

DISTRIBUTION AND VEGETATION ASSOCIATION OF GREVY'S ZEBRA (*Equus grevyi*) IN TSAVO EAST NATIONAL PARK AND THE SURROUNDING RANGLANDS

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree or any other award in any other University.

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DEDICATION

To my beloved wife Phenny Mwake, my son Joshua Mwazo and my parents.

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Even though this piece of work is a product of my effort and time, the dream of accomplishing it could not have been realized without the hands of numerous people whom I must credit. Foremost are my supervisors Dr. Eunice Kairu of Kenyatta University, Dr. Benson Mwangi of Kenyatta University, and Dr. Bruce Patterson of the Field Museum of Natural History in Chicago. Their professional advice, guidance and constructive criticism in this work cannot go unmentioned for they contributed immensely in its exactness and completion.

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LIST OF ABBREVIATIONS

CITES Convention on International Trade of Endangered Species of Flora and Fauna

FAO Food and Agriculture Organisation

GIS Geographical information system

GPS Global positioning system

IUCN International Union for Conservation of Nature and Natural resources

KWS Kenya Wildlife Service.

PCA Principal Component Analysis

ABSTRACT

Grevy's zebra (*Equus grevyi*), the world's largest wild equine, is endemic to the arid Horn of Africa. Originally, its range extended throughout the Horn of Africa but currently it is found only in Kenya and Ethiopia. The population has declined from 15,000 in the late 1970s to between 1,964 and 2,445 animals by the year 2008. The population declines as report by William and Low (2004) is probably as a result of being killed for meat, medicinal purposes, loss of access to critical resources due to competition with livestock, and increasing scarcity of resources as a result of over-exploitation. The Kenya Wildlife Service is mandated to conserve and manage Grevy's zebra in Kenya. However, this mandate is hampered by lack of information on the Grevy's zebra distribution and vegetation association in Tsavo East National Park and the surrounding ranchlands. This study, therefore, investigated the distribution and vegetation association of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands. Grevy's zebra distribution data was collected using a sampling route method. This involved driving along the roads and recording data of Grevy's zebra. Recorded data included the date, time, Global positioning system (GPS) locations of Grevy's zebra and their numbers seen in Tsavo East National Park and the ranchlands surrounded by the Park. GPS locations of both natural and artificial water pans where Grevy's zebra were found were also recorded. Grevy's zebra vegetation preferences were studied by analyzing land cover maps generated from satellite images. Vegetation selection index was used to asses the most preferred vegetations by Grevy's zebra. The association between Grevy's zebra and their vegetation types was assessed using Chi-square test. Distribution of Grevy's zebra was determined by projecting the Grevy's zebra GPS locations in ArcGIS. Point pattern analysis was used to asses the distribution patterns of Grevy's zebra and Pearson correlation was used to test the relationship between Grevy's zebra locations and distance to water pans. Results showed that Grevy's zebra live in groups with mean group size of 9.5 ± 3.08 . Ninety five percent of Grevy's zebra locations were found in ranchlands and five percent in Tsavo East National Park. Distribution patterns were clustered $R < 1$ and the mean distribution densities of Grevy's zebra in different vegetation types was 0.24 ± 0.07 . Grevy's zebra preferred seven vegetation types in Tsavo East National Park and the surrounding ranchlands while vegetation selection index showed that Grevy's zebra mostly preferred four vegetation types. There was positive correlation between Grevy's zebra locations and distance to water pans $p < 0.05$ and the mean distance of Grevy's zebra locations to water pans in different land parcels was 6251.20 ± 1798.57 meters. Chi-square test result showed an association between Grevy's zebra distribution and vegetation types $p < 0.05$. This study concluded that Grevy's zebra preferred open formation vegetation types and preferred ranchlands areas than the park. The results of this study will assist Kenya Wildlife Service and ranchlands owners to devise management and conservation strategies for the Grevy's zebra. The study recommends further research to be conducted to determine whether competition with livestock and predation are impacting the distribution of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Grevy's zebra (*Equus grevyi*), the world's largest wild equine weighs 350-450 kg and is endemic to the arid Horn of Africa. Historically, it ranged in distribution from east of the Rift Valley in Kenya to western Somalia, and in northern Ethiopia from the Alledeghi Plain through the Awash Valley, the Ogaden, and northeast of Lake Turkana in Ethiopia to north of Mt. Kenya and southeast down the Tana River in Kenya (Bauer *et al.*, 1994).

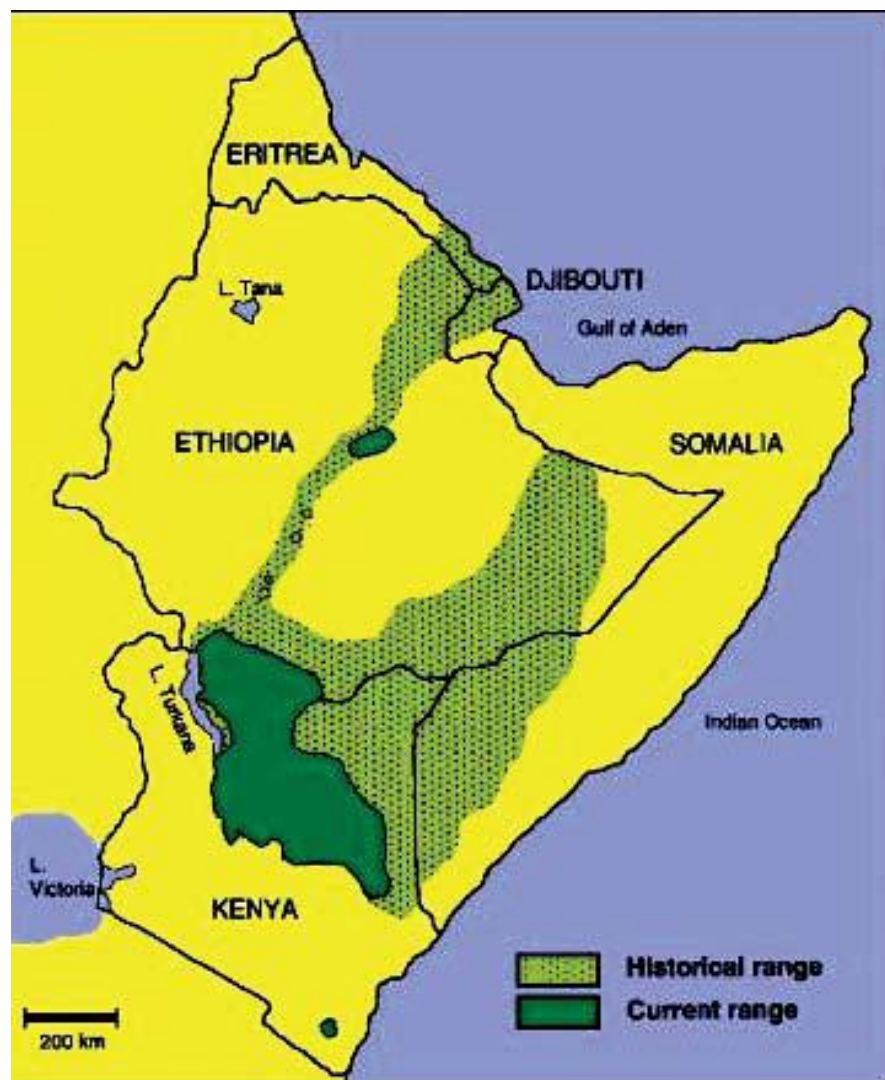


Figure 1. 1 : Historical and current distribution of Grevy's zebra in the horn of Africa (Source: Kingdon, 1979, 1997; Yalden *et al.*, 1986).

In recent years, Grevy's zebra has undergone one of the most substantial reductions in range (Kingdon, 1997) and population numbers (Rowen and Ginsberg, 1992; Williams, 2002; Nelson, 2003) of any African mammal. Towards the end of the 1970s, the global population was estimated to be approximately 15,000 (Klingel, 1980; Grunblatt *et al.*, 1989; Grunblatt *et al.*, 1996) while present-day estimates are between 1,964 and 2,445 animals (Mwasi and Mwangi, 2007). This represents an 84-87% decline in global numbers over the past three decades. Estimates of Grevy's zebra populations in Ethiopia suggest at least a 90% decline throughout the country, with an estimated 1,900 animals in 1980 (Klingel, 1980), 577 animals in 1995 (Thouless, 1995a; 1995b), and 110 in 2003 (Williams *et al.*, 2003). The most recent survey estimated 126 Grevy's zebra remaining in Ethiopia (Fanuel Kabede, pers. comm. 2007).

The rate of decline has been slower in Kenya than in Ethiopia. The 1977 estimate for Grevy's zebra population in Kenya was 13,718 (Dirschl and Wetmore, 1978). The estimate was 4,278 in 1988 (Grunblatt *et al.*, 1989) and 2,571 animals in 2000 (Nelson, 2003; Nelson and Williams, 2003). In 2004, estimates of Grevy's zebra population in Kenya were between 1,600 and 2,000 animals (William and Low 2004) and in 2007 the population was between 1,838 and 2,319 (Mwasi and Mwangi, 2007).

According to Williams (2002), the decline in Grevy's zebra population is primarily the result of killing for meat or medicinal purposes. Williams and Low (2004) found that loss of access to critical resources due to competition with livestock, and an increasing scarcity of these resources as a result of over-exploitation are some of the causes in decline of Grevy's zebra population. In addition, there has been a significant decline in the species in northern Kenya due to disease and

drought (Manyibe *et al.*, 2006; Muoria *et al.*, 2007). To save the species from extinction prudent management is necessary. In order to do this, a good understanding of the distribution and vegetation association of the species is necessary.

Grevy's zebra range in Tsavo East National Park and the surrounding ranchlands is a result of two introductions. In 1964, 22 individuals from Isiolo were released in Tsavo East National Park and dispersed over the area between Aruba and Voi, and in 1977, around 30 animals were introduced in Tsavo West National Park from Isiolo and scattered into the northwest of Tsavo. In 1980, 4 adults and young were seen near the Rombo River, as noted by Churcher (1983). Grevy's zebra seem to adjust readily and become acclimated to the vegetation in Tsavo, which provide a far more secure and stable area for their continued persistence.

This study aimed at investigating distribution of Grevy's zebra and their vegetation association in Tsavo East National Park and the surrounding ranchlands. Knowledge on the vegetation characteristics preferred by Grevy's zebra is essential to conservationists and wildlife managers dealing with reintroductions, translocations and the development of new protected areas (Araujo and Williams, 2000; Rotenberry *et al.*, 2006; Stamps and Swaisgood, 2007).

1.2 Justification and statement of the problem

The number and range size of Grevy's zebra populations have reduced drastically in Kenya. Over a period of 27 years, the species' natural range has undergone one of the most dramatic constrictions of any animal species in Africa (KWS, 2008). Today, the species persists only in Kenya and Ethiopia, with over 90% of the global population found in Kenya (KWS, 2008). Grevy's zebra seem to adjust readily to their new habitats in Tsavo National Parks since a small

group introduced in the early 1960s and mid 1970s has persisted. Information on the distribution of Grevy's zebra and their vegetation association in Tsavo East National Park and the surrounding ranchlands is lacking, although such information is critical if any management intervention strategies are to be employed. Understanding Grevy's zebra distribution and vegetation association will assist the Kenya Wildlife Service to devise management and conservation strategies for the Grevy's zebra in Tsavo East National Park and the surrounding ranchlands.

1.3 Research questions

- i. What vegetation types are found in Tsavo East National Park and the surrounding ranchlands?
- ii. Which vegetation types are preferred by Grevy's zebra in Tsavo East National Park and the surrounding ranchlands?
- iii. What are the characteristics of the preferred vegetation types?
- iv. How are the Grevy's zebra distributed among the different vegetation types?
- v. How are the Grevy's zebra distributed in Tsavo East National Park and the surrounding ranchlands?
- vi. How are the Grevy's zebra distributed in relation to water pans in Tsavo East National Park and the surrounding ranchlands

1.4 Hypotheses

- i. There is no significant association between vegetation types and distribution of Grevy's zebra.
- ii. Distribution of Grevy's zebra in Tsavo East National Park and ranchlands is random

iii. There is no significant relationship between Grevy's zebra locations and water pans locations in Tsavo East National Park and the surrounding ranchlands

1.5 Objectives

1.5.1 General objective

The objective of the study was to investigate the distribution of Grevy's zebra and their vegetation association in Tsavo East National Park and the surrounding ranchlands.

1.5.2 Specific objectives

- i. To establish and categorise vegetation types of Tsavo East National Park and the surrounding ranchlands.
- ii. To assess the vegetation preferences of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands
- iii. To document the vegetation characteristics preferred by Grevy's zebra in Tsavo East National Park and the surrounding ranchlands.
- iv. To assess the distributions patterns of Grevy's zebra in their preferred vegetation types.
- v. To generate distribution map of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands.
- vi. To assess the relationship between Grevy's zebra locations and water pans locations in Tsavo East National Park and the surrounding ranchlands.

CHAPTER TWO: LITERATURE REVIEW

2.1 Grevy's zebra

Grevy's zebra (*Equus grevyi*) is the world's largest wild equine averaging 350-450 kg in weight and standing 135 cm at the shoulder and 125-150 cm at the withers (Grooves, 1974; Willoughby, 1974). The skull of Grevy's zebra has a relatively long rostrum and wide occipital crest that overhang the occipital condyles (Roosevelt and Heller, 1914). According to Willoughby (1974), Grevy's zebra have the narrowest and closest-set stripes of all zebras, averaging 25-38 mm wide and spaced 20 mm apart on the flanks (Plate 2.1).



Plate 2. 1 : Grevy's zebra in Taita Ranch.

Nelson and Williams (2003) reported that Grevy's zebra are found in semi-arid to arid (annual rainfall range 100-650 mm) grass and shrub land where permanent water is available. Grevy's

zebra are predominantly grazers with a caecal digestive system. Most importantly, they require free-standing water as part of their diet. Most adults can tolerate up to five days without water, whereas lactating females require water every one to two days (Ginsberg, 1989; Becker and Ginsberg, 1990; Rowen, 1992).

