservancies were created as additional protected areas on the pastoral ranging lands that surround the MMNR. Wildlife in the GME are free-ranging and while the provision of additional protected areas in the form of wildlife conservancies is undoubtedly beneficial, there is no information to date as to whether wildlife are utilising these areas i.e. are they working? This research therefore aimed to determine whether wildlife conservancies are effective as a management tool, both in terms of elevating wildlife populations and providing refuge to resident and migrating wildlife in areas outside the MMNR.

Major Findings

Prior to this research there were major concerns among researchers, conservation managers and governing bodies about the ecological viability of wildlife conservancies. There was limited understanding of how tracts of land incorporated into conservancies would recover as a result of the change of land use/management. The primary concern was that the condition of the grasslands in these areas had become degraded beyond repair as a consequence of decades of exposure to intensive livestock grazing, so much so that the proposed re-wilding of the designated areas would not be achievable. This research provides an accumulation of evidence in support of wildlife conservancies as ecological refuges, presenting them as a management tool that has the potential to promote rapid recovery from degradation and consequently support substantial numbers of wildlife. The main outputs from this research demonstrate that grasslands in the GME respond positively (increases in species composition and reduction of bare ground) to conservancy creation and that habitat heterogeneity increases with conservancy maturity. This in turn attracts significant number of wild ungulates to the area, which are integral to the natural function of savannah ecosystems. On this understanding, a site selection tool was developed to identify additional areas in the GME that have the potential to mirror the success of the conservancy studied here, Ol Kinyei Conservancy, which yielded positive results in terms of ecological viability.

To assess the ecological viability of Ol Kinyei Conservancy an examination and comparison of wild ungulate abundance in an established wildlife conservancy (OK1), and in a newly designated and adjacent conservancy area in the three years following its establishment (OK2) was conducted (Chapter 3). Wild ungulate densities (grazers, mixed feeders and browsers) were found to have increased in both OK1 and OK2 over the course of three years, indicating both increased reproductive success and wider use of the conservancy. Initially, population estimates were higher in the 'older' part of the conservancy (OK 1), but with time numbers became comparable between the two areas. These changes suggested that OK1 accelerated wildlife colonisation in OK2 due to its close proximity acting as a 'population reservoir' of individuals attracted from the high densities of wild ungulate species found in OK1, the surrounding community grazing lands, other conservancies and the MMNR. Patterns of spatial distribution of grazing ungulates over the course of the three year period in the established wildlife conservancy (OK1) and in the newly designated area (OK2) were also investigated. Findings demonstrated how the previously identified numerical uplifts in population sizes (Chapter 3) manifested themselves in the spatial distribution of grazing ungulates in the newly extended conservancy (Chapters 4 & 5). Results revealed that the study species were successfully increasing their distribution into OK2 over a short period of time, with all species present in significant hotspots in OK2 approximately a year after it was established as a wildlife conservancy (Chapter 4). Despite expected fluctuations, the distributions of all study species persisted in OK2 through to the final year of study, confirming that populations were beginning to establish themselves in the new conservancy area. The most important fluctuation in wild ungulate abundance results was identified in sample season 2 where there was a significant escalation in the population sizes of all four grazing species; Thompsons's gazelles, wildebeest, zebra and topi. The creation of OK2 and the resulting decrease in the utilisation of the area by domestic livestock will have resulted in a in competitive ‘vacuum’ that could be attributed to the surge in occupancy by wild ungulates in the conservancy as a result of migration from surrounding pastoral lands and the MMNR. The high densities found in the conservancy in sample season 2, were not expected to be sustainable long term. This was borne out by results from sample season 4 which demonstrated that even though the population estimates were lower than in sample season 2 in both parts of the conservancy, they were more evenly distributed between them. Additionally, variations in migration timings could still influence results from data collected in October/November, as ungulates sometimes return to the Serengeti at a later date than expected. This research concludes that to fully understand the impact of these fluctuations a longer term study of wild ungulate abundance and distributions both within Ol Kinyei and across the GME is necessary.

Examination of habitat use and selectivity of grazing ungulates was also conducted to determine whether ungulate species used the habitats present in Ol Kinyei Conservancy differentially. As expected, the analysis identified open grasslands as the most important habitat to most species and therefore confirmed that their recovery should comprise a fundamental component in the forward management of the conservancies. Nevertheless, patterns of habitat use and selectivity in areas of high clustering also highlighted the importance of habitat heterogeneity in small conservation areas. Results revealed that in Ol Kinyei Conservancy the study species (grazers, mixed feeders and browsers) utilised the resources available quite differently. Small bodied grazers (Thompson’s gazelles) were restricted to large open spaces where short, palatable new grass growth is available. Larger bodied grazers such as zebra and wildebeest utilised open grassland, but were more adaptable to other habitats with more vegetative cover. These findings correspond to the ecological theory of resource partitioning, which suggests that larger bodied species have the ability to utilise a larger proportion of a landscape as a result of both a higher tolerance for low quality resources, and due to the fact that they are less susceptible to increased levels of predation. Resource partitioning is heavily dependent upon high spatial heterogeneity of habitats within landscapes, particularly in the allocation of small protected areas designed to ensure the persistence of complex species assemblages and to provide resistance to temporal variations in resource availability (Fryxell *et al.,* 2005; Cromsigt *et al.,* 2009). When considered together with results that identify an elevation of wild ungulate abundance in both OK1 and OK2, these findings suggests that the habitat composition and heterogeneity in Ol Kinyei Conservancy are proving to be acceptable refugia to the diverse ungulate dietary guilds represented by the most abundant species in the GME.

The results that demonstrated that habitat heterogeneity and vegetation productivity had increased with conservancy maturity were consequently highly encouraging. When considered with the increases in ungulate populations, results suggest that the removal of livestock grazing has allowed the vegetation to begin to recover and regenerate. Additionally, investigation of changes to the herbaceous layer in term of species composition, cover and grass height and comparisons of these between the established wildlife conservancy and the newly designated area revealed that short pastures were being maintained with increasing species composition and cover improving the overall palatability of the grasslands to the benefit of the diverse ungulate feeding guilds. In particular these changes increased the conservancies' attractiveness to the small and medium herbivores that represent an important proportion of herbivore biomass in "healthy" savannah environments. When considered together with the findings that demonstrate elevations in ungulate abundance these results further support the concept of wildlife conservancies in the GME, where in Ol Kinyei Conservancy, habitat heterogeneity and ungulate abundance were found to have increased concurrently.

The site selection model, constructed by identifying environmental parameters driving ungulate distributions and abundance revealed three significant results. Firstly, 11 locations were identified as highly suitable for conservancy designation in the north-east of the GME, one of them an important migratory corridor (Loita migration) that is under considerable threat from agri-expansion and fencing. These proposed conservancy sites varied in size (from 6.8 km^2 to 63.6 km^2), but there was potential for the smaller areas to be linked to cover larger areas as the areas between them were predominantly classified as having 'medium suitability' indicating that no significant physical or anthropogenic barriers were identified between them. Most interestingly the larger area identified was neighbouring an existing conservancy (Naboisho Conservancy). This finding is particularly encouraging as this would be an ideal location to begin the extension of the conservancy network in the GME, whilst ensuring that proximity to existing conservancies is maintained. Secondly, suitable locations were found for the south-eastern part of the GME. Although less defined, the results revealed a mosaic of highly suitable areas embedded amongst less suitable areas. More in depth analysis of the habitat composition of this area would help to identify better defined areas that would be suitable for future conservancy creation. This part of the GME is important because the majority of wildlife conservancies in the GME are currently concentrated to the north of the MMNR. The creation of additional wildlife conservancies in this area would be highly beneficial in expanding the network of protected areas across the GME by forming an additional network of wildlife conservancies in close proximity to the GME's newest conservancy (Siana Conservancy). Large tracts of the GME were also identified as being of 'medium suitability' these areas are equally important as they would represent the optimum areas to create wildlife corridors between existing conservancies and protect migratory routes. Although these areas were not classified as highly suitable, the positive response of the vegetation and wild ungulates demonstrated in Ol Kinyei Conservancy suggests that similar response as consequence of their designation as conservancy areas could elevate their suitability standing to 'high'.

To conclude, the results described here demonstrate that small wildlife conservancies, such as Ol Kinyei Conservancy, have the potential to provide suitable refugia for grazing ungulates among the pastoral dispersal lands located around the MMNR, a fact that until this research was conducted remained unsubstantiated. Furthermore, the rapid colonisation by wild ungulates and the demonstrated diversity of habitat use between feeding guilds and body size uncovered in this research indicates that the spatial heterogeneity found in Ol Kinyei Conservancy is able to maintain a representative assemblage of savannah ungulates in significant abundance. These findings were additionally supported by increases in habitat heterogeneity and the positive changes described to the quality and cover of forage, which further confirm that grassland recovery and habitat regeneration is achievable using the wildlife conservancy model. The patterns of rapid utilisation of wild ungulates described in the newly designated conservancy area are equally encouraging for both potential investors in future conservancies and those land owners interested in leasing their land to diversify their livelihood. The findings of this research therefore demonstrate that a short time for re-wilding and landscape recovery can be expected and that with appropriate management, significant increases in both numbers and distribution of ungulates can be achieved , so long as a careful consideration is given as to where new conservancies are to be situated.

Finally, the GIS database of species distributions and densities, anthropogenic and biotic features of the GME produced from this research as well as the resulting suitability models, will provide valuable material for wildlife managers, researchers and conservancy managers involved in decision making exercises concerning future tourism developments in the ecosystem. In addition, the suitability model created from the results of this research could be replicated with ease, dependent on the availability of wild ungulate distribution data, to other wildlife areas in savannah biomes. It is therefore anticipated, that these results can help pave the way for wildlife conservancies to become recognised by governing bodies, conservation organisations and financial investors as viable management options in pastoral landscapes to promote the protection of savannah wildlife.

Scope for future work

More long term monitoring of ungulate species in Ol Kinyei Conservancy would provide a detailed insight to population stability and fluctuations and patterns of habitat use and selectivity. It would also provide further understanding of changes that occur from climatic variations and the resultant yearly shifts in the timing of the migrations. Overall, much deeper understanding of the role that wildlife conservancies are having in protecting and encouraging the uplift of wildlife numbers would be achieved by expansion of the research conducted in this study with regards to ungulate abundance and patterns of distributions throughout the extensive network of existing conservancies, some of which occupy significantly different landscapes to Ol Kinyei. Furthermore, several conservancies implement varying management strategies to Ol Kinyei Conservancy in terms of livestock grazing allowances, it would therefore be interesting to assess how wild ungulates respond to the different grazing plans.

Within those areas identified as suitable for future conservancy creation, particularly in the south-east of the GME, additional areas that should be excluded from conservancy designation could be identified as a result of finer scale analysis. This would be achieved by the creation of a detailed land cover map produced from a large scale ground truthing exercise of habitat composition in the Greater GME. Further attention to wildlife corridors and migration routes in the greater expanse of the ecosystem would not only aid investors in ensuring that conservancies are created in areas highly likely to attract high volumes of wildlife, but will also aid developers to make informed decisions regarding expansion to infrastructure in a landscape where free ranging wildlife is prevalent. Finer scale analyses would also need to incorporate social factors such as small (manyatta) settlements and grazing requirements of those people living in close proximity to the proposed areas. Because conservancies are established on land owned by resident pastoralists, it is important to ensure that both the people who own the land and those that live nearby are receptive to the idea of living in close proximity to a wildlife conservation area. These additional developments to the site selection model would produce a more refined output, and would identify areas that would be manageable in size from the financial point of view of the investors and land owners. In addition to increasing ecological understanding these advances would provide conservancy managers with essential information on the condition of their conservancies and help to develop management plans that incorporate the needs of wildlife and enable the Maasai to maintain their traditional livelihood through grazing agreement with conservancies, removing any discord that might arise from the increased coverage of protected areas in the GME.

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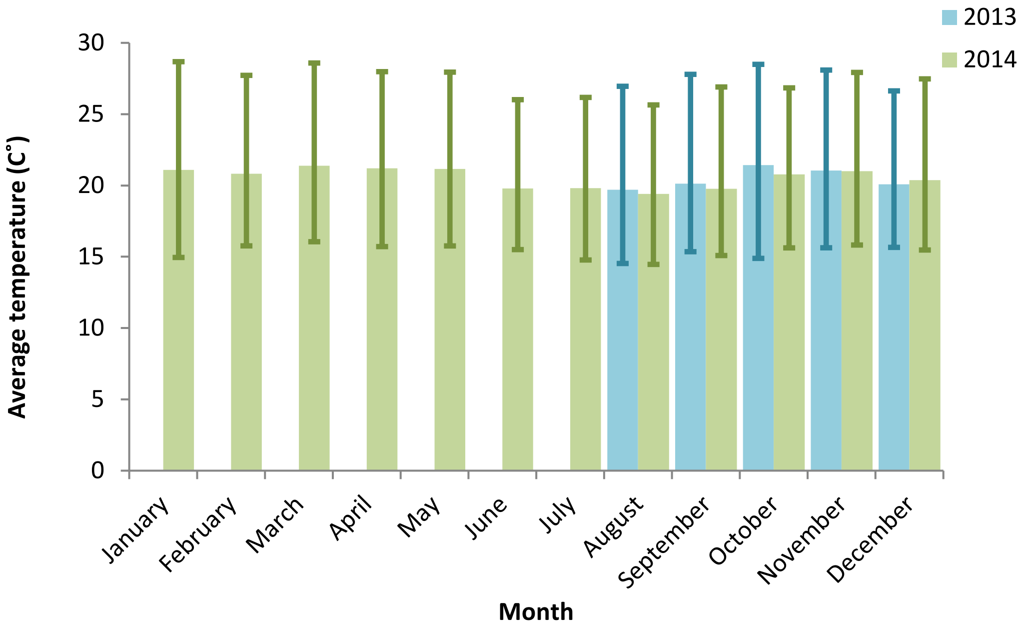
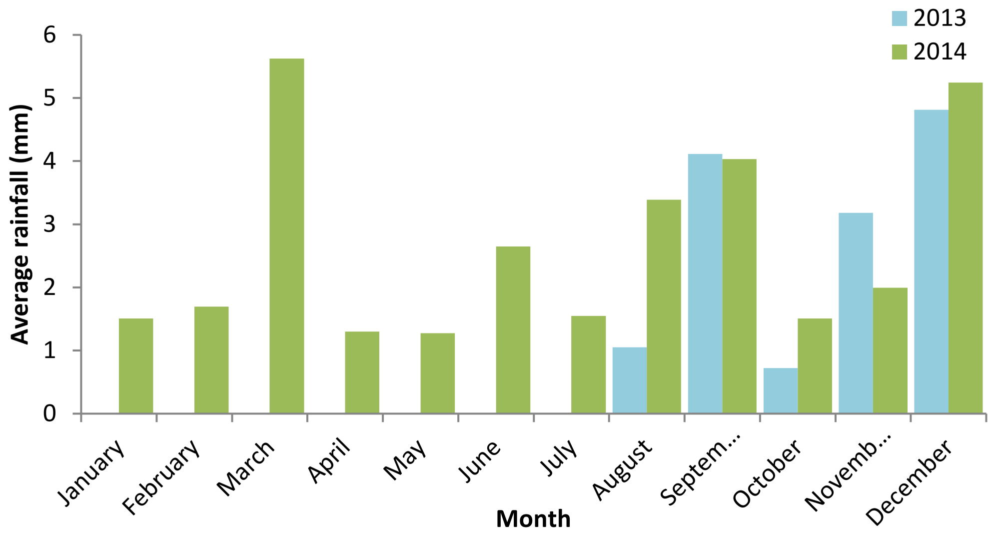
Appendices & R Scripts

Appendix 1: Monthly rainfall and temperature at Predator Hub, Olara Orok

From: KWT: http://www.maracheetahs.org/weather-data/)



Appendix 1.1: Average, maximum and minimum monthly temperature (C˚) for August to December 2013 and January-December 2013, Olare Orok, Maasai Mara



Appendix 1.2: Average rainfall (mm) in August-December 2013 and January-December 2014, Olare Orok, Maasai Mara

Appendix 2: Equations - DISTANCE analysis

The estimated abundance is calculated using that detection probability and the Horvitz-Thompson methods (Horvitz & Thompson 1952). Developed to estimate a value for a target population from a subset of data where different proportion of individuals may have been missed using inverse probability weighting to produce a total and mean for the metapopulation:

(Equation 1)

$$\widehat{N} = \sum_{i=1}^{n} 1/\widehat{P_i}$$

Where $\widehat{P_i}$ is the probability that animal i is within the sampling area and an estimate of the probability of its detection. n is the number of observations.