2.2 Grevy's zebra historical and current distribution

Historically, Grevy's zebra had a wide distribution in its natural range across the horn of Africa. Once, it spread from the Awash Valley, the Ogaden region, and northeast of Lake Turkana in Ethiopia, south into Kenya east of the Rift Valley and Lake Turkana, north of Mount Kenya and the Tana River, and east into western Somalia (Bauer *et al.*, 1994) (Fig 1.1). However, following a major decline in the 1970's and late 1980's, Grevy's zebra occurs in three isolated populations; in Kenya, north of the Tana River, Ethiopia, on the east side of Omo River to Lake Chewbahir and Somalia where it is now believed to be extinct as last sighting was in 1973 (Kingdon, 1979; Duncan 1992; IUCN, 2002). Eventually, in the dawn of the new millenium, Grevy's zebra occurs in few restricted ranges in Kenya, Ethiopia and possibly in Sudan (KWS, 2008). However, recent attempts of translocation of Grevy's zebra to Tsavo East, West and Meru National Parks have been made in Kenya though much is not known about the success of the population establishment in these areas (Nelson and Williams, 2003).(Fig 2.1)

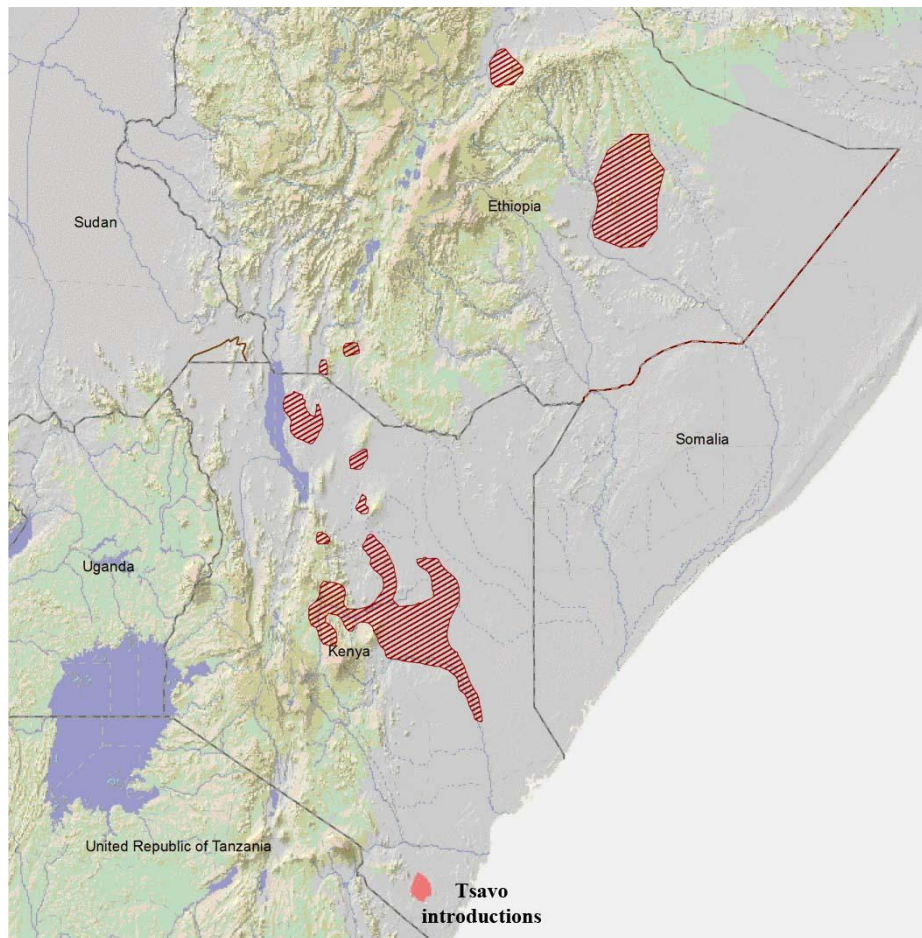


Figure 2. 1 : Current distribution range of Grevy's zebra. Red dot shows where Grevy's zebra were introduced in Tsavo and the red-lined shapes shows the current distribution of Grevy's zebra (IUCN Website).

2.3 Behaviour of Grevy's zebra

Grevy's zebra has no permanent adult bonds or a herd system as in *Equus burchelli* and *Equus zebra* (Grooves, 1974; Klingel, 1974a; 1974b). Groups of Grevy's zebra have no leaders, although males usually dominate females. Adults may live alone on territories, in bachelor groups or in mixed herds none of which is permanent (Klingel, 1977). The male Grevy's zebra defend individual territories of 2.5-10 km². Grevy's zebra male territorial boundaries follow natural features such as watercourses, roads and mountains. These territories are occupied

throughout the year (Keast, 1965; Klingel, 1974b). Resident males patrol their territorial boundaries marking them with urine and peripheral dung piles and advertise their presence by braying (Klingel, 1972; 1974b). Territorial males may tolerate other males in their territory but if an estrous female enters, the territorial male usually expels other males (Grooves, 1974; Klingel, 1974a; 1974b; Kingdon, 1979). A territorial male meets a challenger with head, neck and ears extended forward (Klingel, 1969; 1974b). In an earnest challenge, he may fight by biting at the neck, back, flanks, legs or rear while seeking an advantage, or rearing and flailing with the fore hooves (Klingel, 1974b), and may vocalize (Kingdon, 1979). Females repel aggressive or defeated males by kicking them with the hind legs. When threatened, the females stand facing away from the attacker with one hind leg raised, ready to kick if assaulted (Kingdon, 1979). Estrous females urinate frequently, which intrigues or arouses males, who approach with measured steps or prance with arched neck, chin down and ears pricked horizontally forward (Read *et al.*, 1988). The male sniffs her urine, inhales the scent and raises his head in flehmen grimace (Klingel, 1969). He follows her closely, sniffing, flehming, nipping, nuzzling, jostling or wrestling her until she responds (Read *et al.*, 1988).

2.4 Grevy's zebra population decline

The historical importance of Grevy's zebra in human culture has not been studied well. The present day range of this species overlaps with pastoralist communities of Ethiopia and Kenya which includes the Afar, Somali, Borana, Hamar, Arbore, Dassenetch, Turkana, Samburu, Aarial, Rendille, and Gabbra in Ethiopia and Kenya (Williams, 2002). Of these communities, Somali, Hamar, Arbore, Dassenetch, Borana and Turkana are known to exploit Grevy's zebra for food (Williams, 2002). Until the early 1980s, Grevy's zebra skins were sought by hunters as

trophies and for export in the markets of Europe and North America. This condition contributed to a major decline of Grevy's zebra population in Kenya. Hunting for skins in the late 1970s may have contributed to this dramatic decline. But since CITES listing, the killing of Grevy's zebra for their skins ceased. At present, there is no legal trade of their skins (Williams, 2002). Nevertheless, Grevy's zebras are hunted for meat by Borana, Somali and Turkana communities in both Kenya and Ethiopia (Williams, 1998; IUCN, 2002). However, the decline of their population in Kenya is continuing as recruitment is very low due to low juvenile survival. This is as a result of competition for resources both food and access to water with pastoral people and domestic livestock (Williams, 1998).

Diseases are cited as one of the cause in Grevy's zebra decline. Research conducted by Muoria *et al.* (2007) found that anthrax outbreak which occurred between December 2005 and March 2006 in the communally owned pastoralist area in southern Samburu Kenya, killed 53 Grevy's zebra. Studies in Laikipia-Samburu ecosystem indicated that Grevy's zebra recruitment is adversely affected by pastoralists and livestock (Williams 1998, Nelson and Williams 2003). In Ethiopia, the decline is attributed to illegal hunting with automatic weapons (Williams *et al.*, 2003). Killing, loss of access to critical resources due to competition with livestock, and decline of these resources due to over exploitation have a direct effect on the decline of Grevy's zebra (KWS, 2008).

Reduction of water sources is another cause for Grevy's zebra population decline. According to Williams (2002) heavy water use in populous highland areas, particularly for irrigation schemes, continues to threaten perennial water sources in the historic range of Grevy's zebra. Central and critical to this issue is the Ewaso Ng'iro River basin on which between 60% and 70% of Grevy's zebra in Kenya (including the southern population in Kenya, and the Lewa Wildlife Conservancy and Laikipia populations) are dependent. Habitat degradation and loss due to heavily sustained livestock grazing by lowland populations in the historic range of Grevy's zebra is one of the causes of Grevy's zebra population decline (Williams 2002). Overgrazing directly affects the composition of the vegetation communities. The principal vegetation changes that have occurred in the Grevy's zebra range in order of importance are: increases in woody cover (tree, shrub, and dwarf shrub), quantitative decreases in herbaceous and particularly grass cover and a qualitative decrease in the herbaceous composition (e.g. change from large to small perennials and from perennials to annuals) (Naylor and Herlocker 1987; Bronner 1990 and Herlocker 1992). In addition to altering the vegetation communities, overgrazing also reduces overall plant cover, thus increasing the susceptibility of the soil to water and wind erosion (Bronner, 1990).

Study by Williams (1998) has shown that Grevy's zebra competes for critical resources with pastoral people and their domestic livestock in northern Kenya. The long-term vegetation changes and erosion have reduced the availability of forage for Grevy's zebra in the areas used by pastoral people (Williams, 2002). But, on a seasonal basis, the use of forage by the relatively high densities of domestic livestock species also limits food availability. This means that, while in these areas, Grevy's zebra must feed in vegetation communities with the highest food

abundance regardless of quality in order to sustain their intake requirements (Williams, 2002). On the other hand, water points in the community areas are occupied by pastoralists and their livestock forcing Grevy's zebras to drink at night increasing their vulnerability to be preyed upon by the nocturnal big cats. This also engages them in long movements to get water thus jeopardizing the survival of the foals which is highly dependent on the distances made by the mothers in search of the fundamental resources (Williams, 1998). Nevertheless, competition with livestock results to low survival of the foals in the pastoral areas (Rubeinstein, 1986).

2.5 Critical resources for Grevy's zebra

Seasonal limitation of forage in pastoralist areas and predators are important factors determining use of space by Grevy's zebra. In the absence of pastoralists, Grevy's zebra drink during the day to avoid predation. In pastoralist areas, the monopolization of water sources by people and livestock forces Grevy's zebra to drink nocturnally, and to move long distances between areas with sufficient grazing forage and water. Foals do not travel to drinking points with their mothers, but remain in "kindergartens" which can be up to 8 km from water (Klingel, 1974; Becker and Ginsberg, 1990; Rowen, 1992). There is no specific anti-predator behavior (Klingel, 1974), making the foals vulnerable to predation. Further, foals may be energetically constrained (Rubenstein, 1986; Williams, 1998), and foal survival has been related to the distance their mothers must move in order to get water (Williams, 1998).

2.6 Habitat choice

Resource and habitat selection are central themes in ecology, as these selective processes may facilitate species coexistence and act as important driving forces in evolution and speciation (Lack, 1933; McPeck, 1996; Morris, 2003). Understanding the basis of habitat choice has

important implications for explaining the distribution of organisms, as well as helping to distinguish among habitats of different quality for effective management. Knowledge of those habitat characteristics essential for the viability of a species can also provide crucial information to wildlife managers dealing with reintroductions, translocations, and the development of new protected areas (Araujo and Williams, 2000; Rotenberry *et al.*, 2006; Stamps and Swaisgood, 2007). Sundaesan *et al.* (2007) reported that our understanding of habitat use is central to the conservation of many species. Most large-bodied vertebrates range widely, thereby encountering diverse habitats. According to Sundaesan *et al.* (2007), Grevy's zebra in Laikipia exemplify many endangered species facing these challenges.

Margules and Pressey (2000) reported that information on species distribution patterns is crucial for effective conservation and management of biodiversity. Given the alarming situation of extreme habitat alterations due to human activities, it is important to accurately assess the distribution and conservation status of threatened species to prevent future loss of global biodiversity (Honnavalli *et al.*, 2009). For conservation of any endangered species, it is important to generate information on their distribution, abundance, habitat requirements and associated threats so that a manageable conservation strategy is identified before they reach the brink of extinction (Honnavalli *et al.*, 2009).

2.7 Conservation status

Activities that lead to habitat loss may threaten the persistence of wildlife. Conservation and management planning require not only an understanding of how wildlife use habitat in space and time, but how habitat use changes in response to landscape disturbances and modifications (Berland *et al.*, 2008). Animals select their habitats in order to satisfy vital requirements

concerning food, shelter and reproduction (Bond *et al.*, 2002). Specific requirements are influenced by inherent characteristics of species such as life history traits, individual characteristics such as sex and age, and extrinsic environmental factors such as competition, predation pressure and seasonal food supply. For prey species, predation pressure represents one of the most important extrinsic factors influencing the spatial behavior of individuals and habitat selection (Lima and Dill, 1990; Kotler, 1997; Bos and Carthew, 2003).

During the last decade, ecologists have devoted great efforts to understanding the forces behind the selection of certain habitat types and its implications for predator avoidance. It has been noted that some prey species benefit by selecting different habitats in different environments in order to decrease vulnerability to predators (Lima, 1998). Habitat selection is considered a hierarchical process (Johnson, 1980; Orians and Wittenberger, 1991) where selection patterns should be modulated by factors that affect an individual's fitness and for which the importance varies according to the considered spatial scale (Rettie and Messier, 2000). Therefore, a factor showing strong potential for limiting fitness could dictate selection patterns at a larger scale. Once its impacts are attenuated, fine-scale selection behavior will aim at minimizing the effects of secondary limiting factors. Thus, selection scale will reflect a hierarchy in the various limiting factors, therefore mandating the conduct of selection studies at numerous spatial scales (Rettie and Messier, 2000; Dussault *et al.*, 2005). Prediction of species distribution is also an important element of conservation biology, endangered species management (Palma *et al.*, 1999; Sanchez-Zapata and Calvo, 1999), and ecosystem restoration (Mladanoff *et al.*, 1997).

Habitat structure is one of the most important features for habitat selection by wildlife (Cody, 1981), and species conservation plans often focus on preserving their preferred habitats. This approach relies on the assumption that individuals optimise their fitness by occupying a restricted part of the environment within their range (Weins, 1989; Rosenzweig, 1991). Contemporary strategies for wildlife habitat mapping (Boyce and McDonald, 1999), biodiversity analysis (Scott *et al.*, 1993), and animal movement modeling (Bian, 2001) require the use of spatially explicit environmental map layers, such as those derived from land inventory databases and remote sensing. These data are commonly processed for a variety of environmental attributes, including vegetation cover (Carroll *et al.*, 1999; McClain and Porter, 2000), land use (Osborne *et al.*, 2001; Dash Sharma *et al.*, 2004), landscape structure (Ripple *et al.*, 1997; Hansen *et al.*, 2001), and phenology (Verlinden and Masogo, 1997; Leimgruber *et al.*, 2001), and form part of the foundation for derived habitat models and other information products designed to support research and management initiatives.

Quantitative habitat models and predictive distribution maps are now important tools for the conservation and management of animals and plants (Guisan and Zimmerman, 2000; Raxworthy *et al.*, 2003; Jeganathan *et al.*, 2004; Johnson *et al.*, 2004). Loss of biological diversity is a serious ecological problem, with a major cause being human action in the form of altering land use (Freedman, 1989). Human-caused changes have accelerated extinction (Wilcove *et al.*, 1998), which threatens biodiversity. With sufficient research and data, conservationists and wildlife managers can minimize further biodiversity loss due to human activity. One important tool is biodiversity gap analysis, which has been developed by geographers and biologists to map

distributions of vertebrate species and vegetation communities and identify gaps in their protection (McKendry and Machlis, 1991; Scott *et al.*, 1993).

2.8 Conceptual framework

The historical importance of Grevy's zebra in human culture has not been studied well. The present day range of this species overlaps with pastoralist communities of Ethiopia and Kenya (Afar, Somali, Borana, Hamar, Arbore, Dassenetch, Turkana, Samburu, Aarial, Rendille, and Gabbra in Ethiopia and Kenya). Of these communities, Somali, Hamar, Arbore, Dassenetch, Borana and Turkana are known to exploit Grevy's zebra for food (Williams, 2002). Both in northern Kenya and Ethiopia, it is likely that Grevy's zebra are dependent on resources used by pastoral people and their livestock. With increasing human and livestock populations, access to forage and water has become more difficult and Grevy's zebra have lost habitat (Hack and Rubenstein 1998; Williams, 2002).

In arid and semi-arid environments, livestock and humans are more water dependent than wildlife species that are adapted to local conditions (Voeten and Prins, 1999). Reduction of water sources is another cause for Grevy's zebra population decline. According to Williams (2002) heavy water use in populous highland areas, particularly for irrigation schemes, continues to threaten perennial water sources in the historic range of Grevy's zebra. Central and critical to this issue is the Ewaso Ng'iro River basin on which between 60% and 70% of Grevy's zebra in

Kenya (including the southern population in Kenya, and the Lewa Wildlife Conservancy and Laikipia populations) are dependent. Habitat degradation and loss due to heavily sustained livestock grazing by lowland populations in the historic range of Grevy's zebra is one of the causes of Grevy's zebra population decline (Williams 2002).

Exclusion from water sources by pastoral people has been identified as a serious threat to successful recruitment into Grevy's zebra populations (Rowen, 1992; Williams, 1998; Nelson and Williams, 2003). Because lactating females must drink water daily (Ginsberg, 1989; Becker and Ginsberg, 1990), in areas of high livestock density the resulting monopolisation of water sources by livestock forces lactating females to graze further from water (Nelson and Williams, 2003). As a result of moving considerable distances to access water, and often at night, foal and juvenile survival is lower as the risk of predation increases at night (Williams, 1998) and the distances travelled may place physiological stress on foals (Rubenstein, 1986). Since foals are the weak link in the life cycle of Grevy's zebra, targeting access to resources that are required by lactating females is critical for enhancing foal survival and improving recruitment rates into populations (Williams, 1998; 2002). Overgrazing directly affects the composition of the vegetation communities. The principal vegetation changes that have occurred in the Grevy's zebra range, in order of importance, are: increases in woody cover (tree, shrub, and dwarf shrub), quantitative decreases in herbaceous and particularly grass cover and a qualitative decrease in the herbaceous composition (e.g. change from large to small perennials and from perennials to annuals) (Naylor and Herlocker 1987; Bronner 1990 and Herlocker 1992).

2.9 Knowledge gaps

Much of the information available on Grevy's zebra comes from single populations of Grevy's zebra on their distribution and numbers. Little is known about Grevy's zebra re-introduced populations (Nelson and Williams, 2003). Recent attempts of translocation of Grevy's zebra to Tsavo East, Tsavo West and Meru National Parks have been made in Kenya though much is not known about the success of the population establishment in these areas, their distributions and vegetation association (Nelson and Williams, 2003). Vegetations in Grevy's zebra ranges needs to be investigated so as to assess changes in vegetation and consider how these may have affected and will continue to affect Grevy's zebra distribution (Williams, 2002). In the year 1964 twenty two Grevy's zebra from Isiolo were introduced in Tsavo East National Park and dispersed over the area between Aruba, Voi and the ranchlands. Information on the distribution of this population, the vegetation they associate with and their relationships with existing water pans is lacking. This study therefore investigated the distribution of Grevy's zebra, the vegetation they preferred and their relationships with water pans in Tsavo East National Park and the surrounding ranchlands.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Location of the study area

This study was conducted in Tsavo East National Park in Taita County (Fig. 3.1). The surrounding ranchlands were also studied as they are an integral part of Tsavo East National Park (Fig 3.2). Tsavo East National Park is located at 2° and 4° S and 37°30' and 39°30' E. and lies 70 to 250 km from the coast. Tsavo National Parks area covers about 22,000 km², and is subdivided into two administrative units: Tsavo West National Park, measuring about 9,000 km² and Tsavo East National Park measuring approximately 13,000 km². Taita and Rukinga Ranches are wildlife conservancies while other ranches are livestock ranches. The ranches are located off the Nairobi – Mombasa highway at 3° 34' to 3°53'S and 38°40' to 39°02'E and vary in size from over 40,000 hectares to less than 50 hectares (Table 3.4). They border Tsavo East National Park on the southeastern side, between the towns of Maungu and Mackinnon.

Table 3. 1 : Area in hectares of the ranchlands occurring in the Tsavo East National Park where research was conducted.

Ranch/conservancy	Area (Hectares)
Rukinga conservancy	30,000
Taita conservancy	39,300
Bachuma ranch	4,000
Graziers ranch	2,000
Amaka ranch	5,500
Dawida ranch	5,500
Washumbu ranch	1,200
Kasigau ranch	21,000
Maungu ranch	25,000
Wangala ranch	50
Lualenyi ranch	43,374
Mgeno ranch	20,290
Choke ranch	10,106
Wananchi ranch	8,711
Mkuki ranch	2,647
Mbale ranch	10,000
Mindi ranch	2,607
Sagalla ranch	15,705
Oza ranch	11,587

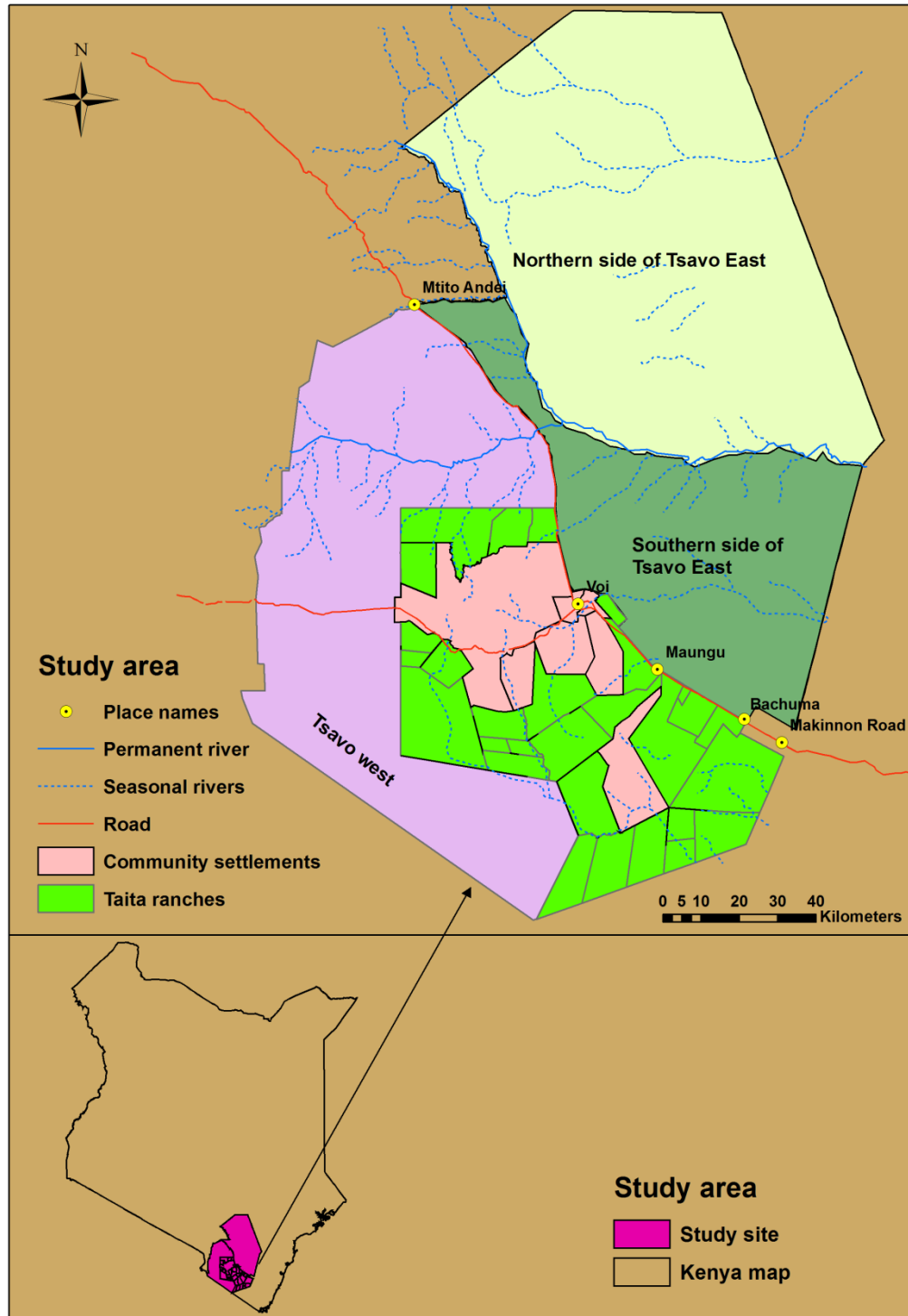


Figure 3. 1 : Location of the study area. (Source: KWS GIS Lab 2012).

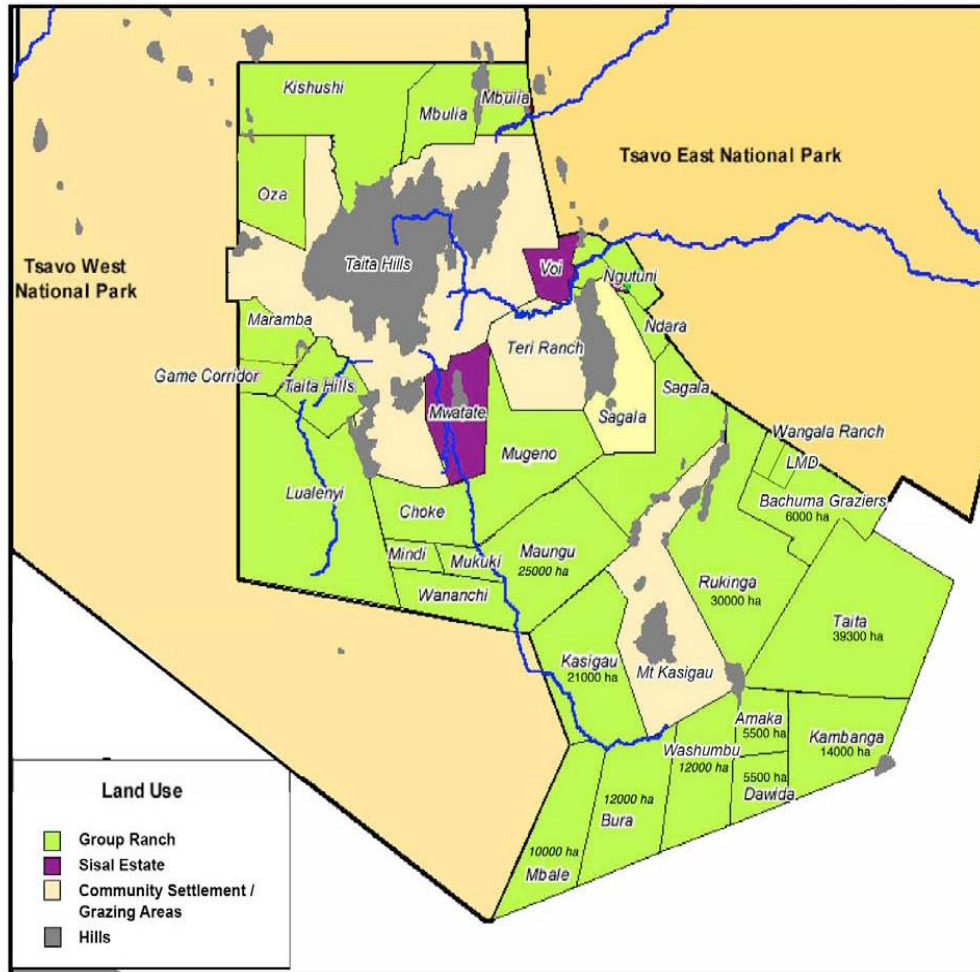


Figure 3. 2 : Tsavo East National Park and the surrounding ranchlands where the research was conducted (Source: Wildlife Works in Rukinga Ranch).

3.1.2 Climate

The ranches are in a semi arid area with rainfall ranging from 350 to 700 mm annually. Temperatures range from 24°C to 33°C. Although the ranches lack permanent rivers or lakes, they contain scattered water pans that hold water during the rainy season but dry up during the dry season. Historically, rains are seasonal, occurring in two periods around December and April, known as the short rains period and the long rains period respectively. However, in the past ten years, local climatic conditions appear much more irregular and there have been two periods of extended drought in this time period. Tsavo East National Park is in semi-arid area,

with an unpredictable, bimodal rainfall distribution of between 200 and 700 mm per annum (Wijngaarden, 1985). The long rainy season is experienced in the months of March, April and May and the short rain season in November and December. The short rains are generally considered to be more reliable and less erratic than the long rains. Rainfall in Tsavo West is generally higher and usually less erratic in spatial and temporal distribution than in Tsavo East (Wijngaarden, 1985; Leuthold and Sale, 1973). Average normal daily temperatures range between 20°C and 30°C. The temperatures are slightly higher in the dry season than in the wet season with a general decrease in temperature with increasing altitude. Contrary to the ranches, Tsavo East National Park has one permanent river (Galana river) and scattered water pans that hold water during the rainy season but dry up during the dry season.