Where animal were recorded in clusters abundance is estimates as:

(Equation 2)

$$\widehat{N} = \sum_{i=1}^{n} s_i/\widehat{P_i}$$

Where s_i is the size of the cluster.

Alternatively the estimate can be generated by multiplying the estimated cluster size by an estimate of the mean cluster size $\hat{E}(s)$ where the mean cluster size is regressed on the estimated probability detection function. This removes the size bias where larger clusters are easier to detect at larger distances and where cluster size tends to be underestimated at larger distances.

(Equation 3)

$$\widehat{N} = \hat{E}(s) \sum_{i=1}^{n} 1/\widehat{P_i}$$

The density of animals can be calculated by:

(Equation 4)

$$\widehat{D} = \frac{1}{2}\frac{n}{L}\hat{f}(0)$$

$\hat{f}(0)$ is the probability function of the perpendicular distances where:

(Equation 5)

$$\hat{f}(0) = 1/\mu$$

Where μ is the effective strip half-width (the perpendicular distance of the object within which the number of undetected objects is equal to the number of object that were detected beyond that distance. So, the total area (A) surveyed is:

(Equation 6)

$$A = \mu * 2L$$

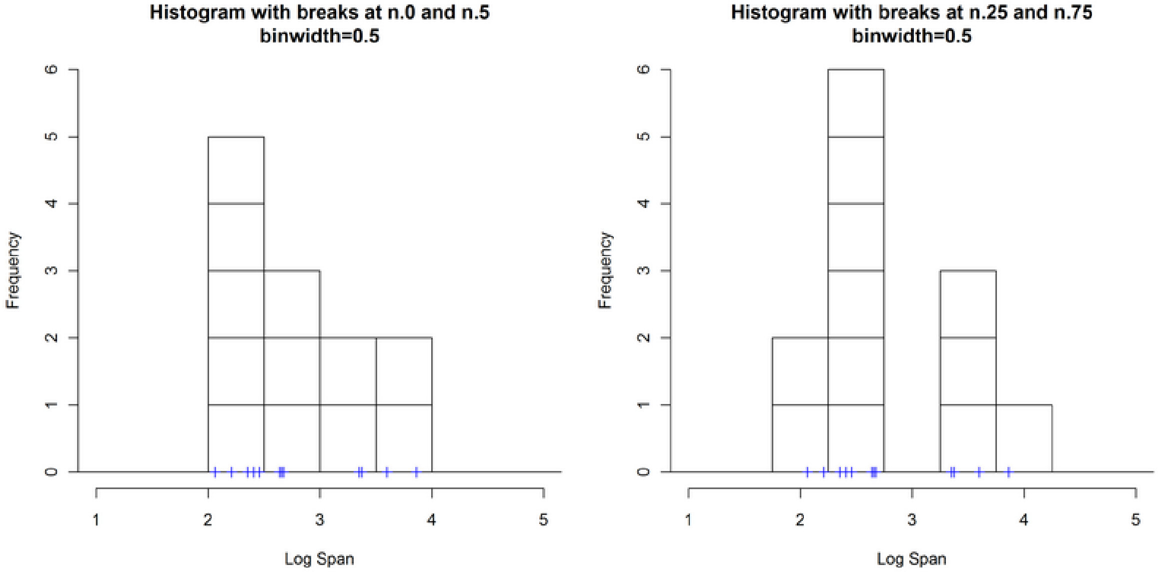
Where L is the total length of the transect.

To determine the precision of the estimates generated, DISTANCE the analytical variance is estimated using an estimation of encounter rate, the detection function and mean cluster size.

The final outputs from the DISTANCE® software include: density and population size outputs, coefficient of variance, standard error and the 95% confidence interval (upper and lower) for each estimate, detection probability, encounter rate and cluster size.

Appendix 3: Equations & background - Kernel Density estimation

KDE is based on the basic concepts of histograms. A histogram is a non-parametric density estimator, it is a representation of a data that has been divided into intervals which in themselves represent equal sub-intervals or bins. The interpretation of histograms is highly dependent on the width and start and end points of the bins (Figure 2.4).



Appendix 3.1: Example of effect bin size and start point on histogram interpretation (Taken from: http://www.mvstat.net/tduong/research/seminars/seminar-2001-05 on: 07/09/15)

To remove the problem points of bins by using a smooth kernel can be applied (Figure 2.5). A kernel density estimate smooths the distribution of the data creating a more continuous pattern than is possible when using histograms without a kernel smoothing function. A kernel density estimator can be defined as (Silverman 1986):

Equation 7

$$\widehat{f_\lambda}\,(x) = \frac{hv}{n\lambda}\sum_{i=1}^{n} K_o\left(\frac{x-x_i}{\lambda}\right)$$

Where $K_0(\cdot)$ is the kernel function; λ is the bandwidth; *n* is the sample size*;* x_i is the *ith* observation; and *v* is the vertical scaling factor.

Equation 8

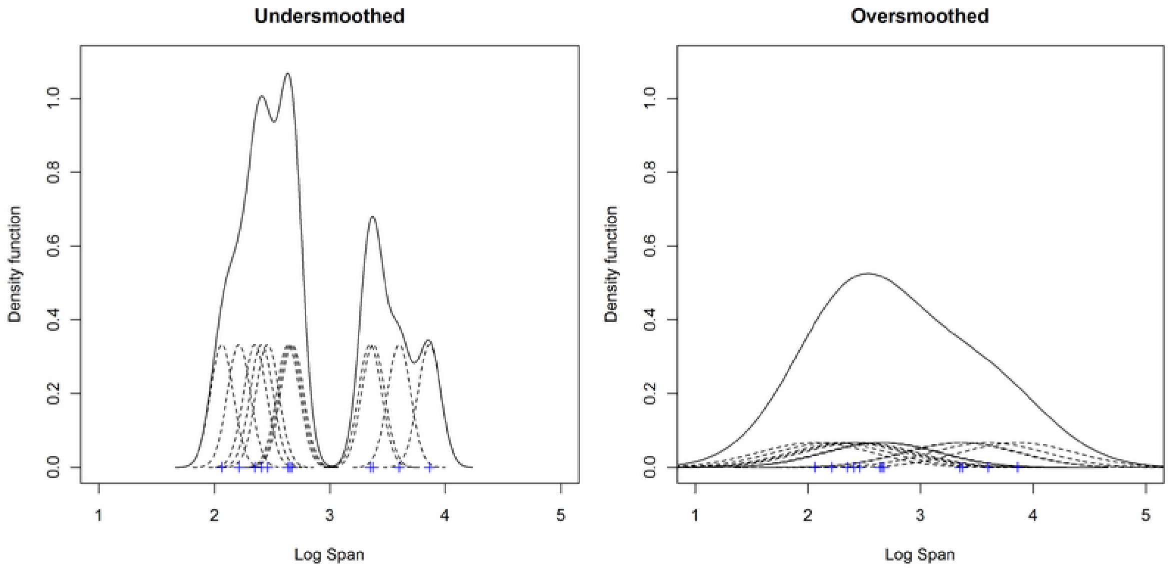
$$v = \begin{cases} n & for\ v\ scale = count \\ 100 & for\ v\ scale = percent \\ 1 & for\ v\ scale = proportion \end{cases}$$

The kernel function K_o used in ArcGIS® is the quadratic function:

Equation 9

$$K_0(t) = \frac{3}{4}(1 - t^2) \qquad for\ |t| \leq 1$$

The bandwidth λ should be chosen with caution because using values that are too small or too large may result in under-smoothing or over-smoothing and lead to the exaggeration or concealments on trends (Figure 2.4).



Appendix 3.2: Example of inadequate bandwidth that affect the precision of histograms. Taken from: http://www.mvstat.net/tduong/research/seminars/seminar-2001-05 on: 07/09/15)

In a GIS kernel functions smoothing parameters are applied to each data point (animals sighting), the density value is highest at the location of the point and decreases with distance from the point at a rate dependent on how the proximity of other data points. The bandwidth (or search radius) determine how far from the data points the smoothing parameter should reach before reaching a value of 0. In ArcGIS, the search radius for point data is fixed to circular. Data points can be given weight by specifying a 'Population field' which specifies how many times that point should be counted. For count data where clusters of animals were counted, the population field should be the total number of individuals in each cluster. The values of the kernel surfaces are summed where they overlay a cell centre to provide a cell density output for each cell in the raster map grid.

Appendix 4: Equations - Anselin's Local Moran's hotspot analysis

Anselin's Local Moran's analysis is a measure of autocorrelation that calculates a Local Moran's I value, a Z score, a p-value, and a code representing the cluster type for each weighted feature. The local Moran's statistic *I* is given as:

(Equation 7)

$$I_{\mathrm{i}} = \left(x_i - \frac{\bar{X}}{S_i^2}\right) \sum_{j=1,\ j\neq 1}^{n} w_{i,j}(x_j - \bar{X})$$

Where x_i is an attribute of feature i, $\bar{X}$ is the mean of the corresponding attribute and $w_{i,j}$ is the spatial weight between feature i and j

(Equation 8)

$$S_i^2 = \frac{\sum_{j=1,j\neq 1}^{n} w_{i,j}\left(x_j - \bar{X}\right)^2}{n-1} - \bar{X}^2$$

Where n = total number of features

The z_{I_i} score are generated as:

(Equation 9)

$$z_{I_i} = \frac{I_{i-}E[I_i]}{\sqrt{V\ [I_i]}}$$

Where

(Equation 10)

$$E[I_i] = -\frac{\sum_{j=1,j\neq 1}^{n} w_{ij}}{n-1}$$

And

(Equation 11)

$$V[I_i] = E\left[I_i^2\right] - E[I_i]^2$$

Appendix 5: Equations - Fuzzy kappa analysis

Fuzzy Kappa analysis produces and index statistic that on a scale of 0 to 1 calculates the similarity of categories at a location on one map (the value of a cell) with the categorical value of the matching cell of the map being compared. It also calculates the similarity of cells in the direct vicinity of the corresponding cells on the map being compared (Hagen-Zanker 2006).

The one way similarities s between cell i map A and Map B:

(Equation 12)

$$s_i(A,B) = \ max_j^N\left(f\left(A_i, B_j\right) * w\left(d_{i,j}\right)\right)$$

Where index j repeats through all N cells in the neighbourhood of cell i and $w(d)$ determines the weight pertaining to the neighbourhood distance.

The two one way similarities are combined to calculate the overall similarity $S_i(A,B)$ is:

(Equation 13)

$$S_i(A,B) = \min(s_i(A,B), s_i(B,A))$$

And the mean of similarities over all locations is:

(Equation 14)

$$S(A,B) = \frac{1}{n}\sum_{i=1}^{n} S_i(A,B)$$

The function $f(a,b)$ calculates the similarity of two values

(Equation 15)

$$f(a,b) = 1 - \frac{|a-b|}{\max(|a|,|b|)}$$

Where a and b are the two numerical values of the corresponding cells

Appendix 6: Assumptions and components of GLM's

There are three components to any GLM:

- **Random Component** - or the probability distribution of the response variable (Y); e.g. normal distribution of parameter *Y* in the linear regression, or binomial distribution for *Y* in the binary logistic regression.
- **Systematic Component** - specifies the explanatory variables (X_1, X_2, ... X_k) in the model, and their linear predictors ($\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_k x_k$) as in a linear regression.
- **Link Function**, η *or* $g(\mu)$ –that shows how the expected value of the response relates to the linear predictor of explanatory variables.

Where:

- The dependent variable Y_i does not need to be normally distributed, but should assume a distribution from an exponential family (e.g. binomial, Poisson, multinomial, normal)
- GLM does not assume a linear relationship between the dependent variable and the independent variables, but it does assume linear relationship between the transformed response in terms of the link function and the explanatory variables; e.g., for binary logistic regression $logit(\pi) = \beta_0 + \beta X$.
- The homogeneity of variance it is not possible in many cases given the model structure, and overdispersion is likely to be present.
- Maximum likelihood estimation (MLE) is employed instead of ordinary least squares (OLS) to estimate the parameters, and thus relies on large-samples

Appendix 7: Chapter 3 - Population estimates, Lower and Upper confidence values for study species in four sample seasons

Appendix 7.1: Populations values and confidence intervals (DISTANCE generated) for each study species in OK1 and OK2 in four sampling seasons

Species	Sample season	N	LCL	UCL
Thompson's Gazelle	1	1791	1657	1924
	2	3022	2787	3257
	3	2435	2263	2607
	4	1837	1719	1955
Wildebeest	1	822	719	924
	2	2411	2205	2617
	3	3166	2933	3398
	4	1504	1362	1646
Impala	1	600	548	652
	2	1319	1183	1455
	3	1971	1907	2036
	4	1216	1146	1286
Zebra	1	218	143	293
	2	1047	827	1266
	3	2925	2605	3245
	4	609	477	740
Grant's Gazelle	2	546	471	621
	3	851	757	944
	4	622	557	687
Giraffe	2	120	89	152
	3	315	255	375
	4	239	198	279
Topi	2	220	157	283
	3	467	384	551
	4	347	282	413

N = Population estimate; LCL = Lower confidence limit; UCL = Upper confidence limit

Appendix 7.2: Population values and confidence intervals (DISTANCE® generated) for each study species in OK1 and OK2 in four sampling seasons.