3.1.3 Geology and soil

The ranches are geologically dominated by the remnants of the Eastern Arc Mountains, which include the Taita Hills, Mt. Kasigau, and lesser hills such as Sagalla and the Marungu range that run along the western boundary of the Rukinga. These hills fall within the Kasigau Corridor that is home to remnant patches of montane cloud forest, and to several endemic bird and flora species. The dominant soil type within the ranches is red laterite soil which is typical of this region, although there are small scattered bands of black cotton soil that occur sporadically within the ranches. There are also areas within the ranches where Gneiss Islands or rocky outcrops emerge from the soils to form small rocky hills. The geomorphology of the Tsavo National Parks is dominated by the occurrence of extensive planation levels of both erosional and sedimentary origin (Wijngaarden, 1985). A number of erosional surfaces can be identified, but only the latest, the Nyika level of the end-Tertiary age, is present over large areas. Remnants of the older surfaces are found at the base of Chyulu Hills and Yatta Plateau (Wijngaarden,

1985). The Chyulu Hills are relatively recent volcanic hills composed of basalts and in places covered by coarse pyroclastic deposits. The Yatta Plateau consists of a protective cap of Miocene phonolites, only approximately 10 m thick and overlying gneisses of the basement system rocks. The erosional plains are developed on a variety of rock types, such as the basement system rocks and the Duruma sandstones.

Eastwards of Tsavo approximately the 300 m contour line, accumulation processes have formed the landscape. These sedimentary plains are developed on Plio-Pleistocene “bay deposits” of an unconsolidated clay and saline nature. Towards the major rivers, the landscape has been dissected relatively recently, as shown by the gently sloping dissected topography towards the rivers and the V-shaped valleys. Within this extremely flat plain, a number of inselbergs occur, some more than 100 m high. They consist of a quartzitic type of basement system rock, making them more resistant to weathering and erosion. Where the basement system rock consists of crystalline limestone, they often form low elongated ridges. The soils of Tsavo show a wide range in depth, colour, drainage, condition, structure, chemical and physical properties. However, extreme differences in texture are uncommon and most soils have a sandy-clay texture in the subsoil (Wijngaarden, 1985).

3.1.4 Vegetation

The vegetation in the ranches has been stratified into regimes representing homogenous areas of land cover. The elevation ranges from 457.2 to 1066.8m above sea level. However, the actual stratification was performed using Landsat imagery. The main vegetation is Acacia-Commiphora woodland. The dominant plant species are drought specialists. They possess a number of strategies to find and preserve moisture in a semi-arid environment which includes dropping or

folding all foliage in the dry periods to reduce moisture loss from transpiration and photosynthesizing through their bark. Some of the species of *Acacia* and *Commiphora* trees include *Acacia tortilis* (Hayne), *Acacia nilotica* (L.) Delile, *Acacia bussei* (Harms ex B.Y.Sjöstedt), *Acacia hockii* (De Willd), *Commiphora africana* (A. Rich.), *Commiphora campestris* (J.B.Gillett) and *Commiphora confusa* (Vollesen). There are occasional taller hardwood trees species such as *Terminalia spinosa* (Robecchii Chiov), *Melia volkensii* (Guerke), *Boscia coriacea* Pax, *Cassia abbreviata* (Oliv) and *Newtonia hildebrandtii* (Vatke) Torre var. At the lowest elevations of the ranches, the thick Acacia-Commiphora forest thins and eventually transits to patches of grassland. The grassland stratum comprises indigenous savannah grasses and shrubs, with the occasional *Acacia zanzibarica* (S. Moore) Taub.

Tsavo East National Park falls along a lowland savanna with vegetation dominated by *Acacia-Commiphora*, in which the density of trees and shrubs varies significantly over time and space (EIA report for Jipe-Rombo fence). Other tree species include *Delonix elata* (L.) Gamble, *Platyclithium voense*, *Adansonia digitata* L., *Dobera glabra* (Forssk), *Newtonia hildebrandtii* (Vatke), *Acacia elatior* (Brenan), and *Kigelia africana* (Lam.) Benth. Common shrubs include *Azima tetraantha* (Lam), *Capparis sepiaria* (L.) R.Br, *Pluchea dioscordis* (IL.) DC, *Salvadora persica* L, *Combretum ukambensis* (C.B.Clarke), *Cordia goetzei* (Gürke), *Gardenia jovis-tonantis* (Welw.), *Lawsonia inermis* L., *Vernonia hildebrandtii* (Vatke) and *Meyna tetraphylla* (Schweinf. ex Hiern) Robyns. The main grass species include *Brachiaria deflexa* (Schumach.) Robyns, *Brachiaria leersoides* (Hochst.) Stapf, *Cenchrus ciliaris* (L.), *Digitaria macroblephara* (Hack.) Stapf, *Digitaria rivae* (Chiov.) Stapf, *Latipes senegalensis* Kunth, *Panicum maximum* (Jacq.),

Aristida adscensionis L., *Chloris roxburghiana* (Schult), *Tetrapogon tenellus* (K.D. Koenig ex Roxb.) Chiov and *Sporobolus helvolus* (Trin.) T. Durand and Schinz.

3.1.5 Wild animals

The common wildlife species in the region are elephants (*Loxodonta africana*), African buffalo (*Syncerus caffer*), Burchell's zebra (*Equus burchellii*), Coke's hartebeest (*Alcelaphus buselaphus*), waterbuck (*Kobus ellipsiprimnus*), Grant's gazelle (*Gazella grantii*), impala (*Aepyceros melampus*), hippopotamus (*Hippopotamus amphibius*), giraffe (*Giraffa camelopardalis*), lesser kudu (*Tragelaphus imberbis*), gerenuk (*Litocranius walleri*), warthog (*Phacochoerus aethiopicus*), fringe-eared oryx (*Oryx beisa callotis*) and eland (*Taurotragus oryx*). Large carnivore species found in the area include lions (*Panthera leo*), spotted hyena (*Crocuta crocuta*), cheetah (*Acinonyx jubatus*), leopard (*Panthera pardus*), and sliver-backed jackal (*Canis mesomelas*).

3.2 Data collection

3.2.1 Vegetation data

Different vegetation types in Tsavo East National Park and the surrounding ranchlands were studied by analyzing satellite images. Vegetation satellite images were obtained from the United Nations' Food and Agriculture Organization (FAO). The vegetation data was obtained in a raw data as a land cover map of Kenya. The land cover map was projected in ArcGIS and the study area shape files were overlaid on the land cover map. To establish and categorize different vegetation types found in Tsavo East National Park and the surrounding ranchlands, the land cover map was clipped using shape files of the study area (shape file refers to GIS vector files and they derived their name as shape file because they occurs in different shapes). "Symbiology"

command in ArcGIS was used to categorize different vegetation types found in Tsavo East National Park and the surrounding ranchlands.

3.2.2 Vegetation types preferred by Grevy's zebra

ArcGIS was used to extract the vegetation types that Grevy's zebra preferred. This was achieved by firstly projecting the land cover map of Tsavo East National Park and surrounding ranchlands which was obtained from United Nations' Food and Agriculture Organization into ArcGIS. Secondly, the Grevy's zebra GPS locations were overlaid into the land cover map. Thirdly, the command "select by location" in ArcGIS was used to extract vegetation types that contained Grevy's zebra GPS locations and the extracted vegetation types were then exported to a personal geodatabase file created in ArcGIS and saved for subsequent analyses.

3.2.3 Characteristics of vegetation preferred by Grevy's zebra

To document different vegetation characteristics which were preferred by Grevy's zebra, ArcGIS was used to extract different vegetation types which were preferred by Grevy's zebra. This was achieved by firstly projecting the land cover map in ArcGIS, followed by overlaying of Grevy's zebra GPS locations on the land cover map. Thirdly, the command in ArcGIS "select by location" was used to extract vegetation types which completely contained Grevy's zebra GPS locations. The extracted vegetation were exported to a personal geodatabase file. Vegetation description table which was obtained from FAO was used to identify different vegetation characteristics that Grevy's zebra preferred.

3.2.4 Distribution patterns of Grevy's zebra in their preferred vegetation types.

To assess the distribution patterns of Grevy's zebra in their preferred vegetation, Firstly ArcGIS was used to extract the vegetation types that Grevy's zebra preferred in Tsavo East National Park and the ranchlands, Secondly, ArcGIS was also used in extracting the number of Grevy's zebra GPS locations in each vegetation type. This was achieved by firstly projecting the land cover map that contained the vegetation types that Grevy's zebra preferred in ArcGIS, then Grevy's zebra GPS locations were overlaid on the land cover map and the command "select by location" was used to extract number of Grevy's zebra GPS locations in each vegetation type. This was followed by calculating the area in km² of each vegetation type preferred by Grevy's zebra. The areas in km² of each vegetation type preferred by Grevy's zebra and the number of Grevy's zebra GPS locations in each vegetation type was exported to excel. Excel was used to calculate densities of Grevy's zebra locations in each vegetation type both in Tsavo East National Park and ranchlands by dividing the number of Grevy's zebra GPS locations on given vegetation with the area occupied by that vegetation. A command in ArcGIS called "symbology" was used to categorize distribution patterns of Grevy's zebra in their preferred vegetation.

3.2.5 Grevy's zebra distribution data

Grevy's zebra distribution was studied by collecting data on the occurrence of Grevy's zebra. Occurrence data was collected using a sampling route method within Tsavo East National Park and on the surrounding ranchlands. Data were collected by driving along the roads and recording the number of Grevy's zebra observed on either side of the road. When Grevy's zebra were sighted, the date, time, GPS location, and total number of Grevy's zebra was recorded. The GPS readings were taken when in the car at an accuracy of 3-4m using hand held 12 channel GPS receiver. The distances of Grevy's zebra to the car were estimated using a laser range finder. The

vegetations where Grevy's zebra were sighted were visually categorized as open bush when there were 0-2 bushes between the zebra and the viewer, light bush when the vegetation had 3-6 bushes, medium bush when there were 7-12 bushes and thick bush when the vegetation had >13 bushes. All the surveys were done during day time from 06:00 am to 06:30 pm. The collected data were entered into an Excel spreadsheet for further analysis. The Grevy's zebra GPS locations data were used to generate distribution maps for Grevy's zebra. All GIS analysis in this study was done using ArcGIS software 9.3.1 and Arcview 3.3.

3.2.6 Grevy's zebra distribution maps

Distribution maps of Grevy's zebra were generated from the GPS locations that were recorded where the zebras were sighted in Tsavo East National Park and the surrounding ranchlands. This was achieved by firstly adding the GIS shape files of Tsavo East National Park and the ranchlands in ArcMap, Secondly, Grevy's zebra GPS locations were overlaid into the shape files of Tsavo East and ranchlands. By using the command "symbology" in ArcGIS the total numbers of Grevy's zebra were grouped and distribution maps generated. ArcGIS was also used in calculating the area in km² occupied by each parcel of land and extracting the number of Grevy's zebra GPS locations in different land parcels in Tsavo East National Park and in the surrounding ranchlands. The number of Grevy's zebra GPS locations in different land parcels and the area occupied by each land parcel was exported to excel. To calculate the percentages of Grevy's zebra GPS locations and densities in each land parcel simple excel fomulie were used. (Grevy's zebra densities in different land parcels were calculated by dividing the number of Grevy's zebra GPS locations in a given land parcel with the area occupied by that land parcel).

3.2.7 Distribution of water pans

Water pans data were collected by recording the GPS locations of all water pans that contained water both in Tsavo East National Park and ranchlands. This was done concurrently with data collection for distribution of Grevy's zebra. The data (GPS location for water pans) were projected into ArcGIS and a distribution map of water pans was created. Water pans data were used to determine whether water was a key resource influencing distribution of Grevy's zebra by comparing the distances of Grevy's zebra locations from the water pans. This was achieved by firstly projecting the water pans GPS locations in ArcGIS. Secondly, ArcGIS extension tool (Hawths tools) was used to calculate distances between different water pans GPS locations. Thirdly, Grevy's zebra GPS locations were projected in ArcGIS and Hawth's extension tool was used to calculate distances between Grevy's zebra GPS locations. The distances were then tested for correlation using Pearson correlation.

3.2.7.1 Distribution of Grevy's zebra in relation to water pans in different land parcels.

ArcGIS was used to calculate the average distances of Grevy's zebra locations from water pans in different land parcels to assess whether the zebras were within easy reach of watering points. This was achieved by firstly projecting land parcels shape files to ArcGIS. Then water pans GPS locations and Grevy's zebra locations were overlaid respectively. Using GIS Grevy's zebra and water pans GPS locations in each land parcel were extracted and the data was exported to a personal geodatabase file and saved. ArcGIS point distance tool was used to calculate the distances between Grevy's zebra and water pans in different land parcels and the data was exported to excel file for further analysis. Excel was used to calculate the mean distances of Grevy's zebra locations from water pans. The results were presented graphically.

3.3 Data analysis

Point pattern analysis was performed to assess the distribution patterns of Grevy's zebra. Point pattern analysis is a statistical technique that is used to describe patterns of point events that have occurred in a specified geographic area (Gatrell, *et al.*, 1996). Point pattern analysis traces its origin from botanists and ecologists in 1930s (Burden, 2003) and has since spread to many fields. Developments in GIS have led to increased use of point pattern analysis in diverse fields such as epidemiology (Gatrell, *et al.*, 1996), ecology (Bonnicksen and Stone, 1981; Wiegand and Moloney, 2004), and criminology (Bowers and Hirschfield, 1999; Ackerman and Murray, 2004). Wall *et al.* (1985) used nearest neighbor analysis to explore spatial distribution of accommodation units in Toronto Canada. They found that the method captured dispersed patterns adequately; however, it depicted some seemingly clumped patterns as random. Heupel and Simpfendorfer (2005) used nearest neighbor analysis to study the distribution of juvenile black sharks in Terra Ceia bay, Florida. The technique captured adequately temporal aggregation of juvenile sharks over a period of three years.

The GIS software Arcview 3.3 was used to calculate the nearest neighbor distance to test whether the distribution pattern of the Grevy's zebra locations were random, even or clustered. Nearest neighbor distance analysis assessed the distances between Grevy's zebra points and their nearest neighboring point (Lancaster and Downes, 2004). The concept behind nearest neighbor analysis was randomness (Wall *et al.*, 1985). The analysis was based on comparing the observed average distances between nearest neighboring point events and those expected in a random point process to assess whether Grevy's zebra distribution were random, even or clustered (Lee and Wong, 2001). The random points were generated by the software (Arcview 3.3). The total numbers of random points were the same as the total number of Grevy's zebra GPS locations.

The nearest neighbor statistic (R) was calculated. The value of R was the ratio of the average distance from the closest neighbor to each point event and the distance expected based on chance. This meant that, $R = 1$ when the observed average distance between nearest neighboring points was equal to the mean distance expected in a random point process. When $R < 1$, the point process was clustered, but dispersed when $R > 1$. To test that the Grevy's zebra distribution did not occur by chance, the standard error of the distribution was used to compute Z score. The value of Z was calculated by subtracting the expected average distance of Grevy's locations from the observed average distance then divided by the standard error of the distribution, in which significant distribution was exhibited when $-1.96 \geq Z \geq 1.96$. If the Z value was greater than 1.96 or greater than -1.96 then the distribution pattern did not occur by chance.

Kernel density analysis was used to estimate the spatial density of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands. Kernel density analysis is a nonparametric statistical method for estimating probability densities from a set of GPS locations or points. This analysis resulted in smooth estimates of variation in point concentration. The degree of smoothness was determined by the bandwidth used in the analysis and consequently the resultant estimated density surface. The bandwidth was the length of the search radius within which the kernel exerted its influence. Kernel density analysis produced a density map of estimates of Grevy's zebra at a spatial scale. The bandwidth used in a kernel density analysis had some meaning in the context of the study. For instance, the distribution patterns of a given species of wildlife may be estimated in a kernel density analysis using a bandwidth relative to its home range. Kernel density estimation has been used to model hotspot areas of wildlife mortality along a major road in Australia (Ramp *et al.*, 2005) and to isolate problem neighborhoods characterized

as crime hotspots in Lima, Ohio (Ackerman and Murray 2004). Trisalyn and Boots (2005) identified hotspot areas infested with pine beetles in British Columbia forests, and Johnson *et al.* (2006) estimated the risk of exposure to West Nile virus in New York State using kernel density estimation.

Kernel density analysis was performed to identify areas within the study area that had high densities for Grevy's zebra. Kernel density analysis was performed using ArcGIS. A band width of 14.7km was selected in the analysis because it corresponded to the home range size of Grevy's zebra in the study area (the home range size of Grevy's zebra was calculated using minimum convex polygon method using ArcGIS). The analysis was achieved by projecting the Grevy's zebra GPS locations in ArcGIS and the home range extension tool for ArcGIS was used to calculate the Kernel densities of Grevy's zebra.

Chi-square test of association was used to test the association between vegetation types and distribution of Grevy's zebra. The chi-square test of association was performed by comparing the number of Grevy's zebra locations in different vegetation types in Tsavo East National Park and the surrounding ranchlands, as obtained by analyzing land cover maps from United Nations' Food and Agriculture Organization. ArcGIS was used both in extracting the number of Grevy's locations in each vegetation type and in calculating the number of different vegetation types found in Tsavo East National Park and the surrounding ranchlands. This was achieved by firstly overlaying Grevy's zebra GPS locations in different vegetation types, secondly extracting number of Grevy's zebra GPS locations in each vegetation type and thirdly calculating the number of different vegetation types in the study area. The number of Grevy's locations in each

vegetation type and the number of vegetation types where Grevy's zebra occurred were then used to run chi-square test of association. (During the analysis, the vegetations that Grevy's zebra preferred or where Grevy's zebra were found were considered as the vegetation they associated with).

The number of Grevy's GPS locations in each vegetation type and the number of vegetation types where Grevy's zebra occurred were used to test the strength of association between vegetation types and Grevy's zebra. Measures of association such as Cramer's V, Pearson correlation, Lambda symmetric, Lambda Dependent column and Lambda Dependent Row were computed to test the strength of association between vegetation types and distribution of Grevy's zebra. The measures of association had values that ranged from 0 to 1, with values greater than 0.5 showing strong association and values less than 0.5 weaker associations.

Vegetation selection index was calculated to assess vegetation preferences of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands. The Grevy's zebra GPS locations were overlaid on the vegetation type's map and using ArcGIS the numbers of locations (sightings) of Grevy's zebra in each vegetation type were recorded. The area occupied by each vegetation type was calculated using ArcGIS. The proportion of Grevy's zebra locations in each vegetation type, and the proportional area of each vegetation type were used to calculate a selection index. A vegetation selection index was calculated by dividing the proportion of Grevy's zebra locations in each vegetation type by the proportional area of each vegetation type. A selection index of >1 indicated vegetation preference and selection index of <1 indicated vegetation avoidance.

Pearson correlation was used to test the relationship between Grevy's zebra movement and availability of water. ArcGIS was used to calculate the average distances between Grevy's zebra locations and the distances between GPS locations of different water pans. These distances were then tested using Pearson correlation method to determine the relationship between Grevy's zebra locations and distances to water pans.

CHAPTER FOUR: RESULTS

4.1 Vegetation types found in Tsavo East National Park and the surrounding ranchlands

Thirty different Vegetation types were found in different areas of Tsavo East National Park and the ranchlands (Table 4.1). Tsavo East National Park had nineteen different Vegetation types while the ranchlands had twenty four different vegetation types. The most common vegetation type within Tsavo East National Park was very open shrubs with closed to open herbaceous and sparse trees which covered 50.52% of the total area of Tsavo East National Park followed by closed to very open herbaceous with sparse trees and shrubs which covered 24.43% of the total area (Fig 4.1). In the ranchlands the most common vegetation type was very open shrubs with closed to open herbaceous which covered 18.07% of the total ranchland area followed by closed to very open herbaceous with sparse trees and shrubs which covered 16.82% of the total ranchland area (Fig 4.1). The names and codes of different vegetation types were described using international standard land cover classification system (FAO, 2002).

Table 4. 1 : Different vegetation types found in Tsavo East National Park and in the ranchlands.

Code	Vegetation name
2H(CP)	Closed to very open herbaceous
2H(CP)78	Closed to very open herbaceous with sparse trees and shrubs
2H(CP)8	Closed to very open herbaceous with sparse shrubs
2SCJ	Closed shrubs
2SCJ7	Closed shrubs with sparse trees
2SOJ67	Open shrubs with closed to open herbaceous and sparse trees
2SP6	Open general shrubs with closed to open herbaceous
2SR6	Sparse shrubs with sparse herbaceous

2SV6	Very open shrubs with closed to open herbaceous
2SVJ67	Very open shrubs with closed to open herbaceous and sparse trees
2TC8	Closed trees with shrubs
2TO268	Open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs
2TO28	Open trees (broadleaved deciduous) with closed to open shrubs
2TP8	Open general trees with shrubs
2TV268	Very open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs
2TV28	Very open trees (broadleaved deciduous) with closed to open shrubs
2WC7	Closed woody with sparse trees
2WP6	Open general woody with herbaceous
4H(CP)F8	Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water
4H(CP)FF	Closed to Open Herbaceous On Permanently Flooded Land
4HCF	Closed herbaceous on temporarily flooded land - fresh water
4SPF6	Open general shrubs with closed to open herbaceous on temporarily flooded land
4TPF6	Open general trees with closed to open herbaceous on temporarily flooded land - fresh water
4WPF6	Open general woody with closed to open herbaceous on temporarily flooded land - fresh water
8WFP	River
8WP	Natural lakes
HD4	Large-Medium Fields, Rainfed
HD57	Herbaceous - Large to Medium Fields, Irrigated Surface Permanent
HM4	Rainfed Herbaceous - Medium Fields
HR4	Continuous Rainfed Small fields [cereal]

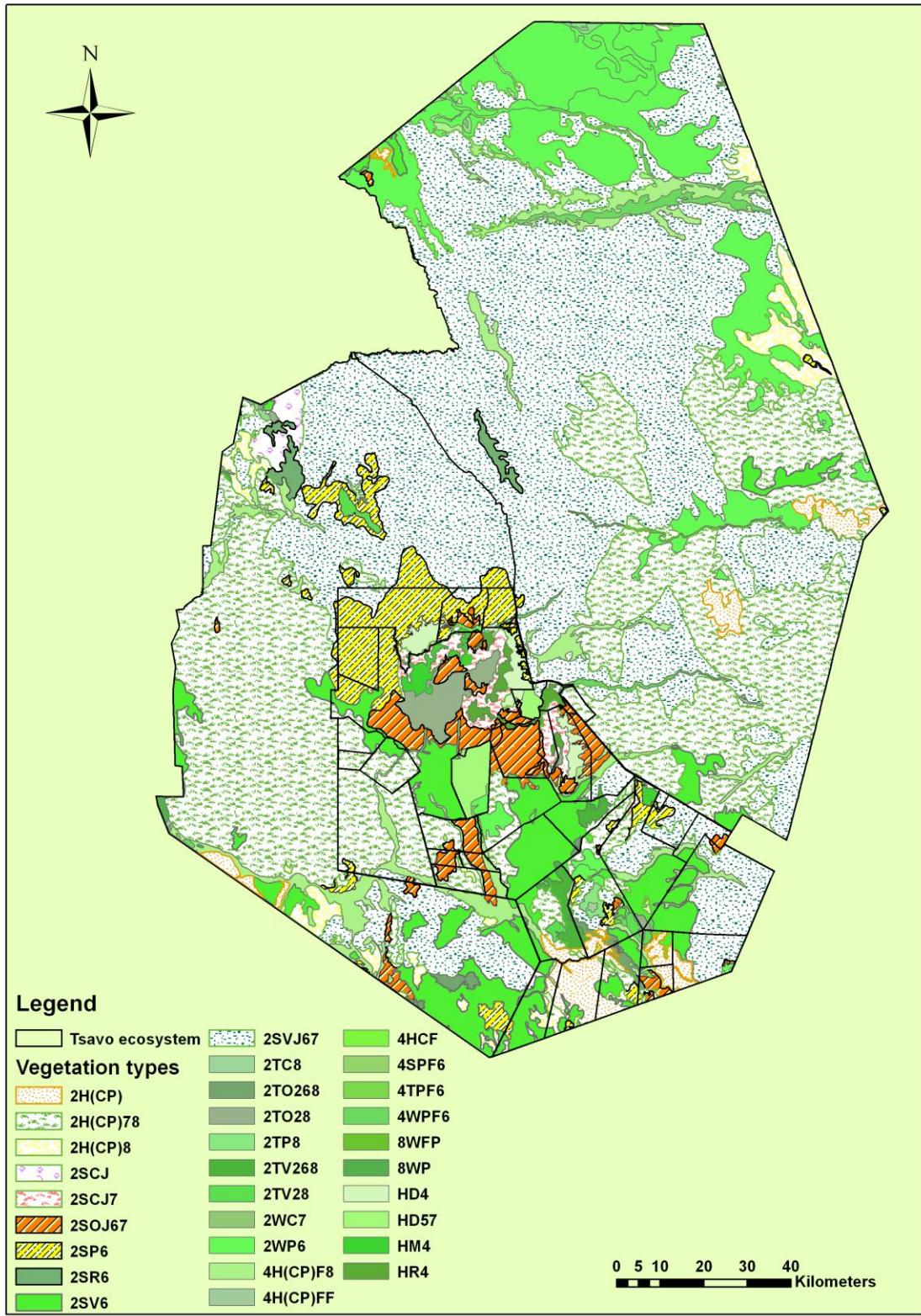


Figure 4. 1 : Different vegetation types that were found in Tsavo East National Park and in the ranchlands.

4.2 Vegetation preferences by Grevy's zebra.

Grevy's were found to occur in seven vegetation types (Table 4.2), namely closed to very open herbaceous with sparse trees and shrubs (2H(CP)78), open shrubs with closed to open herbaceous and sparse trees(2SOJ67), open general shrubs with closed to open herbaceous (2SP6), very open shrubs with closed to open herbaceous (2SV6), very open shrubs with closed to open herbaceous and sparse trees (2SVJ67), closed to very open herbaceous with sparse shrubs on temporarily flooded land (4H(CP)F8) and rainfed herbaceous (HM4) .

Table 4. 2 : Codes and names of different vegetation where Grevy's zebra were found.

Codes	Vegetation names
2H(CP)78	Closed to very open herbaceous with sparse trees and shrubs
2SOJ67	Open shrubs with closed to open herbaceous and sparse trees
2SP6	Open general shrubs with closed to open herbaceous
2SV6	Very open shrubs with closed to open herbaceous
2SVJ67	Very open shrubs with closed to open herbaceous and sparse trees
4H(CP)F8	Closed to very open herbaceous with sparse shrubs on temporarily flooded land
HM4	Rainfed herbaceous

Vegetation selection index results showed that four out of the seven vegetation types where Grevy's zebra were found had a selection index of >1 indicating the vegetations which were mostly preferred by the zebras and these vegetations were open general shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees, closed to very open herbaceous with sparse shrubs on temporarily flooded land.

Table 4. 3 : Vegetation types and their selection indices by Grevy's zebra in Tsavo East National Park the ranchands

Vegetation type	Area in hectares	Proportion of each vegetation type	Number of zebras locations	Proportion of zebras locations	Selection index value
Closed to very open herbaceous with sparse trees and shrubs	1968007	0.1632373	4	0.013468013	0.082506
Open shrubs with closed to open herbaceous and sparse trees	1056656	0.0876449	9	0.03030303	0.345748
Open general shrubs with closed to open herbaceous	559523	0.0464099	15	0.050505051	1.088238*
Very open shrubs with closed to open herbaceous	3929300	0.3259178	101	0.34006734	1.043414*
Very open shrubs with closed to open herbaceous and sparse trees	3572057	0.2962861	110	0.37037037	1.250043*
Closed to very open herbaceous with sparse shrubs on temporarily flooded land	917432	0.0760969	57	0.191919192	2.522038*
Rain fed herbaceous	53133	0.0044071	1	0.003367003	0.763988
Total		1	297	1	

The asterick* in the table indicate vegetations which were mostly preferred by Grevy's zebra

4.3. Characteristics of the preferred vegetation by Grevy's zebra.

The total area that was covered by the vegetation preferred by Grevy's zebra both in Tsavo East and the ranchlands was 3052.64km². The proportional area of the vegetation preferred by Grevy's zebra in Tsavo East National park was 0.67km² while the proportional area in the ranchlands was 0.33km². Different vegetation types that Grevy's zebra preferred had the following proportion in relation to the total area covered by the vegetation preferred by Grevy's zebra. 2H(CP)78 had the proportion of 0.65km², 2SOJ67 had 0.0036km² while 2SP6, 2SV6, 2SVJ67, 4H(CP)F8 and HM4 had 0.015km², 0.09km², 0.21km², 0.03km² and 0.003km² respectively.(codes of vegetation names are as explained in table 4.2).

The vegetation namely closed to very open herbaceous with sparse trees and shrubs that Grevy's zebra preferred had characteristics that included shrubs with herbaceous layer and crown cover ranging from 40-100%, herbaceous cover of 15-60% and shrub height of 0.03-m., Open shrubs with closed to open herbaceous and sparse trees vegetation had characteristics which included shrubs with herbaceous layer and sparse trees, the height of shrubs varied from 0.5 to 5 m, shrubs cover varied from 40 to 65 % and the crown cover was between 60-70%. Open general shrubs with closed to open herbaceous vegetation had shrubs with herbaceous layers, the height of shrubs varied from 0.3 to 5 m and shrubs cover varied from 15 to 65 % while the crown cover was between 60-70%.