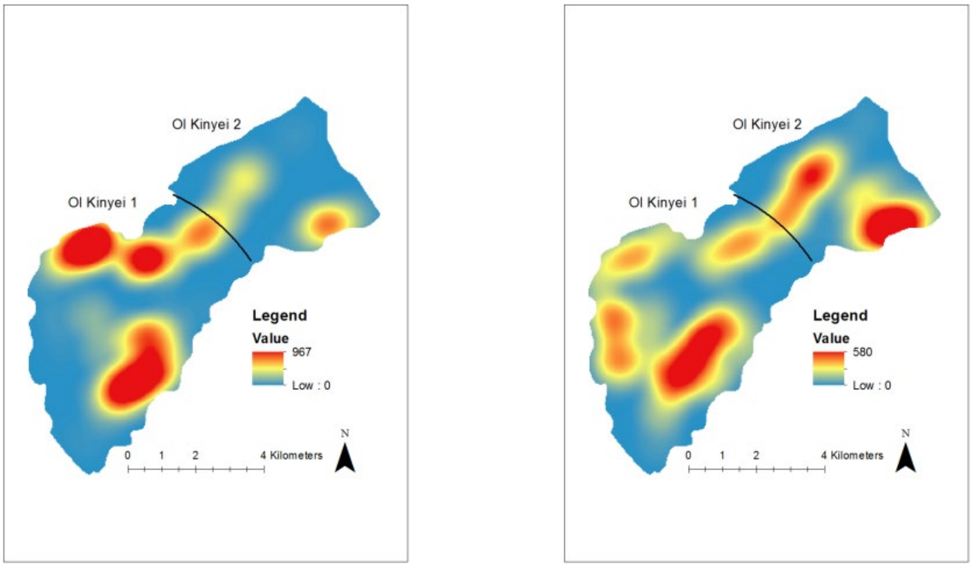
Species	Sample season	OK1			OK2		
		N	LCI	UCI	N	LCI	UCI
Thompson's Gazelle	1	1048	915	1182	742	581	904
	2	1811	1576	2046	1211	1060	1362
	3	1210	1038	1382	1225	1059	1391
	4	941	823	1059	896	741	1052
Wildebeest	1	552	450	655	269	168	371
	2	1338	1131	1544	1074	940	1208
	3	1696	1463	1929	1469	1341	1597
	4	689	547	830	815	693	937
Impala	1	414	362	466	186	101	270
	2	653	517	789	665	567	764
	3	900	836	965	1071	899	1243
	4	518	448	588	698	598	798
Zebra	1	167	92	242	51	3	99
	2	634	414	853	413	329	497
	3	1804	1484	2124	1121	968	1273
	4	248	116	379	361	258	464
Grant's Gazelle	2	340	265	415	205	161	250
	3	574	480	667	277	161	393
	4	417	352	482	204	114	294
Giraffe	2	60	28	91	61	32	90
	3	204	144	264	112	47	176
	4	89	49	129	150	83	216
Topi	2	143	80	206	77	47	108
	3	310	227	394	157	64	251
	4	130	64	195	218	172	264

N = Population estimate; LCL = Lower confidence limit; UCL = Upper confidence limit

Appendix 8: Chapter 4 – Grazer Kernel density distributions for each sample season

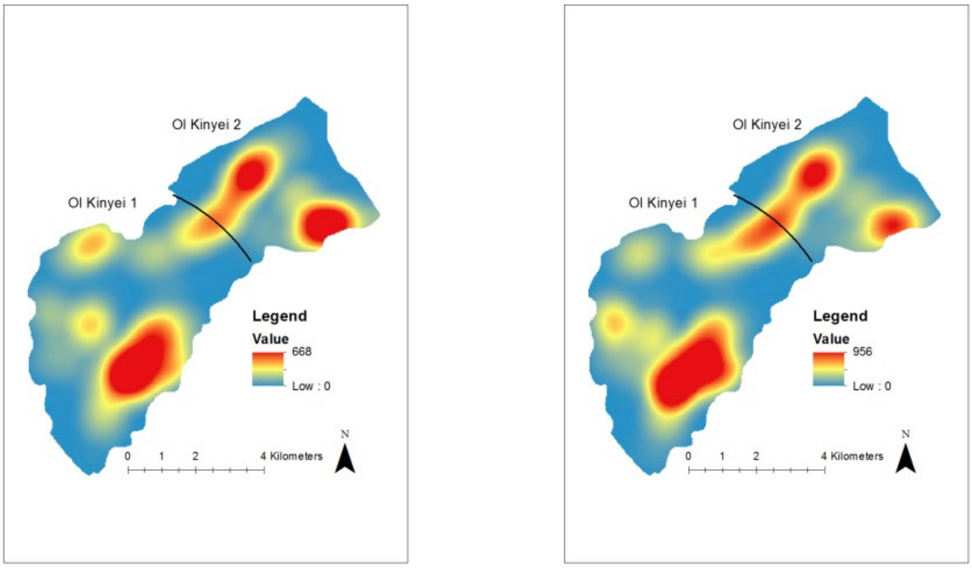
a. Sample season 1

b. Sample season 2



c. Sample season 3

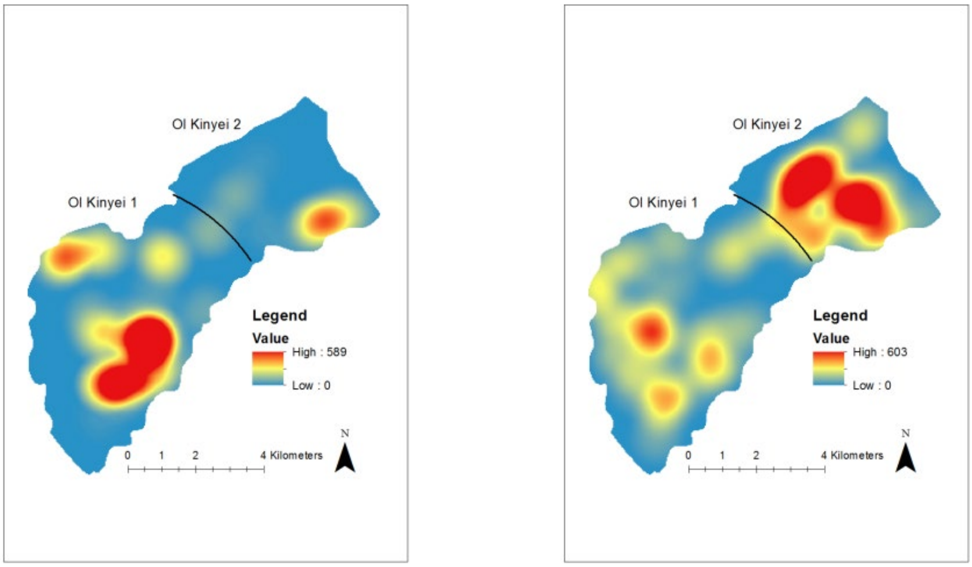
d. Sample season 4



Appendix 8.1: Thompson's gazelle distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

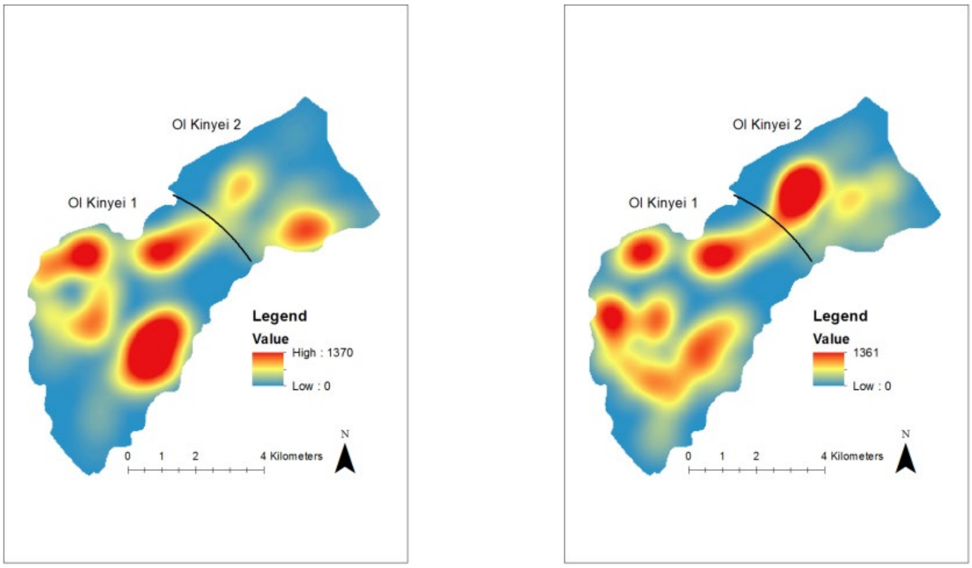
a. Sample season 1

b. Sample season 2



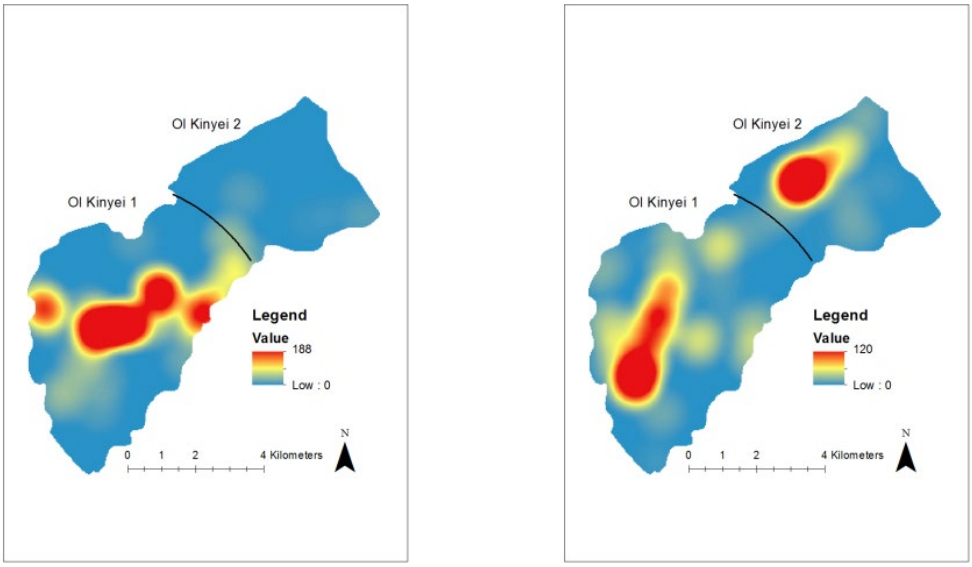
c. Sample season 3

d. Sample season 4

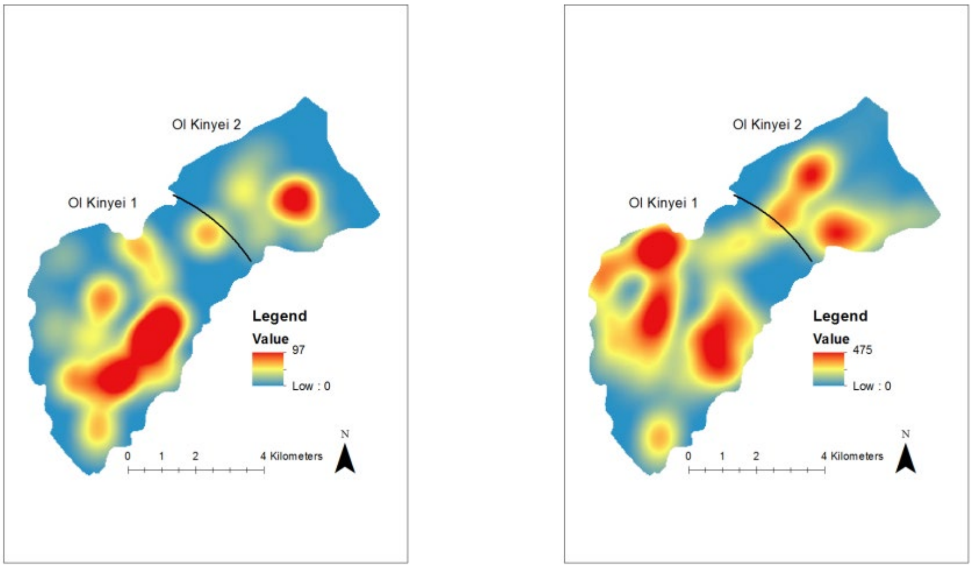


Appendix 8.2: Wildebeest distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