Very open shrubs with closed to open herbaceous vegetation had shrubs with herbaceous layer, the height of shrubs varied from 0.3 to 5 m, shrubs cover varied from 15 to 40 % and crown cover was between 60-70%. Very open shrubs with closed to open herbaceous and sparse trees vegetation had the following characteristics, shrubs with sparse tree and herbaceous layers, the

height of shrubs varied from 0.5 to 5 m, shrubs cover varied from 15 to 40 % and crown cover was between 60-70%. Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water vegetation had characteristics which included grassland with sparse shrubs on temporarily swampy area, the height of herbaceous plants varied from 0.03 to 3 m, herbaceous cover varied from 15 to more than 65 %, the land usually flooded for 2 to 4 months in a year and the crown cover was between 15-100%. Rainfed herbaceous - medium fields' vegetation was found in the rainfed herbaceous area. The field size varied from 2 to 5 ha which was a cultivated terrestrial area and managed lands.

4.4 Distribution patterns of Grevy's zebra in the preferred vegetation types

Grevy's zebra occurred in groups of either 1-4, 5-12 and 13-22 individuals (Fig 4.4). Small groups were more prevalent with 85% of all sightings consisting of group size of 1-4, 13% of the total sightings consisted of group size of 5-12 individuals while 2% of the total sightings consisted of group size of 13-22 individuals. The mean distribution group of Grevy's zebra was 9.5 ± 3.08 (Mean \pm SE). In Tsavo East National Park Grevy's zebra were distributed in four preferred vegetation types which were closed to very open herbaceous with sparse trees and shrubs, very open shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees and closed to very open herbaceous with sparse shrubs on temporarily flooded land. The zebras occurred in densities of 0.002 indiv./km², 0.22 indiv./km², 0.82 indiv./km² and 0.04 indiv./km² respectively in their preferred vegetation types (Fig 4.2). (The densities of Grevy's zebra in their preferred habitats were calculated using number of GPS locations of Grevy's zebra in their respective vegetations. indiv./km² refers to Grevy's zebra GPS locations per kilometer square in the preferred vegetation type).

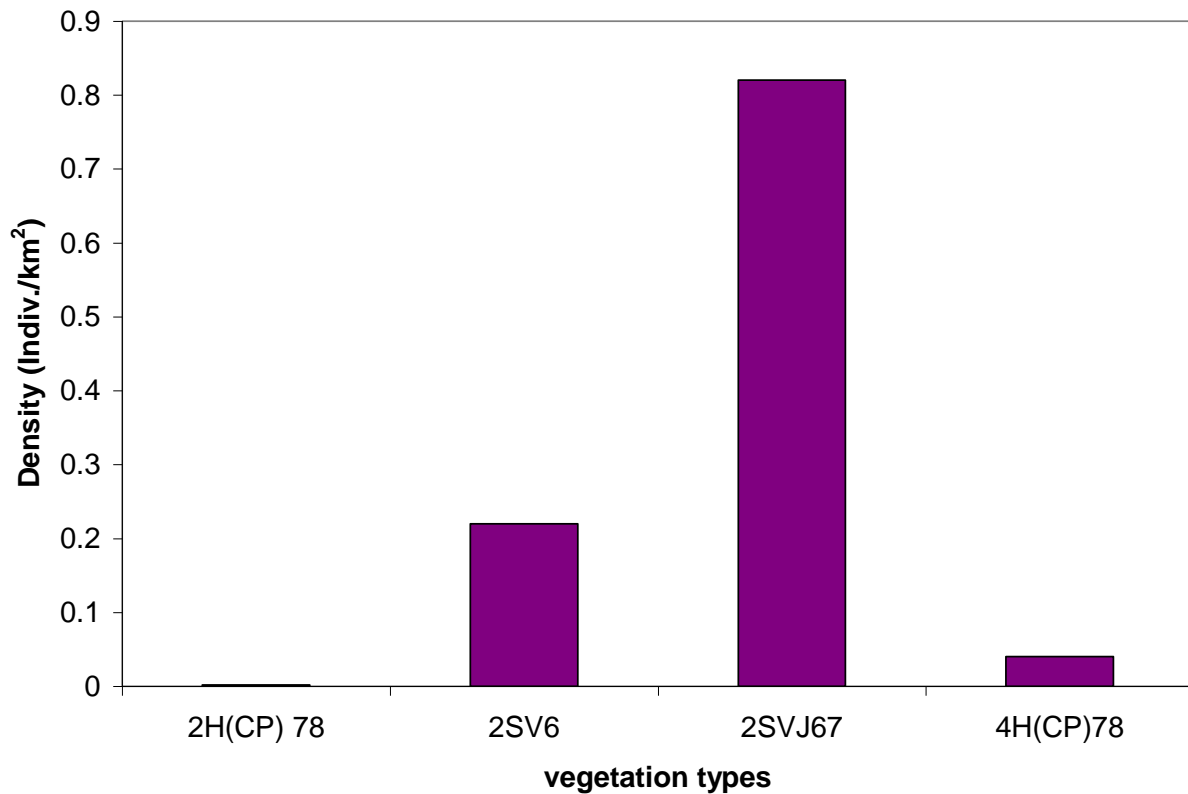


Figure 4. 2 : Grevy's zebra densities in their preferred vegetation types in Tsavo East National Park.

In the ranchlands Grevy's zebra preferred six vegetation types which were open shrubs with closed to open herbaceous and sparse trees, open general shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees, closed to very open herbaceous with sparse shrubs on temporarily flooded land and Rainfed herbaceous. The zebras occurred in densities of 0.80 indiv/km², 0.32 indiv/km², 0.39 indiv/km², 0.17 indiv/km², 0.97 indiv. /km² and 0.09 indiv/km² respectively in their preferred vegetation types (Fig 4.3).

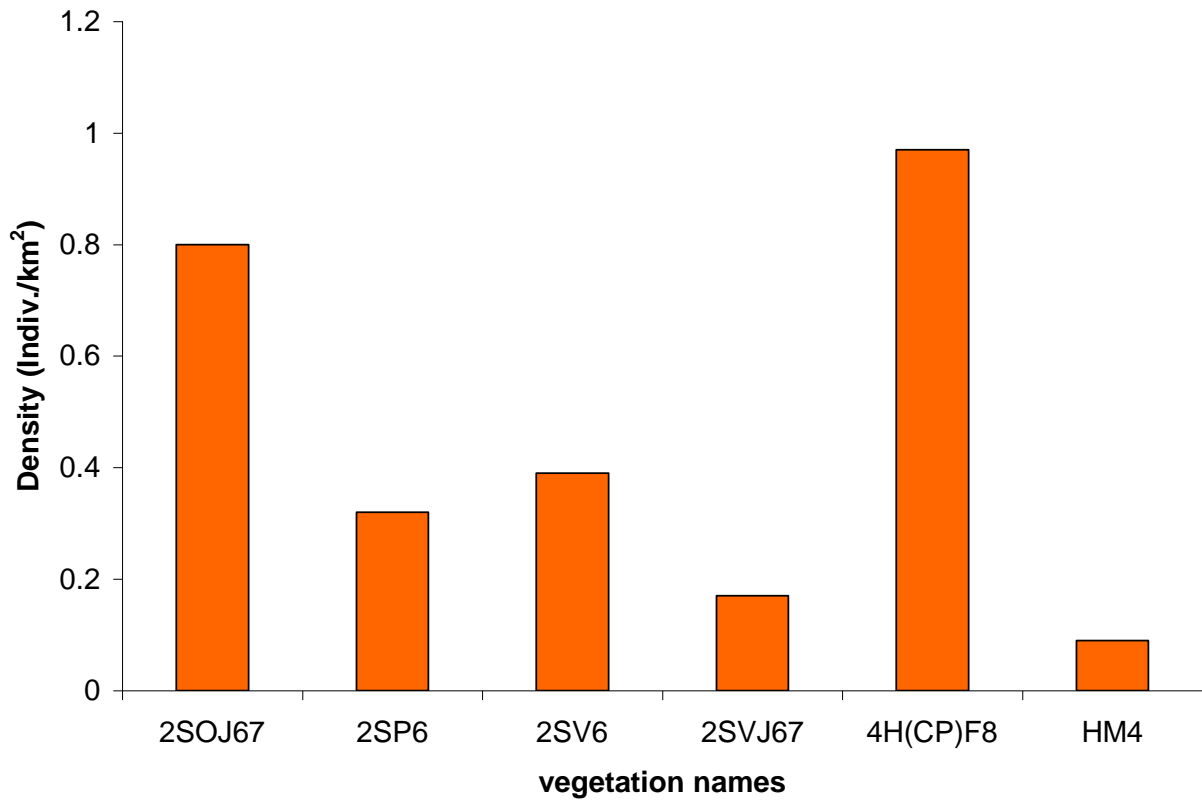


Figure 4. 3 : Grevy's zebra densities in their preferred vegetation types in the ranchlands

Results of Grevy's zebra distribution in the vegetation types which were visually estimated during route sampling survey showed that 73% of Grevy's zebra locations were found in open bush cover, 20% were found in medium bush cover , 5% were found in light bush cover and only 2% of Grevy's zebra locations occurred in thick bushes.

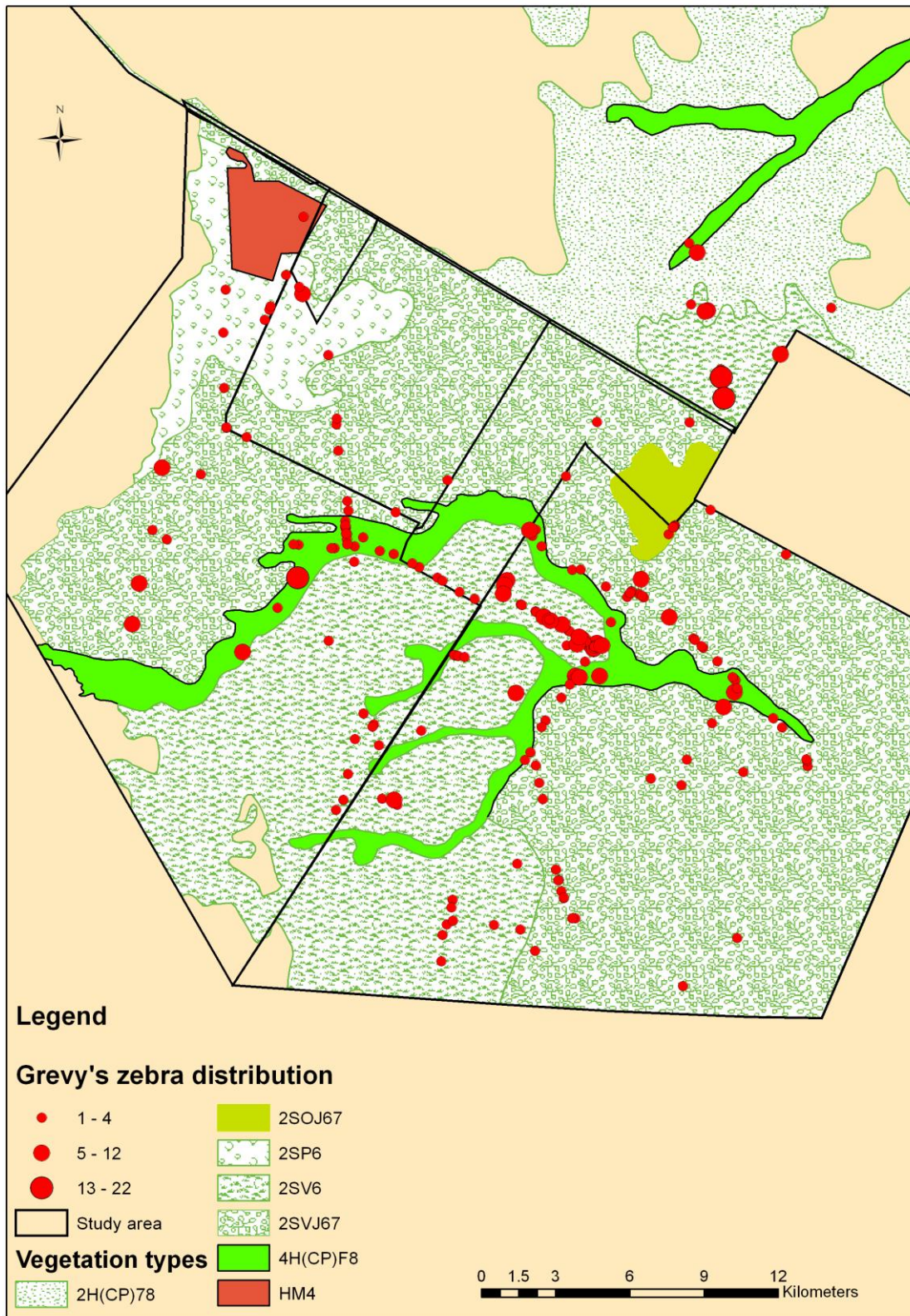


Figure 4. 4 : Distribution map of Grevy's zebra in their preferred vegetation in Tsavo East National Park and the neighbouring ranchlands.

4.5 Distribution of Grevy's zebra in different land parcels in ranchlands and Tsavo East National Park.

Grevy's zebra sightings in the ranchlands constituted 95% of the total Grevy's zebra locations while 5% of the sightings were in Tsavo East National Park. Taita ranch had 64% of Grevy's zebra total sightings, Rukinga had 22% of Grevy's total sightings, Bachuma had 4% of the sightings, Grazier's had 3% of the sightings, Wangala had 1% of the locations and Tsavo East National Park had 5% of Grevy's zebra total sightings.

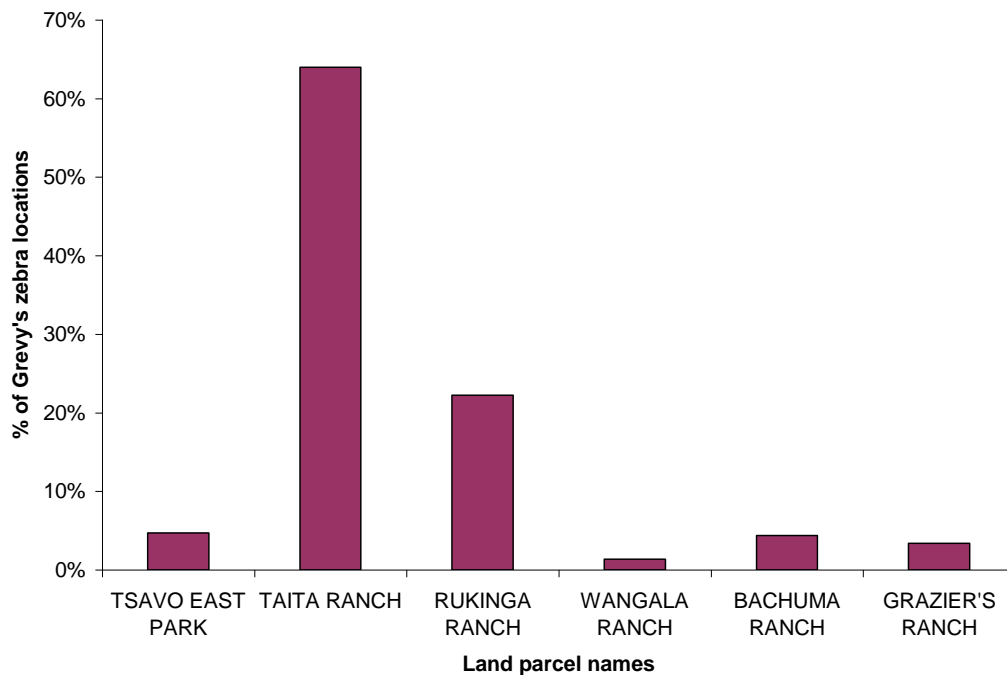


Figure 4. 5 : Distribution of Grevy's zebra in different land parcels.

Results from the nearest neighbor distance analysis showed that the distribution patterns of Grevy's zebra in Tsavo East National Park and the ranchlands were clustered $R < 1.0$, the value of R was 0.46 and $Z = 14.89$. Grevy's zebra distribution densities in the land parcels were significantly different. Taita ranch had the highest Grevy's zebra density of 0.46 indiv. /km² followed by Wangala ranch 0.44 indiv. /km². The densities in Rukinga, Bachuma and Grazier's

ranches were 0.21 indiv./km², 0.14 indiv. /km² and 0.16 indiv. /km² respectively. Tsavo East National Park had the lowest density of 0.01 indiv./km². Chi-square test results showed a significant difference in Grevy's zebra densities in different land parcels ($\chi^2 = 0.669859$, df 5, p=0.001). The mean density of Grevy's zebra in different land parcels was 0.24±0.07.

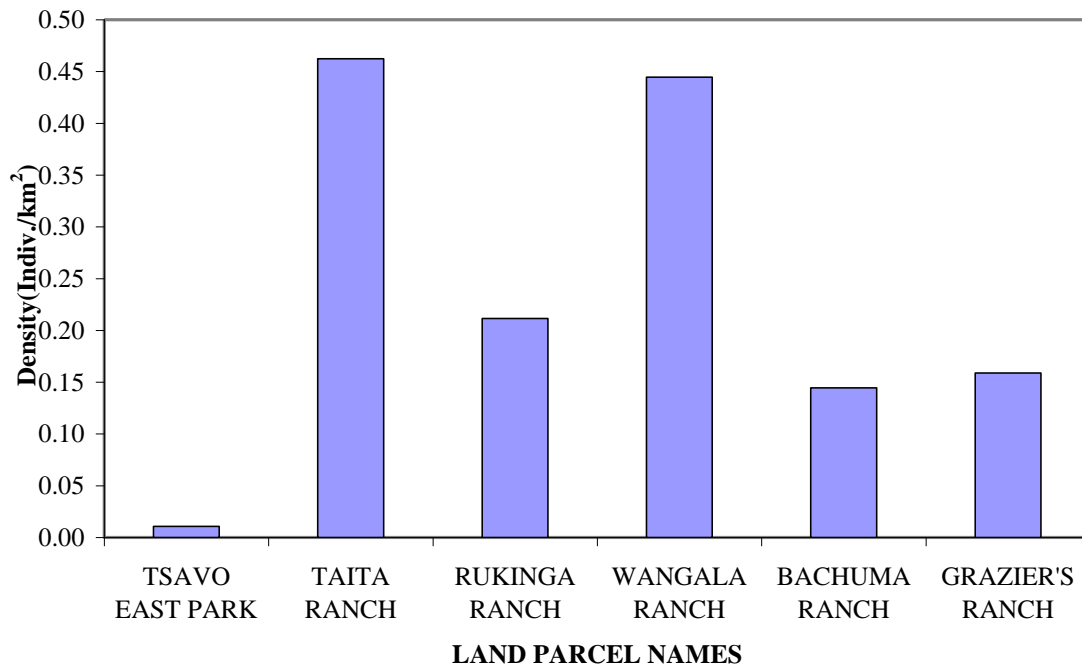


Figure 4. 6 : Grevy's zebra densities in different land parcels in Tsavo East Park and the ranchlands.

4.5.1 Spatial distribution patterns of Grevy's zebra in Tsavo East Park and the ranchlands.

Kernel spatial analysis results showed high densities of Grevy's zebra in northeastern areas of Taita ranch. Medium densities of Grevy's zebra occurred in eastern areas of Rukinga and Taita ranches and in the southern areas of Bachuma, Grazier's and Taita ranches (Fig 4.7). Tsavo East National Park and Wangala ranch had low densities of Grevy's zebra. Western and northern areas of Rukinga ranch and southeastern areas of Taita ranch had low densities of Grevy's zebra.

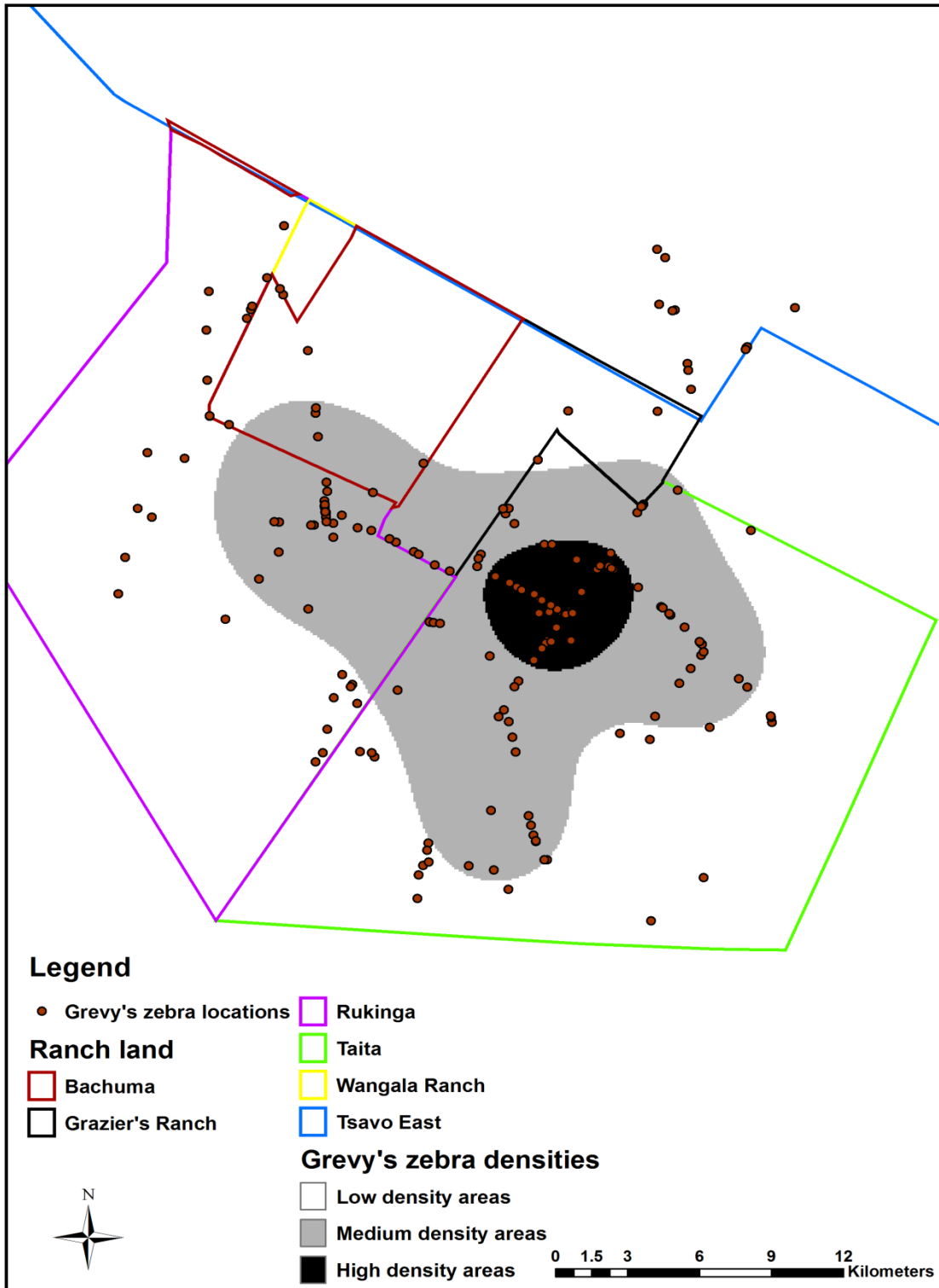


Figure 4. 7: Densities of Grevy's zebra in different land parcels. The dark black patch is the area where high densities of Grevy's zebra occurred. The gray patch shows medium density areas while the white areas show Grevy's zebra low densities areas.

4.6 Grevy's zebra vegetation association.

4.6.1 Grevy's zebra association with vegetation.

Chi-square test of association results showed that Grevy's zebra were significantly associated with vegetation types ($\chi^2 = 109.8$, $df = 6$, $P = 0.001$). The vegetation types which were significantly associated with Grevy's zebra were open general shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees, closed to very open herbaceous with sparse shrubs on temporarily flooded land, closed to very open herbaceous with sparse trees and shrubs, open shrubs with closed to open herbaceous and sparse trees and rain fed herbaceous. (Table 4.4)

Table 4. 4 : Results of vegetation types and Grevy's zebra locations in each vegetation type.

Name of the vegetation	Number of vegetation types	Number of Grevy's zebra locations in each vegetation type
Closed to very open herbaceous with sparse trees and shrubs	27	4
Open shrubs with closed to open herbaceous and sparse trees	26	9
Open general shrubs with closed to open herbaceous	22	15
Very open shrubs with closed to open herbaceous	27	101
Very open shrubs with closed to open herbaceous and sparse trees	24	110
Closed to very open herbaceous with sparse shrubs on temporarily flooded land	24	57
Rainfed herbaceous	7	1

Results from measures of association such as Cramer’s V, Pearson correlation, Labda symmetric, Lambda Dependent column and Lambda Dependent Row showed strong association (values > 0.5) between Grevy’s zebra locations and vegetation types that Grevy’s zebra preferred (Table 4.5).

Table 4. 5 : Results of measures of association between Grevy’s zebra and vegetation types.

Measure of Association	Calculated values
Cramer's V	1.000
Pearson C	0.894
Lambda Symmetric	0.818
Lambda Dependent=Column	0.667
Lambda Dependent=Row	1.000

4.6.2 Grevy’s zebra association with water pans.

Pearson correlation results showed a significant and positive relationship between Grevy’s zebra locations and distances to water pans $r=0.235$, $p=0.001$, $n=297$. In Taita ranch Grevy’s zebra were found at an average distance of 9618 meters to the water pans, in Rukinga, Bachuma, Wangala and Tsavo East Grevy’s zebra were found at an average distances of 8060, 3037, 916 and 9629 meters to the water pans respectively. All Grevy’s zebra locations in different land parcels were within an average distance of less than 10km to the water pans. The mean distance of Grevy’s zebra locations to water pans in different land parcels was 6251.20 ± 1798.57 meters.

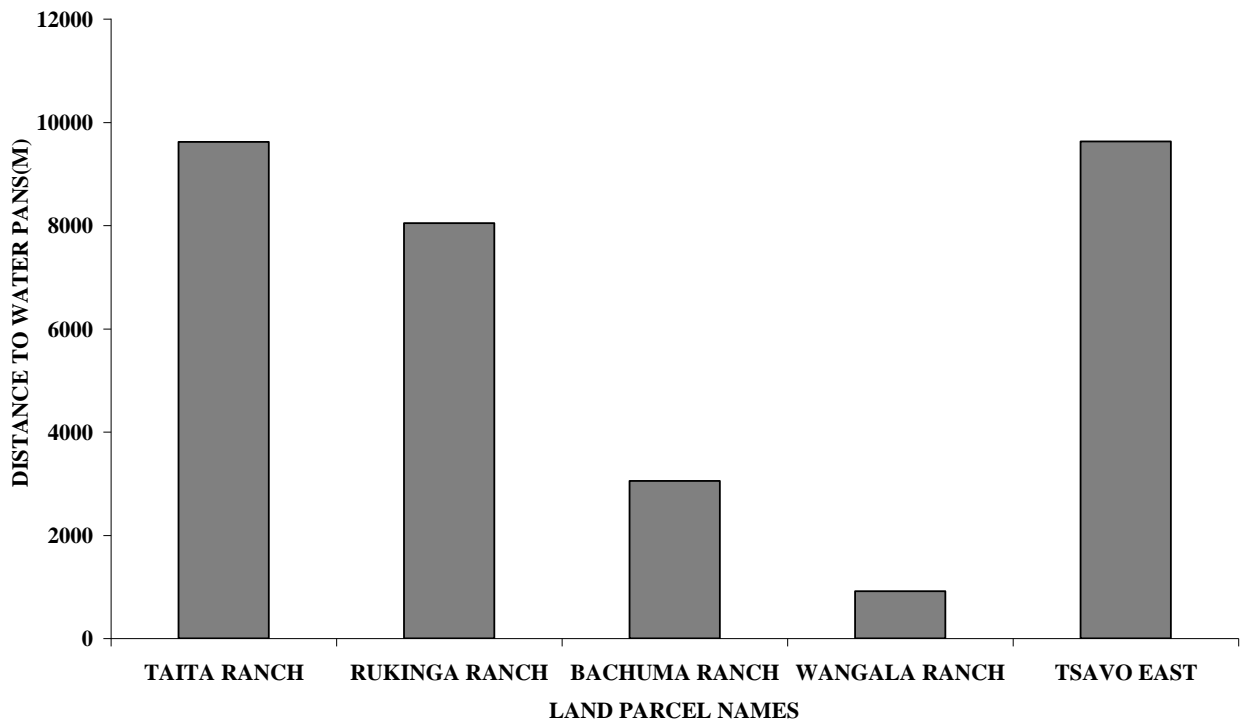


Figure 4. 8 : Average distances (m) of Grevy's zebra locations from water pans in different land parcels.