a. Sample season 1 b. Sample season 2

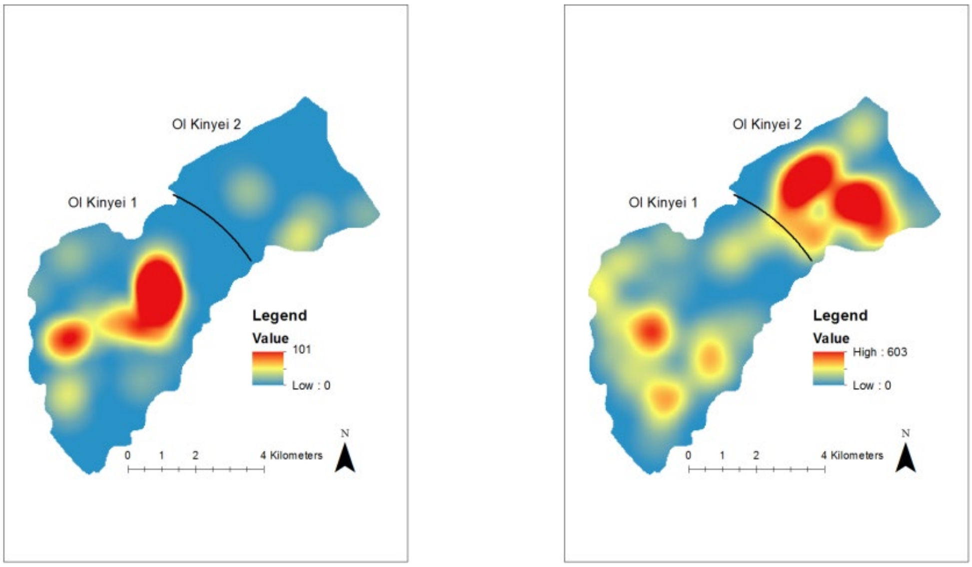


c. Sample season 3 d. Sample season 4

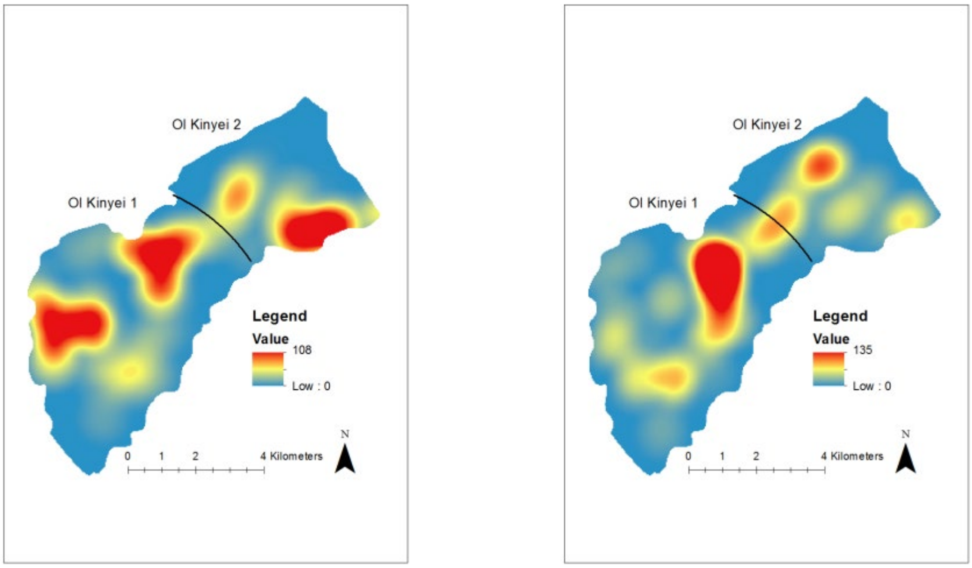


Appendix 8.3: Zebra distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

a. Sample season 1 b. Sample season 2



c. Sample season 3 d. Sample season 4

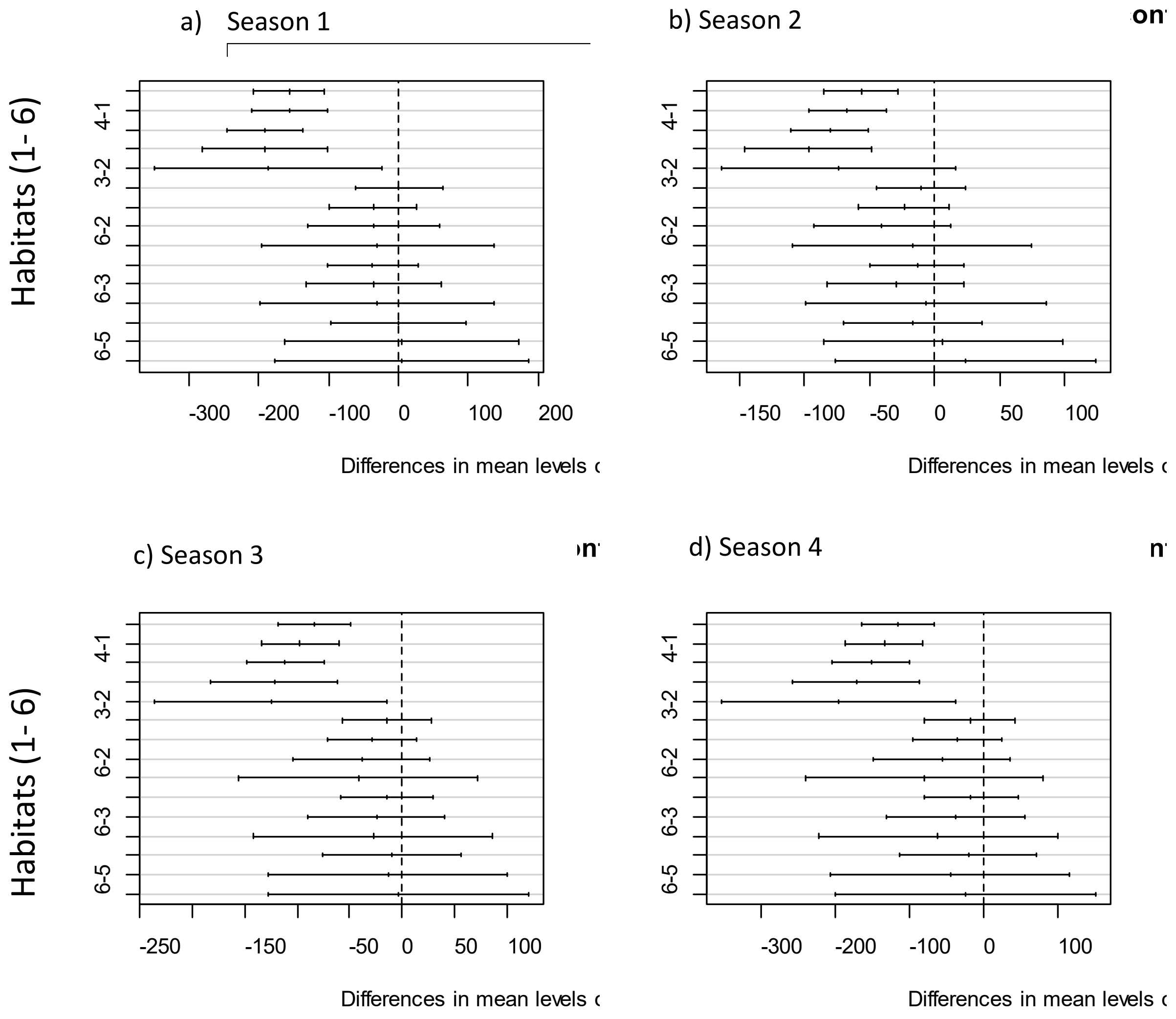


Appendix 8.4: Topi distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

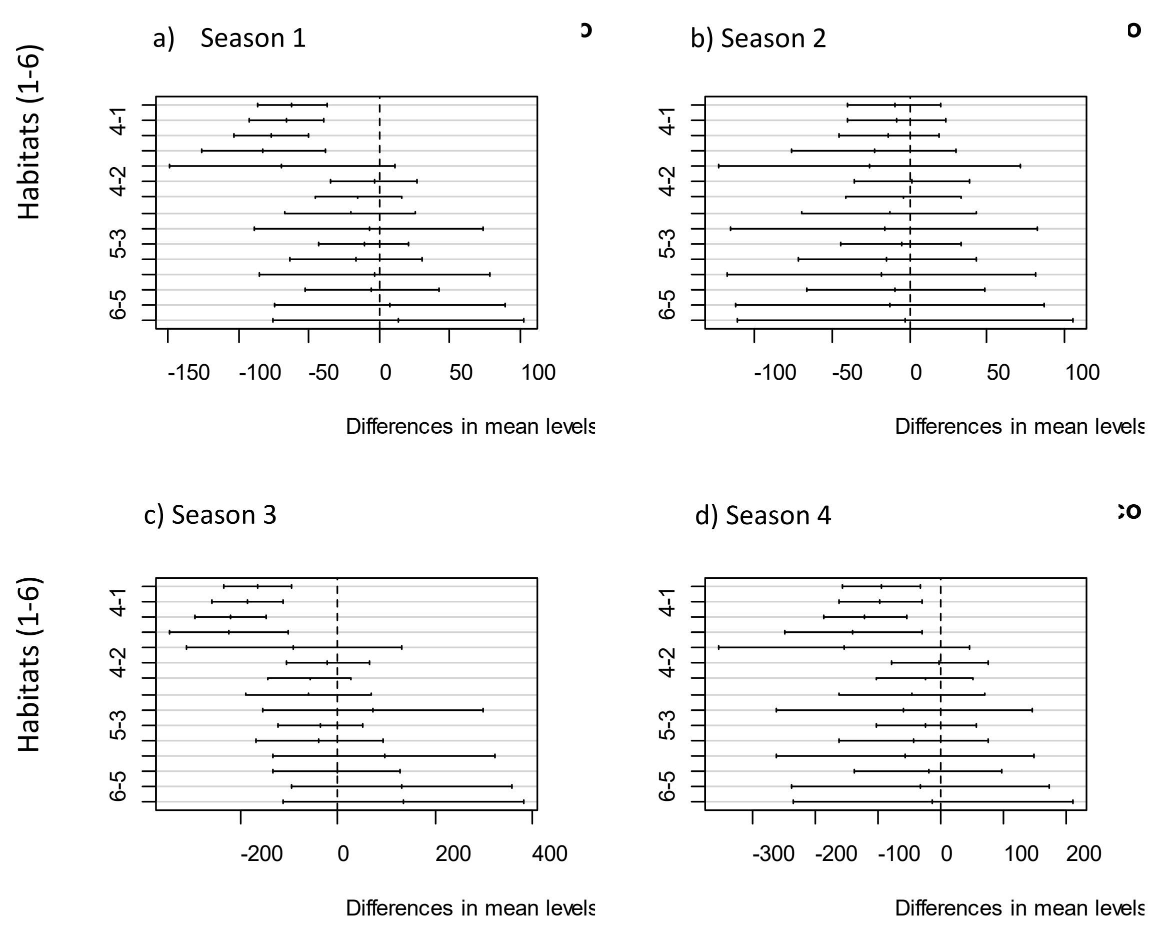
Appendix 8.5: Differential habitat use of grazing species in four field sampling season (ANOVA's)

Species	Season	F -Values	P- Value	Significance
Thompson's gazelles	1	34.22	<2e-16	***
	2	20.19	<2e-16	***
	3	25.99	<2e-16	***
	4	24.84	<2e-16	***
Wildebeest	1	23.93	<2e-16	***
	2	0.612	0.691	
	3	23.86	<2e-16	***
	4	24.84	<2e-16	***
Zebra	1	1.525	0.179	
	2	0.465	0.802	
	3	14.74	2e-14	***
	4	11.96	3.72e-11	***
Topi	1	1.525	0.179	
	2	0.465	0.802	
	3	14.74	8.2e-14	***
	4	11.96	3.72e-11	***

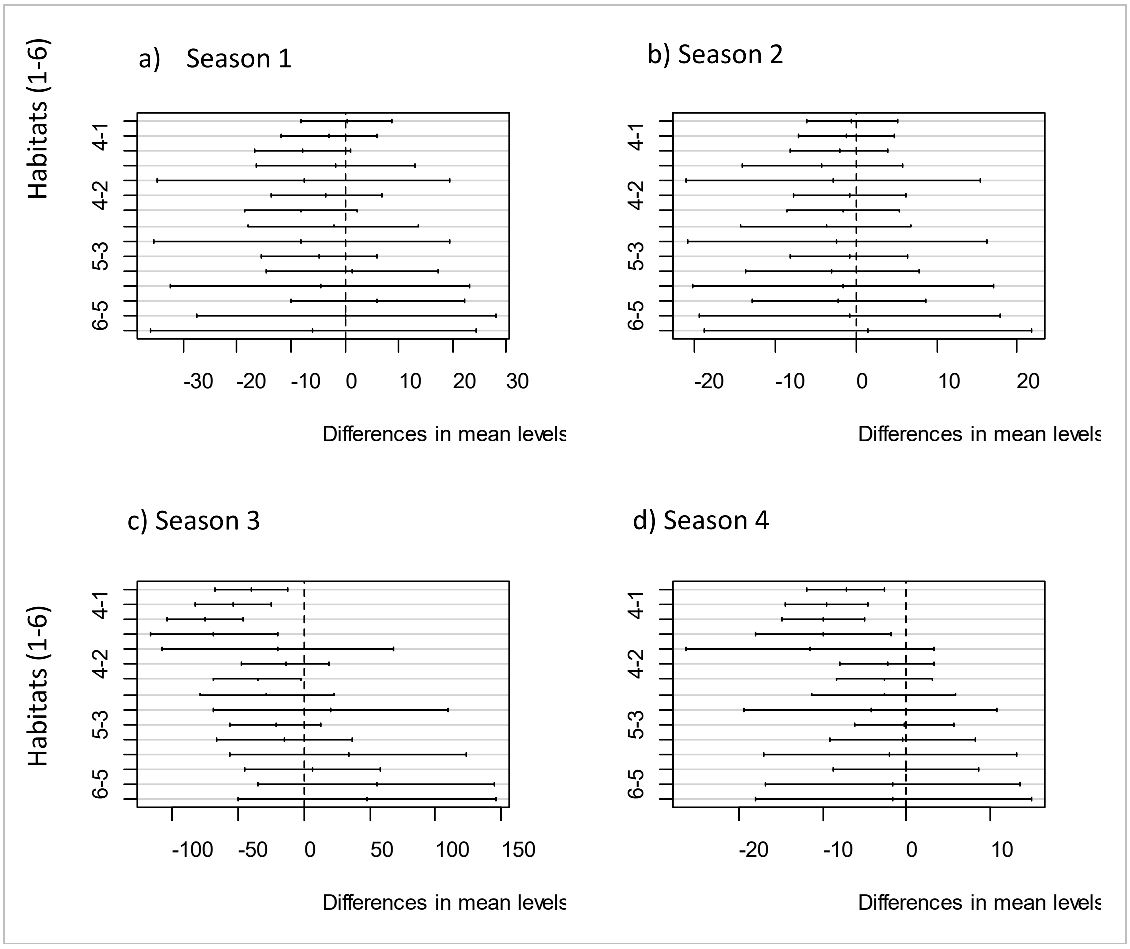
*** = 0.001 significance level



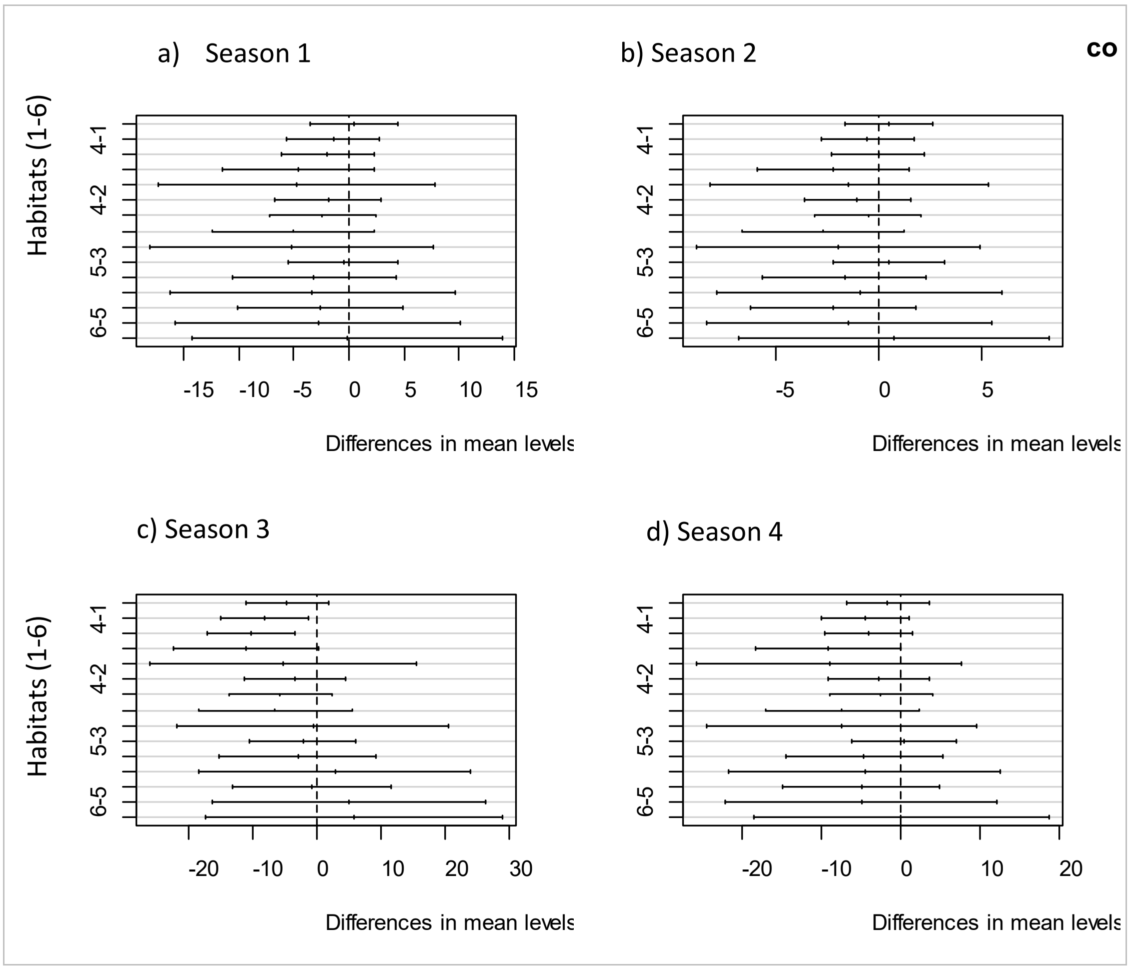
Appendix 8.6: Habitat use of Thompson's gazelles in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (A. drepanolobium), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest



Appendix 8.7: Habitat use of wildebeest in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (Acacia), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest

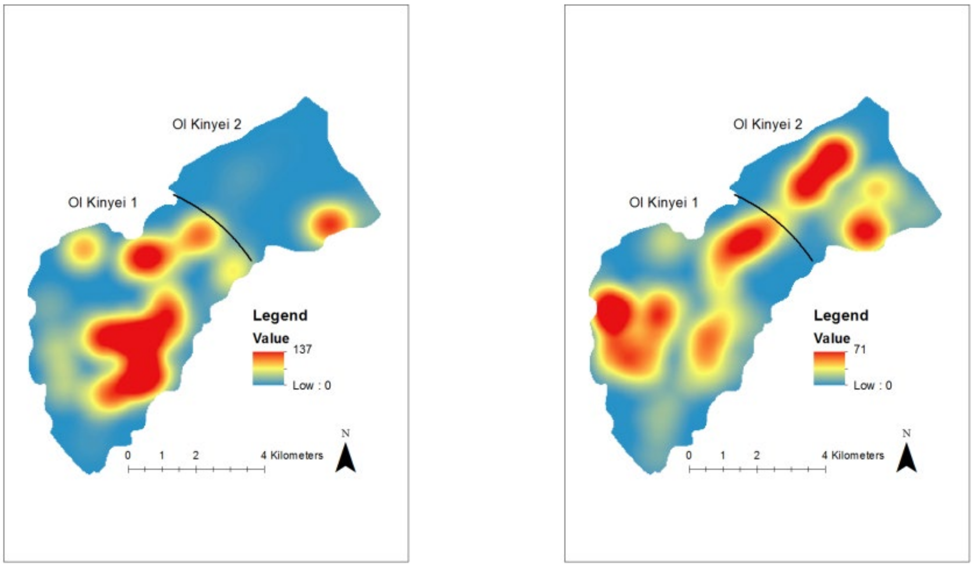


Appendix 8.8: Habitat use of zebra in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (Acacia), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest



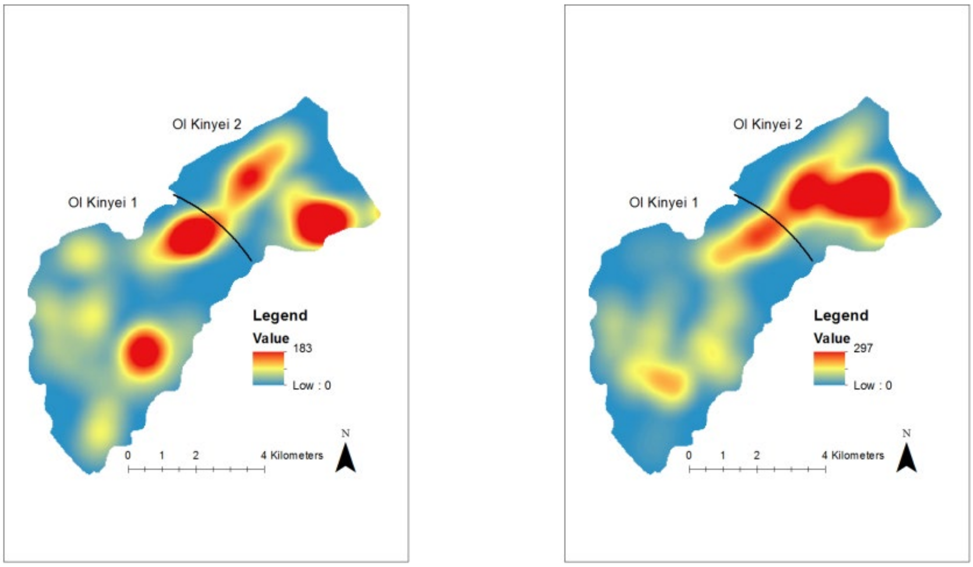
Appendix 8.9: Habitat use of topi in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (Acacia), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest

Appendix 9: Chapter 5 – Mixed feeder & browser density distributions and habitat use for each sample season



a. Sample season 1

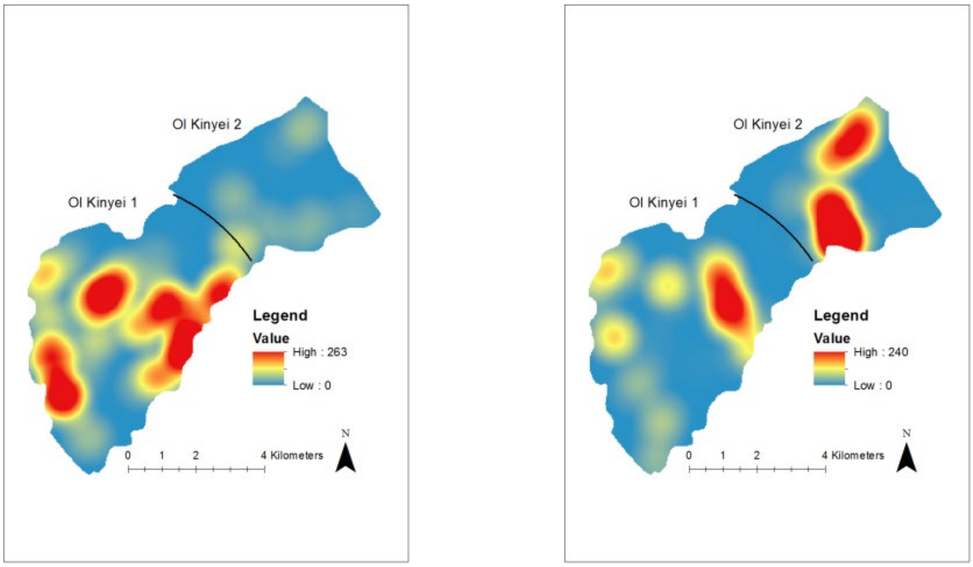
b. Sample season 2



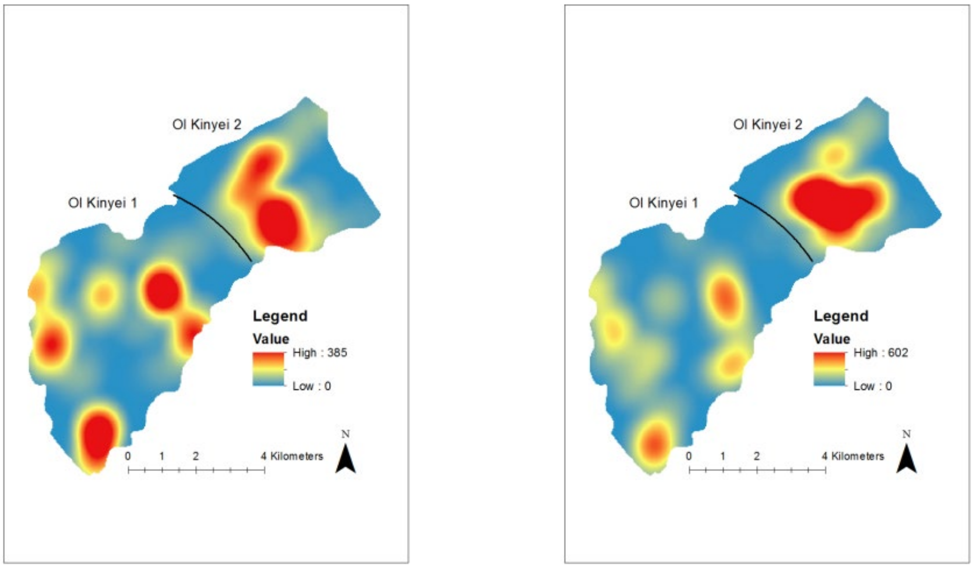
c. Sample season 3

d. Sample season 4

Appendix 9.1: Grant's gazelle distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)


a. Sample season 1

b. Sample season 2

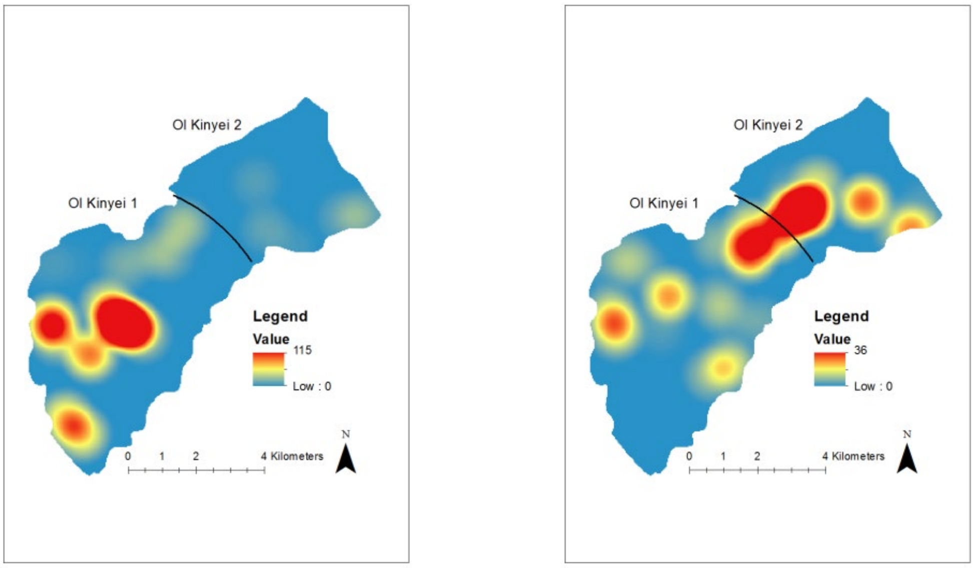

c. Sample season 3

d. Sample season 4

Appendix 9.2: Impala distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

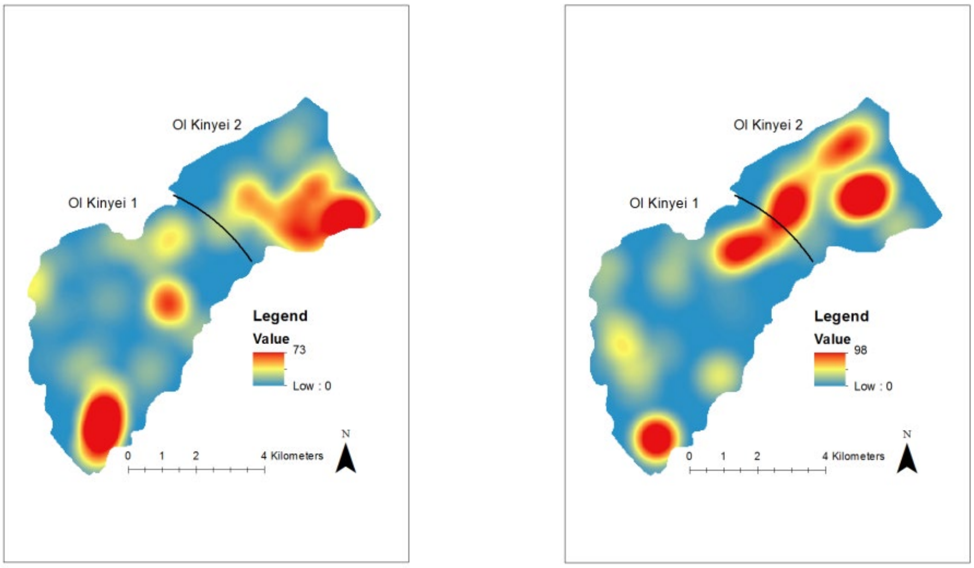
a. Sample season 1

b. Sample season 2



c. Sample season 3

d. Sample season 4

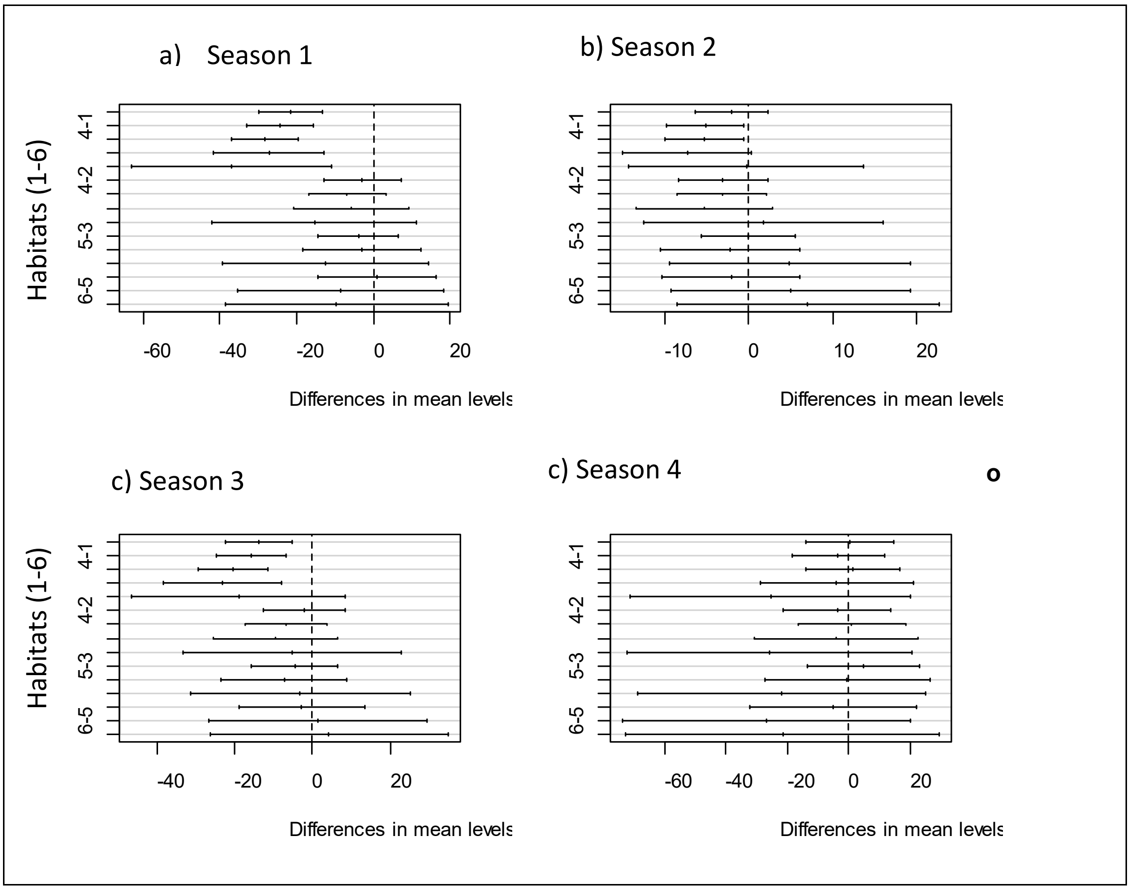


Appendix 9.3: Giraffe distributions in four sample seasons (KDE: bandwidth 1km & cell size 30m)

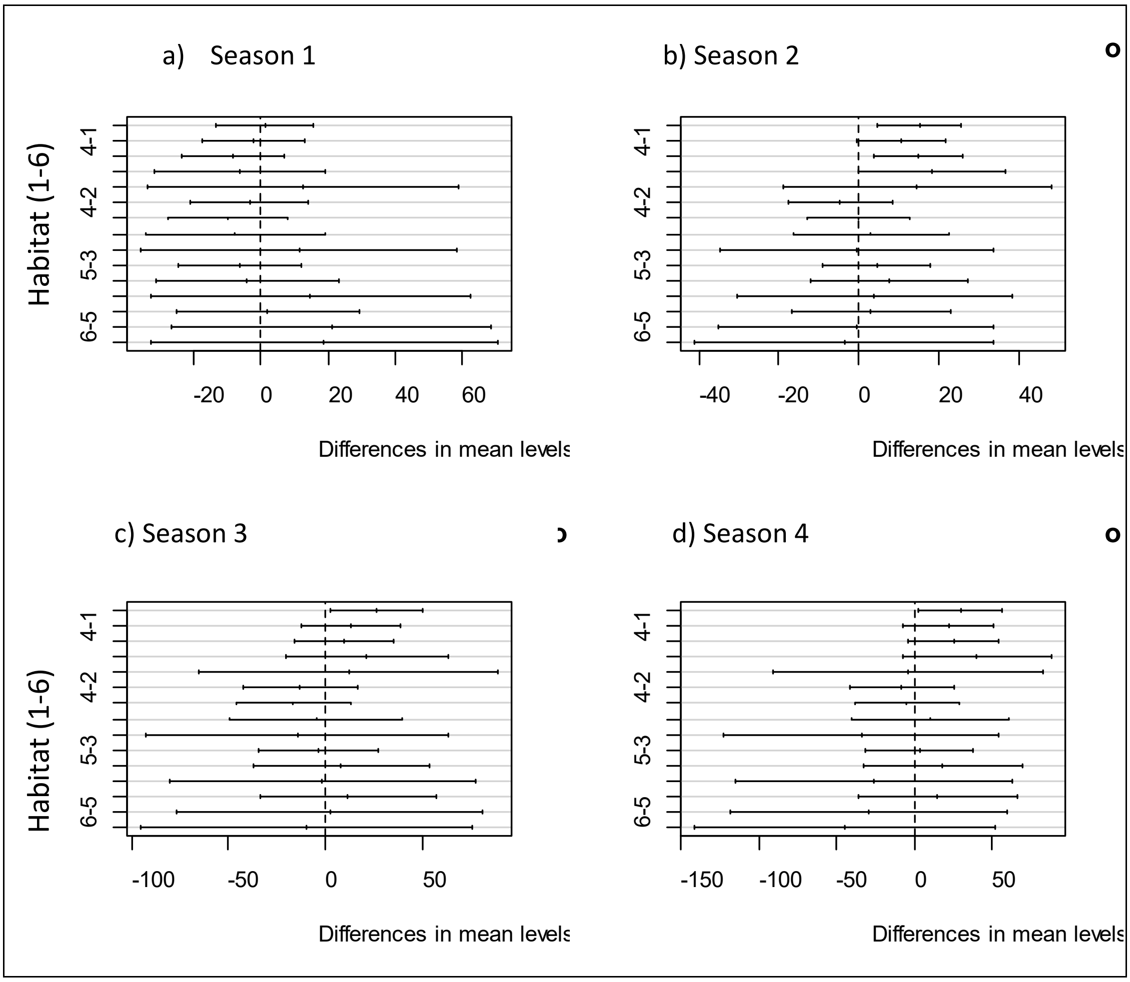
Appendix 9.4: Habitat use (ANOVA DF=5; density and habitat classifications) of Grant's gazelles, impala and giraffe in four field seasons

Species	Season	F-Value	P- Value	Significance
Grant's gazelles	1	29.99	<2e-16	***
	2	4.078	0.00117	**
	3	13.04	3.44E-12	***
	4	0.661	0.653	NS
Impala	1	0.809	0.543	NS
	2	5.817	2.79E-05	***
	3	2.181	0.0545	NS
	4	3.325	0.00561	**
Giraffe	1	0.807	0.545	NS
	2	5.817	2.79E-05	***
	3	1.514	0.183	NS
	4	0.743	0.592	NS

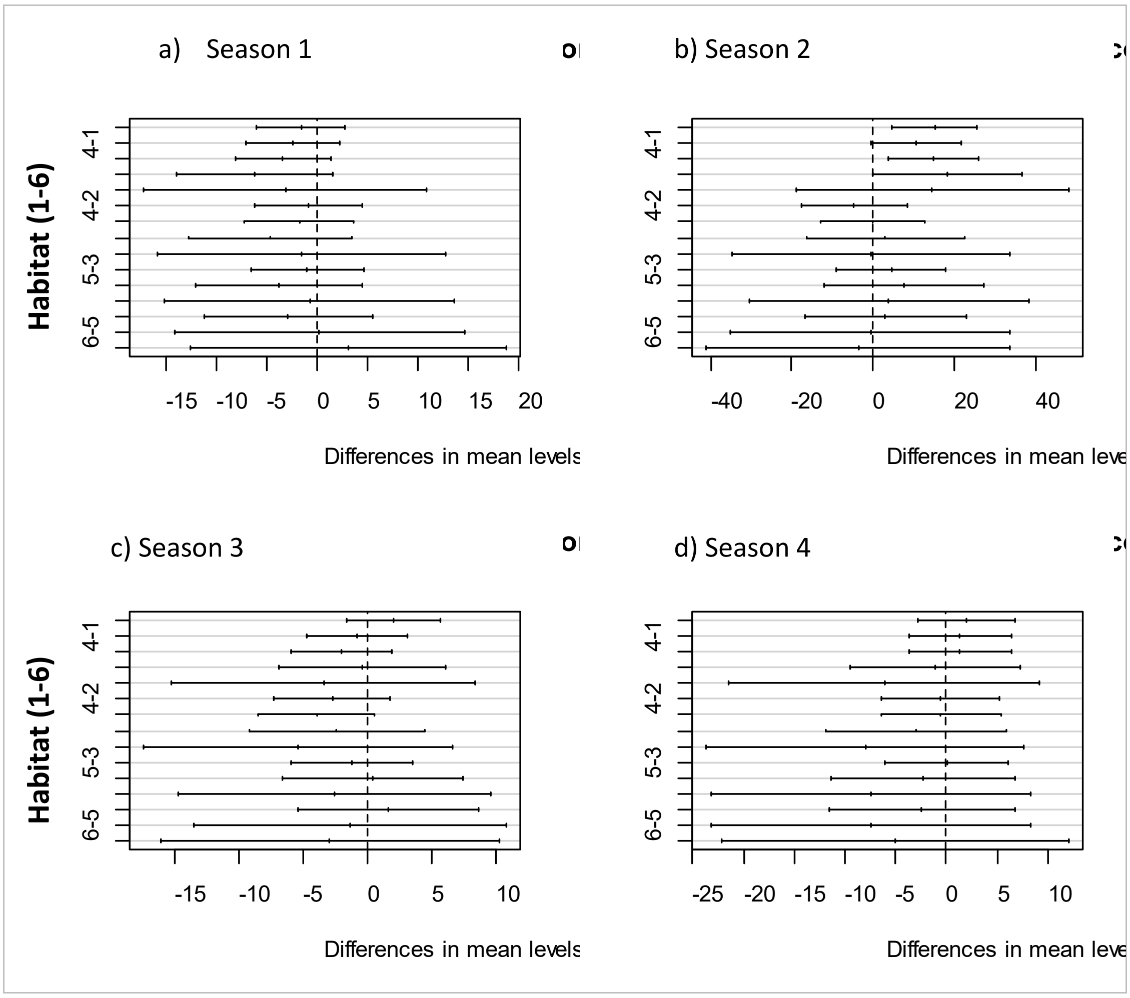
***= 0.001; **= 0.01; *= 0.05



Appendix 9.5: Habitat use of Grant's gazelles in four field season's (post hoc Tukey test) 95% Pairwise confidence level (significant differences do not cross zero value) in classified habitats

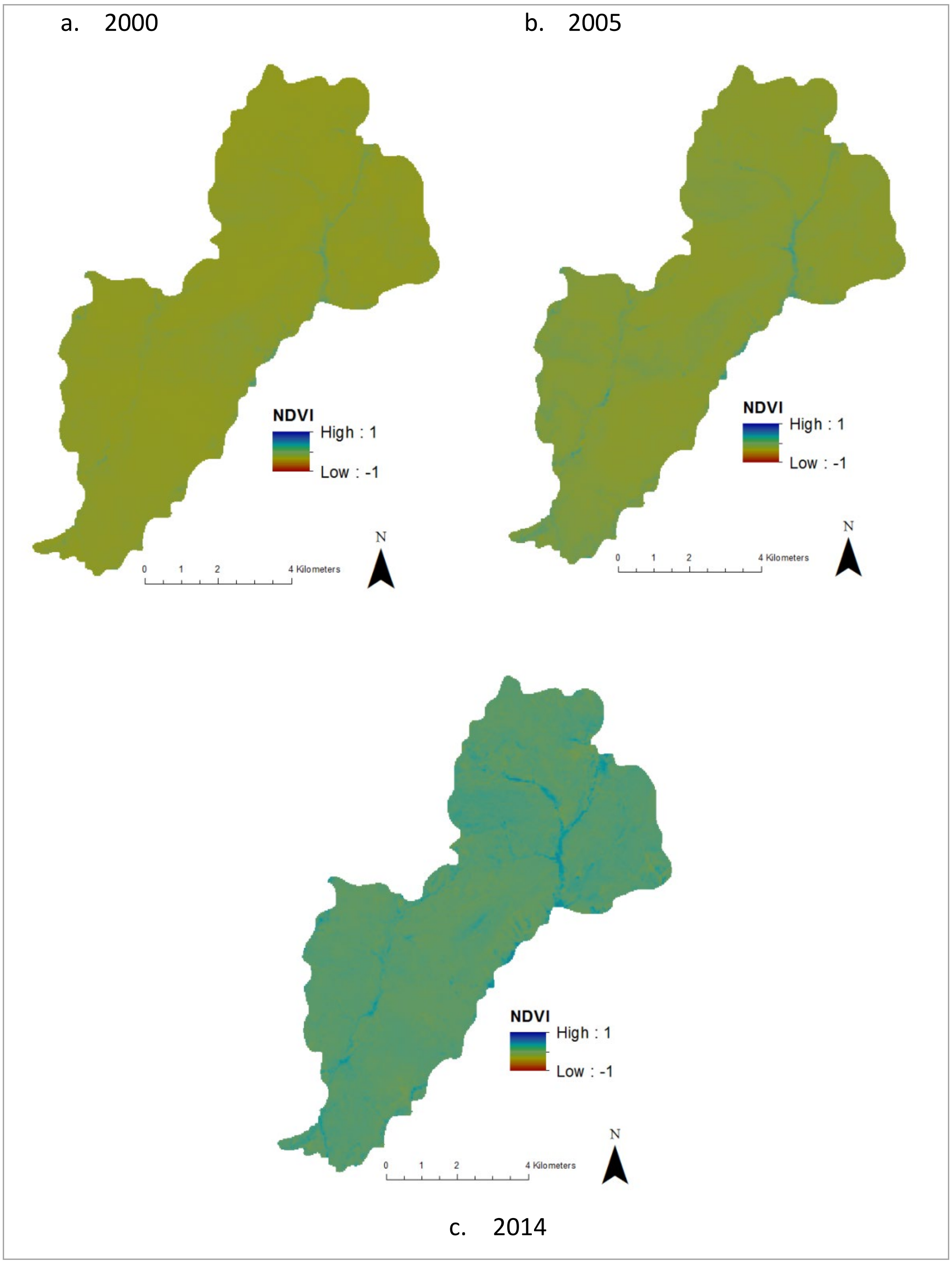


Appendix 9.6: Habitat use of impala in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (A. drepanolobium), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest



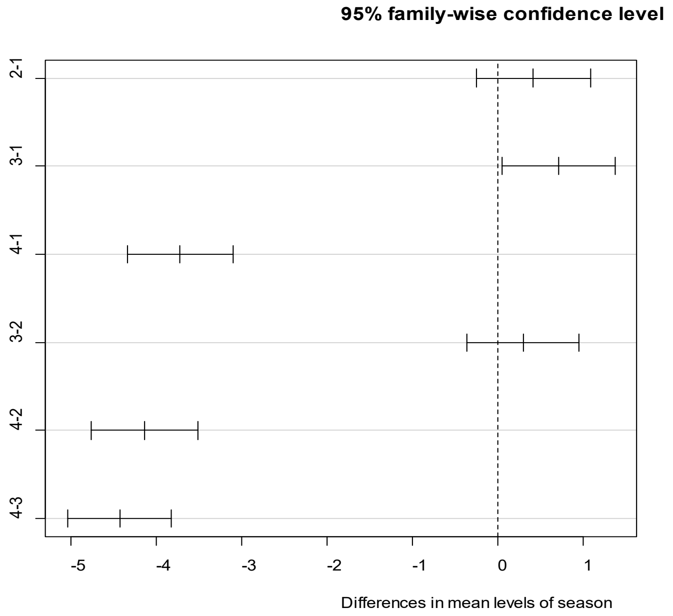
Appendix 9.7: Habitat use of giraffe in four field season's (post hoc Tukey test) 95% Pairwise confidence level – significant differences do not cross zero value. Habitats: 1 = Open grassland, 2 = Shrubland (A. drepanolobium), 3 = Shrubland (Croton spp.), 4 = Acacia woodland, 5 = Hill slope, 6 = Riparian forest

Appendix 10: NDVI in Ol Kinyei Conservancy 2000, 2005 & 2014

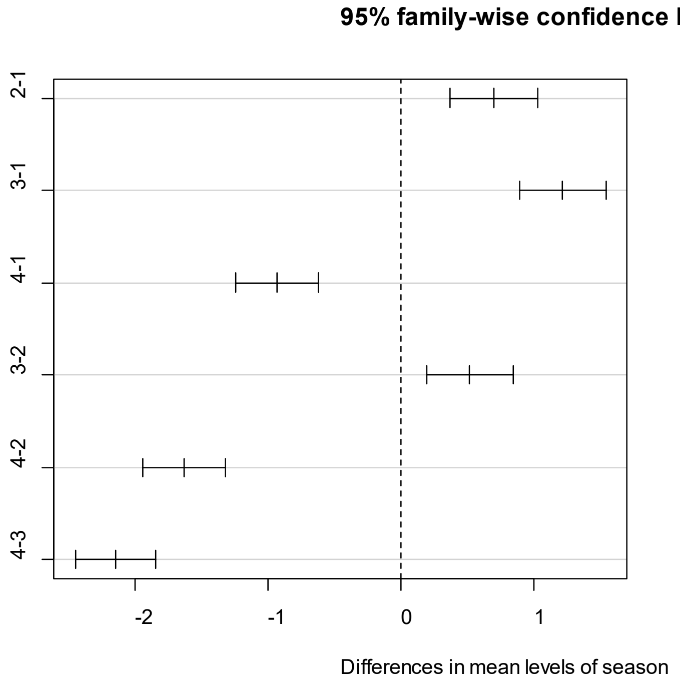


Appendix 10.1: Normalised difference vegetation index (NDVI: 1 = high productivity; -1 = low = no productivity) in Ol Kinyei conservancy in 2000, 2005 and 2014

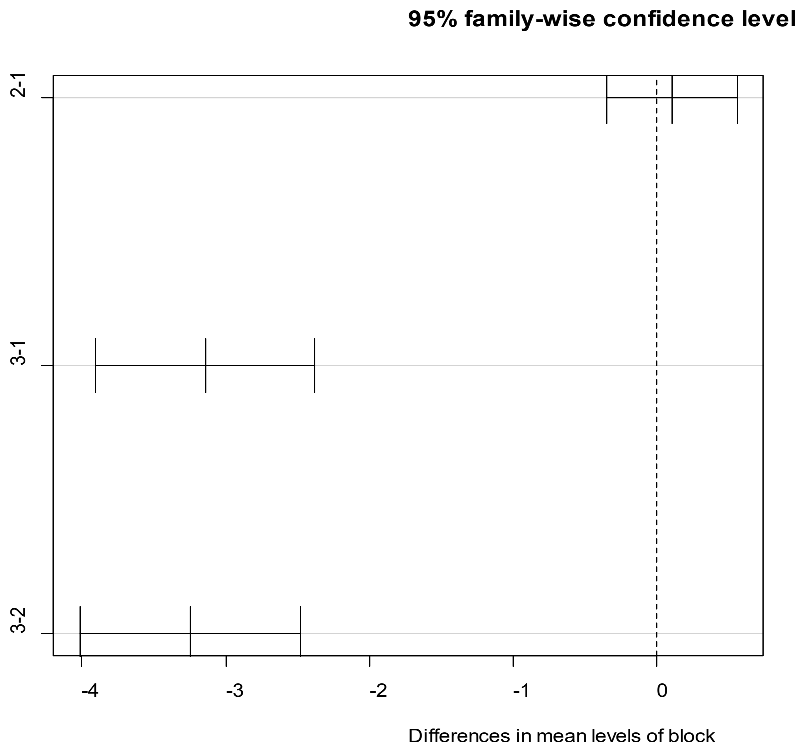
Appendix 11: Chapter 6: Tukey results temporal changes to habitat composition & species composition and height of the herbaceous layer



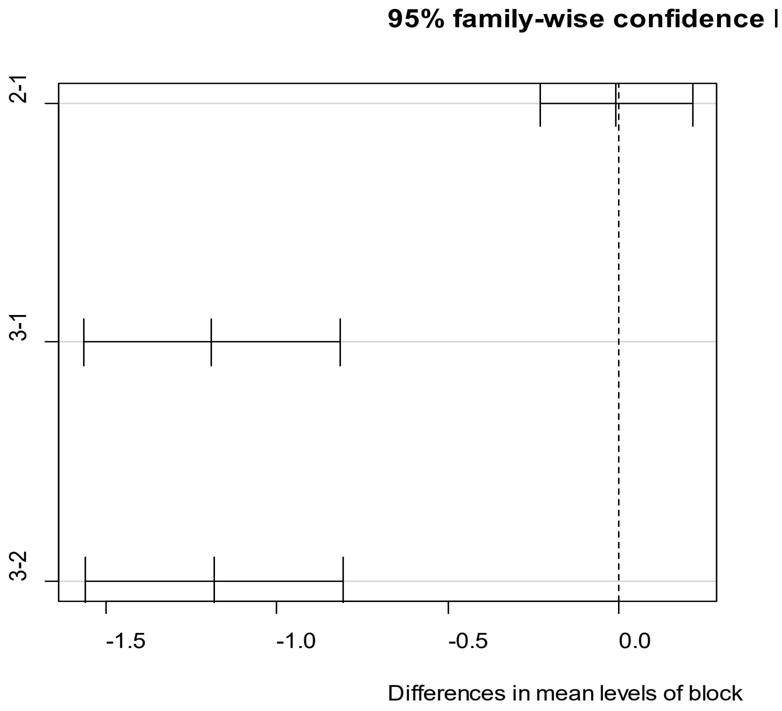
Appendix 11.1: Pairwise comparison of Tukey results for difference in total grass height in four sampling seasons (significant results do not bisect the zero value)



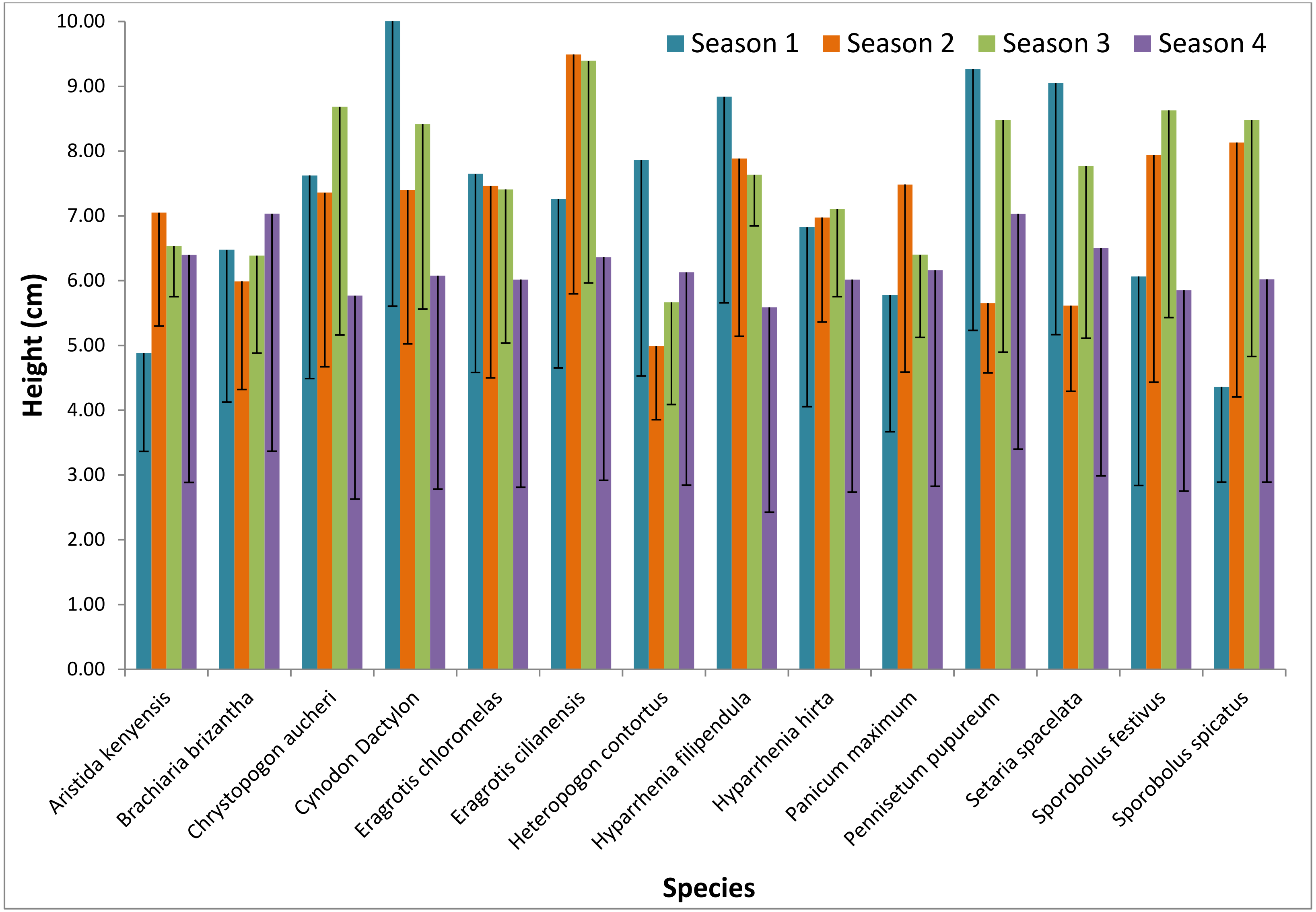
Appendix 11.2: Pairwise comparison of Tukey results for difference in basal grass height in four sampling seasons (significant results do not bisect the zero value



Appendix 11.3: Pairwise comparisons of total grass height in three sampling blocks: 1 = OK1, 2 = OK2, 3= Outside conservancy



Appendix 11.4: Pairwise comparisons of basal grass height in three sampling blocks: 1 = OK1, 2 = OK2, 3= Outside conservancy



Appendix 11.5: Mean height and basal height (error bars) per sampling season

Appendix 11.6: Percentage cover of herbaceous species in each sampling quadrat in sample season 1

Sample season 1	Sampling Quadrat																			
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Aristida kenyensis	2	0	5	0	0	5	2	2	0	7	10	12	2	10	5	10	12	10	5	12.5
Bare ground	25	11	38	38	20	12	21	0	20	49	27	12	14	20	13	20	17	22	15	7.5
Brachiaria brizantha	2	4	5	3	0	5	2	9	4	2	5	2	0	3	5	2	5	0	5	2.5
Chrystopogon aucheri	4	4	5	3	2	5	0	2	2	2	5	5	5	5	8	0	7	2	5	10.0
Cynodon Dactylon	11	4	0	0	20	5	17	26	13	0	22	24	35	10	25	32	29	17	22	20.0
Eragrotis chloromelas	2	2	0	0	2	0	5	2	2	0	2	2	0	8	0	0	2	0	5	5.0
Eragrotis cilianensis	2	7	3	5	0	0	0	0	0	0	0	0	2	0	5	0	2	0	0	0.0
Heteropogon contortus	4	2	3	5	2	5	2	2	2	5	0	5	2	5	3	2	0	10	2	2.5
Hyparrhenia filipendula	0	2	0	0	0	0	7	2	4	0	0	0	2	0	0	2	0	2	0	0.0
Hyparrhenia hirta	2	2	5	0	2	0	2	2	7	5	7	5	5	3	5	10	5	2	10	2.5
Panicum maximum	6	9	5	3	9	7	2	7	2	2	5	5	12	10	10	5	5	10	7	10.0
Pennisetum pupureum	6	2	0	3	5	2	0	2	4	2	2	0	0	0	0	0	0	2	0	0.0
Setaria spacelata	0	4	0	3	0	2	5	2	2	2	0	0	2	3	0	0	2	0	0	0.0
Solamun incanum	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0.0
Sporobolus festivus	0	0	0	0	0	10	0	4	2	5	0	5	0	5	0	2	0	0	7	2.5
Sporobolus spicatus	2	0	0	0	0	5	0	4	4	2	0	7	0	0	5	2	0	2	5	2.5
Themeda triandra	34	46	33	40	36	38	33	33	27	15	15	15	19	20	18	12	12	20	12	22.5

Appendix 11.7: Percentage cover of herbaceous species in each sampling quadrat in sample season 2

Sample season 2	Sampling Quadrat																			
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Aristida kenyensis	9	2	5	0	5	10	7	9	9	2	7	10	9	0	5	2	2	5	17	0
Bare ground	17	9	15	18	14	19	12	15	16	12	22	20	2	10	18	20	24	20	7	12.5
Brachiaria brizantha	4	2	5	3	0	2	12	2	2	5	0	5	7	5	0	0	0	2	2	10
Chrystopogon aucheri	8	7	5	8	5	0	0	7	4	5	0	2	5	3	13	2	7	2	7	5
Cynodon Dactylon	26	11	25	15	14	19	17	15	11	22	15	15	14	23	18	20	7	7	12	15
Eragrotis chloromelas	0	2	3	0	5	2	2	2	0	2	0	2	2	8	0	2	2	10	0	0
Eragrotis cilianensis	2	2	0	5	0	0	0	2	2	2	2	2	0	0	3	0	0	0	2	2.5
Heteropogon contortus	0	7	3	10	0	0	5	4	2	12	0	0	5	3	0	2	5	5	0	5
Hyparrhenia filipendula	0	4	3	0	0	0	2	2	0	0	2	2	2	0	0	0	0	0	0	2.5
Hyparrhenia hirta	6	0	3	0	2	5	2	4	4	2	2	5	7	5	3	15	2	5	5	2.5
Panicum maximum	6	13	10	5	25	7	2	2	7	7	5	2	5	5	8	5	12	10	7	5
Pennisetum pupureum	0	2	0	5	0	2	0	2	2	5	0	2	7	0	0	2	2	0	0	0
Setaria spacelata	0	2	3	3	0	5	0	2	2	2	5	0	2	0	3	2	0	2	0	0
Solamun incanum	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Sporobolus festivus	4	4	0	3	0	2	2	9	2	2	5	2	0	5	0	2	5	0	0	2.5
Sporobolus spicatus	4	0	0	5	5	2	0	0	4	2	2	0	7	3	0	2	0	2	5	5
Themeda triandra	15	33	23	23	27	24	36	22	29	15	32	29	26	33	33	22	29	29	34	32.5

Appendix 11.8: Percentage cover of herbaceous species in each sampling quadrat in sample season 3

Sample season 3	Sampling Quadrat																			
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Aristida kenyensis	7	2	5	0	4	7	7	6	8	2	7	9	9	0	2	2	2	5	19	0
Bare ground	10	6	11	14	12	16	9	10	15	9	13	19	2	10	16	18	24	18	7	12.5
Brachiaria brizantha	8	8	7	5	2	7	11	4	2	7	2	5	9	5	0	0	0	2	2	10
Chrystopogon aucheri	10	8	7	10	4	0	0	4	4	4	2	5	4	2	12	2	7	2	7	7.5
Cynodon Dactylon	18	8	18	12	14	14	18	14	13	20	11	12	13	12	14	18	2	5	9	12.5
Eragrotis chloromelas	3	2	2	0	6	2	2	0	0	2	7	2	2	7	5	2	2	9	2	0
Eragrotis cilianensis	3	4	0	5	0	2	0	6	2	2	4	5	0	2	2	0	2	0	2	5
Heteropogon contortus	3	6	2	10	2	0	5	4	6	11	0	0	4	2	0	2	5	5	0	2.5
Hyparrhenia filipendula	0	4	2	0	0	2	2	2	0	0	2	2	2	0	0	0	0	2	2	2.5
Hyparrhenia hirta	8	0	5	2	6	5	2	6	2	2	4	5	7	5	2	14	2	5	7	2.5
Panicum maximum	5	12	9	5	24	7	2	4	6	7	4	5	4	7	9	5	17	9	9	7.5
Pennisetum pupureum	2	2	0	5	0	5	0	2	2	7	0	0	7	2	0	5	2	5	2	2.5
Setaria spacelata	0	2	7	2	2	5	2	2	0	2	4	0	2	0	2	2	0	2	0	0
Solamun incanum	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Sporobolus festivus	3	4	2	2	0	2	7	10	4	4	4	5	2	7	5	5	5	0	0	2.5
Sporobolus spicatus	3	0	0	5	0	5	0	0	6	2	4	0	7	5	0	5	0	2	5	5
Themeda triandra	15	32	23	24	22	23	32	26	27	18	29	28	26	32	30	20	29	30	26	27.5

Appendix 11.9: Percentage cover of herbaceous species in each sampling quadrat in sample season 4

Sample season 4	Sampling Quadrat																		
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Aristida kenyensis	0	10	5	6	10	5	13	8	13	5	2	2	3	5	5	0	23	8	3	
Bare ground	18	10	10	13	18	13	8	3	15	7	2	10	10	5	8	8	5	8	5	
Brachiaria brizantha	8	5	5	5	5	0	5	5	3	0	10	0	5	3	0	3	0	8	5	
Chrystopogon aucheri	3	3	3	8	3	8	10	0	3	10	10	7	3	13	8	3	3	5	5	
Cynodon Dactylon	18	0	8	11	10	15	15	18	23	10	7	17	10	18	10	10	5	15	15	
Eragrotis chloromelas	3	3	0	6	3	3	3	0	3	0	5	0	3	0	5	10	0	0	5	
Eragrotis cilianensis	3	0	3	1	3	5	8	3	5	0	5	7	3	3	3	3	3	0	3	
Heteropogon contortus	3	8	5	1	0	8	3	5	0	5	2	7	0	0	3	10	0	8	5	
Hyparrhenia filipendula	3	3	5	5	3	3	0	3	3	5	2	0	0	3	0	0	3	0	3	
Hyparrhenia hirta	3	10	3	1	3	3	3	15	3	2	2	2	8	8	13	5	3	3	13	
Panicum maximum	3	3	5	8	13	8	8	10	10	12	12	7	13	8	10	13	10	10	5	
Pennisetum pupureum	0	3	5	6	3	0	3	5	3	0	2	2	0	0	3	3	0	3	3	
Setaria spacelata	5	5	0	0	0	5	3	3	0	2	5	2	0	3	0	0	3	0	3	
Solamun incanum	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sporobolus festivus	3	0	10	3	8	8	0	3	8	5	0	5	5	3	5	3	0	0	8	
Sporobolus spicatus	0	5	5	1	8	0	5	0	3	5	0	5	8	3	0	3	5	8	5	
Themeda triandra	33	33	30	25	15	20	18	23	10	32	32	24	33	30	30	30	40	28	18	

Appendix 12: Chapter 7 – GLM model parameters

Appendix 12.1: Model parameters Thompson's gazelles

Variable	Trend	P-value	Relationship
Elevation	Negative	***	Density decreased with increased elevation
RTP		NS	
NDVI		NS	
Distance from water	Positive	***	Density increased with increased distance
Aspect		NS	
Habitat	Positive	***	Rank
▪ Grassland		***	1
▪ Shrubland (Acacia)		***	4
▪ Shrubland (Croton)		***	3
▪ Woodland		***	5
▪ Hill slope		***	2
▪ Riparian		*	6

Appendix 12.2: Model parameters Wildebeest

Variable	Trend	P-value	Relationship
Elevation	Negative	***	Density decreased with increased elevation
RTP	Negative	**	Density decreases with increased ruggedness
NDVI		NS	
Distance from water	Positive	***	Density increased with increased distance
Aspect	Positive	***	Rank
▪ Flat		NS	1
▪ North		NS	1
▪ Northeast		NS	2
▪ East		NS	3
▪ Southeast		*	4
▪ South		**	7
▪ Southwest		**	8
▪ West		*	5
▪ Northwest		*	6
▪ North		NS	1
Habitat	Positive	***	Rank
▪ Grassland		***	1
▪ Shrubland (Acacia)		***	5
▪ Shrubland (Croton)		***	4
▪ Woodland		***	6
▪ Hill slope		***	3
▪ Riparian		*	2

Appendix 12.3: Model parameters Zebra

Variable	Trend	P-value	Relationship
Elevation	Negative	***	Density decreased with increased elevation
RTP		NS	
NDVI	Negative	*	Density decreased with increased NDVI
Distance from water	Positive	***	Density increased with increase distance
Aspect		NS	
Habitat	Positive	***	Rank
▪ Grassland		NS	1
▪ Shrubland (Acacia)		**	5
▪ Shrubland (Croton)		**	6
▪ Woodland		*	4
▪ Hill slope		NS	2
▪ Riparian		NS	3

Appendix 12.4: Model parameters Topi

Variable	Trend	P-value	Relationship
Elevation		NS	
RTP	Negative	**	Density decreases with ruggedness
NDVI	Negative	***	Density decreased with increased NDVI
Distance from water	Positive	***	Density increased with increase distance
Aspect	Positive	**	
▪ Flat		NS	
▪ North		NS	
▪ Northeast		NS	
▪ East		NS	
▪ Southeast		NS	
▪ South		NS	
▪ Southwest		NS	
▪ West		NS	
▪ Northwest		NS	
▪ North		**	
Habitat		NS	

Appendix 12.5: Model parameters Impala

Variable	Trend	P-value	Relationship
Elevation	Negative	***	Density decreased with elevation
RTP	Negative	**	Density decreases with ruggedness
NDVI		NS	
Distance from water		NS	
Aspect	Positive	**	Rank
▪ Flat		***	1
▪ North		***	3
▪ Northeast		***	2
▪ East		NS	4
▪ Southeast		NS	1
▪ South		8	7
▪ Southwest		NS	3
▪ West		NS	5
▪ Northwest		**	6
▪ North		**	7
Habitat		***	Rank
▪ Habitat 1		***	1
▪ Habitat 2		***	4
▪ Habitat 3		**	5
▪ Habitat 4		***	2
▪ Habitat 5		***	3
▪ Habitat 6		NS	6

Appendix 12.6: Model parameters Grant's gazelles

Variable	**Trend**	**P-value**	**Relationship**
Elevation	Negative	***	Density decreased with elevation
RTP	Negative	**	Density decreases with ruggedness
NDVI		NS	
Distance from water	Positive	***	Density increased with increased distance
Aspect	Positive	**	Rank
▪ Flat		***	1
▪ North		***	2
▪ Northeast		***	3
▪ East		NS	2
▪ Southeast		NS	5
▪ South		***	8
▪ Southwest		**	7
▪ West		NS	4
▪ Northwest		*	6
▪ North		NS	1
Habitat		NS	

Appendix 12.7: Model parameters Giraffe

Variable	Trend	P-value	Relationship
Elevation	Negative	**	Density decreased with elevation
RTP	Negative	***	Density decreases with ruggedness
NDVI		NS	
Distance from water	Positive	***	Density increased with increased distance
Aspect		NS	
Habitat		NS	

Script 1: Habitat Use analysis -, ANOVA'S and Post hoc Tukey tests

```
# Set directory & getwd

>   setwd("E:/PhD R analysis")
>   getwd()

# tell R what to call dataset (simple better) and what file want to read. header = true to keep column titles and sep="," because csv file

>   dens1 <- read.table("dens_env_data.csv", header=TRUE, sep=",")

# check what type of object (data) & check header labels with names()

>   class(dens1)
>   names(dens1)

# check all categorical right & if integers, change to factors

>   typeof(dens1$habitat)
>   typeof(dens1$tri)
>   typeof(dens1$aspect_class)
>   dens1$habitat <- as.character(dens1$habitat)
>   dens1$tri <- as.character(dens1$tri)
>   dens1$aspect_class <- as.character(dens1$aspect_class)
>   typeof(dens1$habitat)

# Structure & summary of data set

>   str(dens1)
>   summary(dens1)

#GRAZERS#

#Thompson's Gazelles (tom_s?)

#ANOVA : Thompson's distribution (per season) vs habitat

>   tom1_habi <- aov(dens1$tom_s1 ~ dens1$habitat)
>   summary(tom1_habi)

>   tom2_habi <- aov(dens1$tom_s2 ~ dens1$habitat)
>   summary(tom2_habi)

>   tom3_habi <- aov(dens1$tom_s3 ~ dens1$habitat)
>   summary(tom3_habi)

>   tom4_habi <- aov(dens1$tom_s4 ~ dens1$habitat)
>   summary(tom4_habi)

### Tukey test
```

```
    >   tom1_tuk <- TukeyHSD(tom1_habi)
    >   tom1_tuk
    >   plot(tom1_tuk)

    >   tom2_tuk <- TukeyHSD(tom2_habi)
    >   tom2_tuk
    >   plot(tom2_tuk)

    >   tom3_tuk <- TukeyHSD(tom3_habi)
    >   tom3_tuk
    >   plot(tom3_tuk)

    >   tom4_tuk <- TukeyHSD(tom4_habi)
    >   tom4_tuk
    >   plot(tom4_tuk)

# Wildebeest (wild_S?)

#ANOVA : Wildebeest vs habitat

    >   wild1_habi <- aov(dens1$wild_s1 ~ dens1$habitat)
    >   summary(wild1_habi)

    >   wild2_habi <- aov(dens1$wild_s2 ~ dens1$habitat)
    >   summary(wild2_habi)

    >   wild3_habi <- aov(dens1$wild_s3 ~ dens1$habitat)
    >   summary(wild3_habi)

    >   wild4_habi <- aov(dens1$wild_s4 ~ dens1$habitat)
    >   summary(tom4_habi)

#Tukey test#

    >   wild1_tuk <- TukeyHSD(wild1_habi)
    >   wild1_tuk
    >   plot(wild1_tuk)

    >   wild2_tuk <- TukeyHSD(wild2_habi)
    >   wild2_tuk
    >   plot(wild2_tuk)

    >   wild3_tuk <- TukeyHSD(wild3_habi)
    >   wild3_tuk
    >   plot(wild3_tuk)

    >   wild4_tuk <- TukeyHSD(wild4_habi)
```

```
    >  wild4_tuk
    >  plot(wild4_tuk)

#Zebra (zeb_S?)#

#ANOVA : Zebra vs habitat

    >  zeb1_habi <- aov(dens1$zeb_s1 ~ dens1$habitat)
    >  summary(zeb1_habi)

    >  zeb2_habi <- aov(dens1$zeb_s2 ~ dens1$habitat)
    >  summary(zeb2_habi)

    >  zeb3_habi <- aov(dens1$zeb_s3 ~ dens1$habitat)
    >  summary(zeb3_habi)

    >  zeb4_habi <- aov(dens1$zeb_s4 ~ dens1$habitat)
    >  summary(zeb4_habi)

#Tukey test

    >  zeb1_tuk <- TukeyHSD(zeb1_habi)
    >  zeb1_tuk
    >  plot(zeb1_tuk)

    >  zeb2_tuk <- TukeyHSD(zeb2_habi)
    >  zeb2_tuk
    >  plot(zeb2_tuk)

    >  zeb3_tuk <- TukeyHSD(zeb3_habi)
    >  zeb3_tuk
    >  plot(zeb3_tuk)

    >  zeb4_tuk <- TukeyHSD(zeb4_habi)
    >  zeb4_tuk
    >  plot(zeb4_tuk)

#Topi (topi_s?)

#ANOVA : Zebra vs habitat

    >  topi1_habi <- aov(dens1$topi_s1 ~ dens1$habitat)
    >  summary(zeb1_habi)

    >  topi2_habi <- aov(dens1$topi_s2 ~ dens1$habitat)
    >  summary(zeb2_habi)

    >  topi3_habi <- aov(dens1$topi_s3 ~ dens1$habitat)
```

```
    >   summary(zeb3_habi)

    >   topi4_habi <- aov(dens1$topi_s4 ~ dens1$habitat)
    >   summary(zeb4_habi)

#Tukey test

    >   topi1_tuk <- TukeyHSD(topi1_habi)
    >   topi1_tuk
    >   plot(topi1_tuk)

    >   topi2_tuk <- TukeyHSD(topi2_habi)
    >   topi2_tuk
    >   plot(topi2_tuk)

    >   topi3_tuk <- TukeyHSD(topi3_habi)
    >   topi3_tuk
    >   plot(topi3_tuk)

    >   topi4_tuk <- TukeyHSD(topi4_habi)
    >   topi4_tuk
    >   plot(topi4_tuk)

#Mixed Feeders and Browsers

#Grant's Gazelles (grant_s?)

#ANOVA : Grant's vs habitat

    >   grant1_habi <- aov(dens1$grant_s1 ~ dens1$habitat)
    >   summary(grant1_habi)

    >   grant2_habi <- aov(dens1$grant_s2 ~ dens1$habitat)
    >   summary(grant2_habi)

    >   grant3_habi <- aov(dens1$grant_s3 ~ dens1$habitat)
    >   summary(grant3_habi)

    >   grant4_habi <- aov(dens1$grant_s4 ~ dens1$habitat)
    >   summary(grant4_habi)

#Tukey test

    >   grant1_tuk <- TukeyHSD(grant1_habi)
    >   grant1_tuk
    >   plot(grant1_tuk)

    >   grant2_tuk <- TukeyHSD(grant2_habi)
```

```
>   grant2_tuk
>   plot(grant2_tuk)

>   grant3_tuk <- TukeyHSD(grant3_habi)
>   grant3_tuk
>   plot(grant3_tuk)

>   grant4_tuk <- TukeyHSD(grant4_habi)
>   grant4_tuk
>   plot(grant4_tuk)

#Impala (imp_s?)

#ANOVA : Grant's vs habitat

>   imp1_habi <- aov(dens1$imp_s1 ~ dens1$habitat)
>   summary(imp1_habi)

>   imp2_habi <- aov(dens1$imp_s2 ~ dens1$habitat)
>   summary(imp2_habi)

>   imp3_habi <- aov(dens1$imp_s3 ~ dens1$habitat)
>   summary(imp3_habi)

>   imp4_habi <- aov(dens1$imp_s4 ~ dens1$habitat)
>   summary(imp4_habi)

# Tukey test

>   imp1_tuk <- TukeyHSD(imp1_habi)
>   imp1_tuk
>   plot(imp1_tuk)

>   imp2_tuk <- TukeyHSD(imp2_habi)
>   imp2_tuk
>   plot(imp2_tuk)

>   imp3_tuk <- TukeyHSD(imp3_habi)
>   imp3_tuk
>   plot(imp3_tuk)

>   imp4_tuk <- TukeyHSD(imp4_habi)
>   imp4_tuk
>   plot(imp4_tuk)

#Giraffe (gif_s?)
```

```
#ANOVA : Grant's vs habitat

>   gif1_habi <- aov(dens1$gif_s1 ~ dens1$habitat)
>   summary(imp1_habi)

>   gif2_habi <- aov(dens1$imp_s2 ~ dens1$habitat)
>   summary(gif2_habi)

>   gif3_habi <- aov(dens1$gif_s3 ~ dens1$habitat)
>   summary(gif3_habi)

>   gif4_habi <- aov(dens1$gif_s4 ~ dens1$habitat)
>   summary(gif4_habi)

#Tukey test

>   gif1_tuk <- TukeyHSD(gif1_habi)
>   gif1_tuk
>   plot(gif1_tuk)

>   gif2_tuk <- TukeyHSD(gif2_habi)
>   gif2_tuk
>   plot(gif2_tuk

>   gif3_tuk <- TukeyHSD(gif3_habi)
>   gif3_tuk
>   plot(gif3_tuk)

>   gif4_tuk <- TukeyHSD(gif4_habi)
>   gif4_tuk
>   plot(gif4_tuk)
```

Script 2: Vegetation data – ANOVA's and Tukey

Set working directory & tell R what to call dataset (simple better) and what file want to read. header = true to keep column titles and sep="," because csv file

```
>   setwd("E:/PhD R analysis")
>   grass1 <- read.table("grass.csv", header=TRUE, sep=",")
```

check what type of object (data), check header labels with names() & attach data

```
>   class(grass1)
>   names(grass1)
>   attach(grass1)
```

check all categorical right & if integers, change to factors

```
>   typeof(season)
>   typeof(species)
>   typeof(dens1$aspect_class)
>   season <- as.character(season)
>   quadrat <- as.character(quadrat)
>   species <- as.character(species)
>   type <- as.character(type)
>   block<- as.character(block)
>   typeof(quadrat)
```

Structure & summary of data set

```
>   str(grass1)
>   summary(grass1)
```

ANOVA'S & TUKEY POST HOC - Total Height

#ANOVA's

```
>   tot_height_season <- aov(total_height ~ season)
>   summary(tot_height_season)

>   tot_height_block <- aov(total_height ~ block)
>   summary(tot_height_block)

>   bas_height_season <- aov(basal_height ~ season)
>   summary(bas_height_season)

>   bas_height_block <- aov(basal_height ~ block)
>   summary(bas_height_block)

>   tot_height_species <- aov(total_height ~ species)
>   summary(tot_height_species)
```

```
>    bas_height_species <- aov(basal_height ~ species)
>    summary(bas_height_species)

#Tukey tests

>    tot_height_season_tuk <- TukeyHSD(tot_height_season)
>    tot_height_season_tuk
>    plot(tot_height_season_tuk)

>    tot_height_block_tuk <- TukeyHSD(tot_height_block)
>    tot_height_block_tuk
>    plot(tot_height_block_tuk)

>    bas_height_season_tuk <- TukeyHSD(bas_height_season)
>    bas_height_season_tuk
>    plot(bas_height_season_tuk)

>    bas_height_block_tuk <- TukeyHSD(bas_height_block)
>    bas_height_block_tuk
>    plot(bas_height_block_tuk)

>    tot_height_species_tuk <- TukeyHSD(tot_height_species)
>    tot_height_species_tuk

>    bas_height_species_tuk <- TukeyHSD(bas_height_species)
>    bas_height_species_tuk
>    plot(bas_height_species_tuk)
```

Script 3: GLM – Parameter selection for model repeated for each species in each sample season

Set directory & call dataset: select file to read. header = true if want to keep column titles and sep="," becasue csv file

```
>    setwd("E:/PhD R analysis")
>    getwd()
>    dens2 <- read.table("dens_env_data.csv", header=TRUE, sep=",")
```

check type of object (data)

```
>    class(dens2)
>    names(dens2)
```

check all categorical right & if integers, need to change to factors

```
>    typeof(dens2$habitat)
>    typeof(dens2$tri)
>    typeof(dens2$aspect_class)
>    dens2$habitat <- as.character(dens2$habitat)
>    dens2$tri <- as.character(dens2$tri)
>    dens2$aspect_class <- as.character(dens2$aspect_class)
```

plot if want to

```
>    plot(dens2$elev ~ dens2$ndvi
```

Use attach() so don't have to constantly type dens2$

```
>    attach(dens2)
```

Call “Faraway” library

```
>    library(faraway)
```

Build GLM model, by default the link for poisson in R is log

```
>    glm1 <- glm(wild_s4 ~ habitat + dem_stdev + rtp + aspect_class + ndvi + dist_h2o ,
     family=poisson)
>    summary(glm1)
```

Z value only valid if response is Poisson

Residual deviance should be broadly similar

check for over-dispersion (biological terms, counts are not independent but aggregated)

```
>    glmod <- (sum(residuals(glm1, type="pearson")^2)/glm1$df.res)
>    glmod
```

```
#suggests variance is xx times the mean - overdispersion = follows a negative binomial distribution, not part of exponential families of distribution, can be approximated as quasipoisson

# QUASI-POISSON

> glm2 <- glm(wild_s4 ~ habitat + dem_stdev + rtp + aspect_class + ndvi + dist_h2o , family=quasipoisson)
> summary(glm2)

# simplify model to get F-values

> drop1(glm1, test="F")

# AIC values not reliable when quasipoisson is used

> summary(glm1, dispersion=glmod)

# Suitability of model = 1 - (residual deviance/null deviance)



# Check model: residuals vs fitted values

> plot(residuals(glm2) ~ predict(glm2, type="response"), xlab=expression(hat(mu)), ylab="deviance residuals")

# check in poisson for all

> plot(residuals(glm2) ~ predict(glm2, type="link"), xlab=expression(hat(mu)), ylab="deviance residuals")

# check distribution of residuals (normal?)

> shapiro.test(residuals(glm2, type="deviance"))

# residuals are not normally distributed if p<0.001,  to be sure test on standardised residuals

shapiro.test(rstandard(glm1))

# Produce Qq normality plot - how residuals deviate from normal dis

> plot(glm1, which=2, pch=16)

# which = 2 is for the residuals deviations from normal distribution

# Assumption 3 - Residual independence: if some non-random structure seems to be present on plot indicates that residuals are not fully independent

# A more effective test of residual independence:
```

```
> plot(glm1, which=3, pch=16)

# Any increasing, decreasing or non-rectangular distribution of transformed residuals on this plot will suggest that the variance of the residuals is not constant (i.e. a case of heteroscedasticity).

# Model 2

# Remove any variables that are not significant p>0.01 in previous model

> glm3 <- glm(wild_s4 ~ habitat + rtp + dem_stdev + aspect_class  + dist_h2o , family=quasipoisson)
> summary(glm3)

 # Remove any variables that are not significant p>0.01

# Simplify model to get F-values

> drop1(glm3, test="F")
> summary(glm3, dispersion=glmod)

# Residuals vs fitted values

> plot(residuals(glm3) ~ predict(glm3, type="response"), xlab=expression(hat(mu)), ylab="deviance residuals")

# Check in poisson distribution for all

> plot(residuals(glm3) ~ predict(glm3, type="link"), xlab=expression(hat(mu)), ylab="deviance residuals")

#Qq norm plot - how residuals deviate from normal dis

> plot(glm3, which=2, pch=16)
> plot(glm3, which=3, pch=16)
```