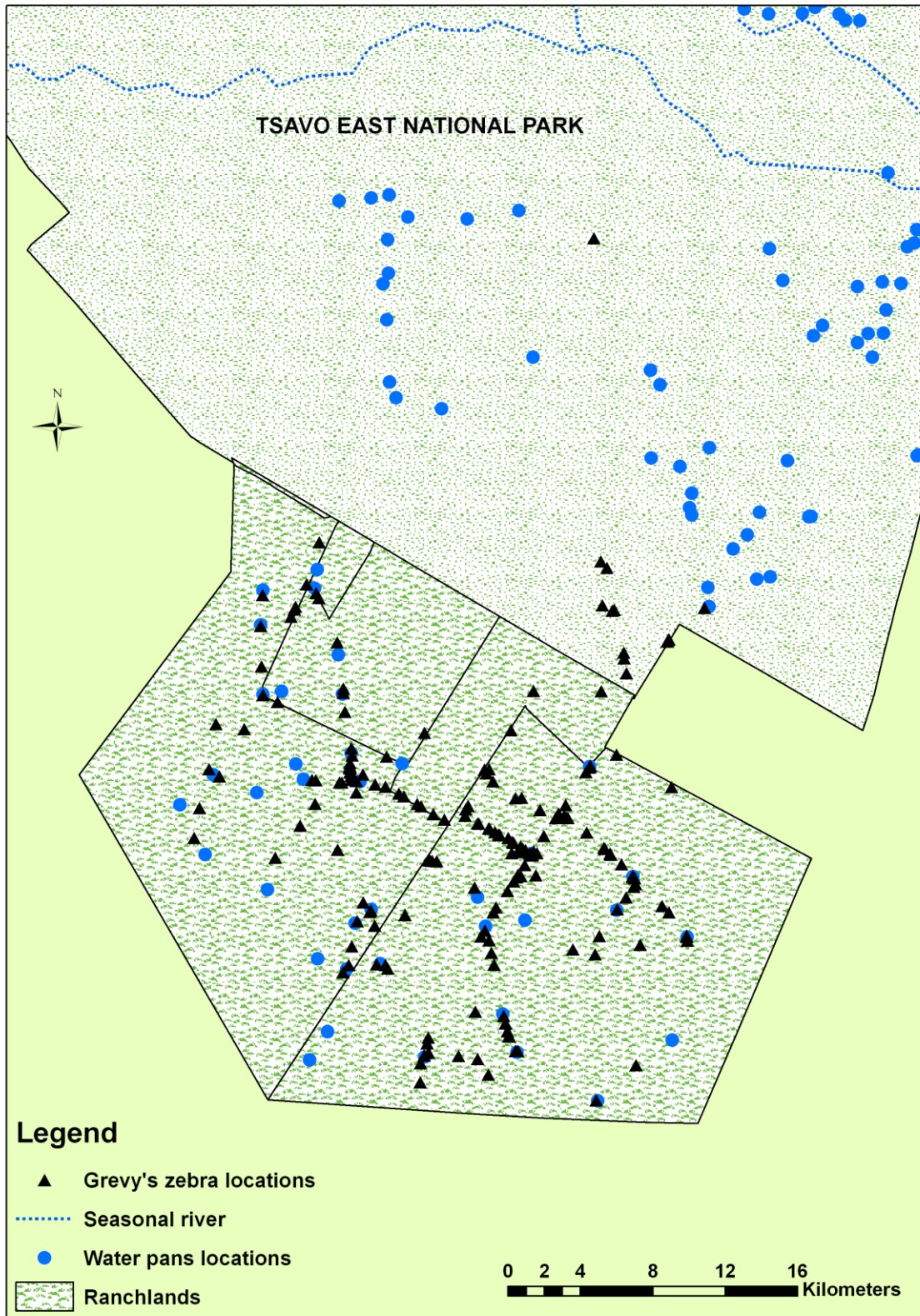


Figure 4. 9 : Distribution of Grevy's zebra in relation to water pans in Tsavo East National Park and the surrounding ranchlands.

In summary, results of this study have revealed that Tsavo East National Park and the surrounding ranchlands contain different vegetation types that vary in their importance for wildlife survival. Grevy's zebra preferred seven vegetation types out of thirty different vegetation types found in Tsavo East National Park and the surrounding ranchlands. All the vegetation types that Grevy's zebra preferred had characteristics which ranged from crown cover of 60-100%, shrub cover of 15-40% and shrub height of 0.03-5m. Another important characteristics found on the vegetation was herbaceous layer. Grevy's zebra were distributed in different groups with majority of them occurring in groups of 1-4 individuals in their preferred vegetation with an overall mean distribution of 9.5 ± 3.08 . The densities of Grevy's zebra in their preferred vegetation varied both in Tsavo East National Park and in the ranchland. In the Tsavo East high density of Grevy's zebra was prevalent on very open shrubs with closed to open herbaceous and sparse trees while in ranchland high density of Grevy's zebra was found in closed to very open herbaceous with sparse shrubs on temporarily flooded land. Grevy's zebra preferred ranchlands to Tsavo East National Park with 95% of the total locations occurring in ranchlands. In the ranchlands high densities of Grevy's zebra were found in Taita and wangala ranch and lowest density was in Bachuma ranch. The study has revealed that water is an important factor influencing Grevy's zebra distribution and all Grevy's zebra were found within an easy reach distance to water pans in all land parcels.

CHAPTER FIVE: DISCUSSION

5.1 Vegetation types in Tsavo East National Park and the surrounding ranchlands

Contemporary strategies for wildlife habitat mapping (Boyce and McDonald, 1999), biodiversity analysis (Scott *et al.*, 1993), and animal movement modeling (Bian, 2001) require the use of spatially explicit environmental map layers, such as those derived from land inventory databases and remote sensing. These data are commonly processed for a variety of environmental attributes, including vegetation cover (Carroll *et al.*, 1999; McClain and Porter, 2000), land use (Osborne *et al.*, 2001; Dash Sharma *et al.*, 2004), landscape structure (Ripple *et al.*, 1997; Hansen *et al.*, 2001), and phenology (Verlinden and Masogo, 1997; Leimgruber *et al.*, 2001). In the current study, land cover maps generated from satellite images from the Food and Agriculture Organization of the United Nations were used to categorize different vegetation types found in the Tsavo East National Park and the ranchlands. Tsavo East National Park and ranchlands were found to have different vegetation types that vary in their importance for wildlife survival, including the endangered Grevy's zebra.

5.2 vegetation preferences by Grevy's zebra.

The vegetation selection index showed that closed to very open herbaceous with sparse shrubs on temporarily flooded land habitat was the most preferred vegetation by Grevy's zebra. This may be because the vegetation had abundant grassland. Grevy's zebra being grazers prefer areas with plenty of grass. The findings of this study conform with the Report on the National Survey of Grevy's zebra in Kenya (Low *et al.*, 2009) that looked at the habitat selection index of Grevy's zebra in Laikipia-Samburu ecosystem and found that Grevy's zebra prefer vegetation with grassland and low density shrubs.

5.3 Grevy's zebra preferred vegetation characteristics.

Grevy's zebra were found in vegetations whose crown cover was 60-100% because those vegetation provided shade for them during the mid day when they rested under the trees. Vegetation is not only a source of food but provides shade for high ambient temperatures experienced in tropical savannas (Kinahan *et al.*, 2007). According to Churcher (1993), Grevy's zebra graze in the early morning, late afternoon and at night but rest under the shade in the mid day when the sun is hot. The shrub cover in the vegetation where Grevy's zebra were sighted ranged between 15 and 40 percent and they had a height of 0.3 to 5m which was an indication of open vegetation type. Vegetation features that are important to zebras include forage quantity and quality, and habitat openness. Bush density affects visibility, which in turn may influence Grevy's zebra ability to detect predators (Sundaesan *et al.*, 2007).

5.4 Distribution patterns of Grevy's zebra in the preferred vegetation.

High Grevy's zebra densities in the national park were found in very open shrubs with closed to open herbaceous and sparse trees vegetation (Fig 4.2). In the ranches high densities were found in open shrubs with closed to open herbaceous and sparse trees and closed to very open herbaceous with sparse shrubs on temporarily flooded land (Fig 4.3). All the vegetation that Grevy's zebra preferred had open formation vegetation characteristics. According to Sundaesan *et al.* (2007), Grevy's zebra prefer open vegetation areas and avoid thick bush density vegetation because vegetation thickness affects their visibility. The findings of this study agree with those of Sundaesan *et al.* (2007). Grevy's zebra did not prefer the vegetation rainfed herbaceous in medium fields and the density of Grevy's zebra in this vegetation was 0.09. This was probably because the vegetation lacked the characteristics that Grevy's zebra prefer. The vegetation was in cultivated terrestrial areas and managed lands. Sundaesan *et al.* (2007) when studying habitat

choice of Grevy's zebras in Laikipia ecosystem found that Grevy's zebra avoided areas close to humans and their livestock because of direct disturbance or due to indirect competition with domestic ungulates over forage. The Grevy's zebra might have avoided this vegetation type because of large number of cattle that grazed in the vegetation area (personal observation).

5.5 Grevy's zebra distribution in different land parcels

Grevy's zebra were found in groups in Tsavo ecosystem with mean group of 9.5 ± 3.08 individuals, the lowest group was 1 individual and the highest group was 22 individuals. Grevy's zebra may be solitary or associate in herds of 6 to 20 animals (Swayne, 1900; Kingdon, 1979). Though Grevy's zebra were found in groups, other studies have shown that there are no permanent social bonds in adult Grevy's zebra, there is no herd system and groups have no leaders, each individual is free to join and leave a group at will (Ginsberg, 1988). The findings of this study were contrary to those of Kivai (2006) who found Grevy's zebra in groups of 41 individuals in Wamba area in Samburu ecosystem and those of Muoria *et al.* (2004), who found that Grevy's zebras form groups of over 200 individuals in Laikipia Samburu ecosystem. Population of Grevy's zebra in Tsavo ecosystem resulted from introduction of 22 individuals from Isiolo in 1964 and there is high possibility that since the introduction the population has not increased much to form big groups of individuals as those observed by Kivai (2006) and Muoria *et al.* (2004).

Results from this study showed that 95% of Grevy's zebra sightings occurred in the ranchlands and 5% of the sightings occurred in the Tsavo East National Park. According to KWS (2008), the majority of Grevy's zebra populations live on non-protected community owned lands such as the pastoralist's ranches and private conservancies. Williams (2002) reported that only 0.5% of

Grevy's zebra range in Kenya falls within protected areas with the majority of populations occurring in community owned land. Results of this study agree with the findings of KWS (2008) and Williams (2002). Even though livestock in ranchlands provided competition with Grevy's zebra, this study and other studies have revealed that 95% of Grevy's zebra range is outside the protected areas (ranchlands, conservancies and community owned lands). Probably Grevy's zebra weighs the consequences of being consumed by predators especially lions to that of competition with livestock. As noted by Woodroffe (2001), predators like lions do well in protected areas than outside protected areas. Grevy's zebra might have preferred the ranchlands because of absence of Predators and learnt to co-exist with livestock in ranchlands by staying further away from human settlement, disturbances and livestock as noted by Sundaresan *et al.* (2007).

Predation by lions also might have caused Grevy's zebra to settle more in ranches than in the park. Lions are the main predator of all zebra species and usually attack them at waterholes in the night (Grzimek, 1972). Predation by lions have been found to have significant impact on Grevy's zebra numbers at Lewa Wildlife Conservancy (Rubenstein, 2004; Rubenstein *et al.*, 2004; Njonjo, 2005 and King and Malleret-King, 2006) and in community areas within the Samburu landscape (King and Malleret-King, 2006; Muoria, personal communication). Ongoing predator research in the Samburu landscape indicates predation by lions to be one of the limiting factors in Grevy's zebra population dynamics (KWS 2008). When lions are present, Grevy's zebra will avoid these areas, sometimes by departing to other less suitable areas (Fischhoff *et al.*, 2007). Tsavo East National Park is known to support a high population of lions compared to the ranches. According to Laurence *et al.* (2006) the lion population in Tsavo East National Parks

was 675 while their population only numbered about 50 in the ranches (Patterson *et al.*, 2004; Earthwatch Lions of Tsavo, unpublished data), thus causing the flight of Grevy's zebra from the park to the ranches.

Grevy's zebra showed an aggregated distribution pattern within the park and the ranches. In many species, individuals choose to be in groups, to gain benefits such as reducing predation danger (Zuberbuhler *et al.*, 1997) or acquiring resources and information (Horn 1968; Vickery *et al.*, 1991; Beauchamp 1999). Aggregation is a common feature among the savannah grassland dwellers as it bestows individuals living in group with a number of advantages; the first advantage is that individuals are able to avoid predation as a result of early detection as many eyes are keeping vigilant (Krebs, 1985b; FitzGibbon and Lazarus, 1995). Secondly, their presence in large numbers and acting together may deter the predator from attacking as it has been demonstrated by mobbing birds and troops of primates. On the same note, if the predator has to attack the group, it has to select a single individual. However, the animals flee in confusion, impairing the predator's concentration on the same animal and thereby reducing its chances of capture (FitzGibbon and Lazarus, 1995).

This study showed that greatest densities of Grevy's zebra were on the ranch lands. Taita ranch had the greatest density of Grevy's zebra and the national park had the least densities. According to Moehlman *et.al* 2008, the density and area of occupancy of Grevy's zebra fluctuates seasonally as animals move in search for resources. During the dry season, when they are dependent on permanent water, animals tend to be more concentrated in one particular area. However, given that they can move up to 35 km in search of water during the dry season, their

densities are never high. This highlights the need to work together with communities and ranch owners in the Tsavo ecosystem to conserve this endangered species.

5.6 Spatial distribution densities of Grevy's zebra in the park and ranches.

Results from kernel density showed that highest densities of Grevy's zebra occurred in the northeastern areas of Taita ranch this was because the area had artificial water pans that held water throughout the year (personal observations). Grevy's zebra live in arid and semi-arid grass and shrubland where there is permanent water (Rowen and Ginsberg 1992). They require free-standing water as part of their diet although non-lactating females, bachelor males and territorial males can stay between two to five days without drinking water, while lactating females drink daily and can only tolerate two days without drinking (Becker and Ginsberg 1990). Open formation habitats were found in the areas where high densities of Grevy's zebra occurred. According to Sundaresan *et al.* (2007), vegetation features presumed to be important to Grevy's zebra include forage quantity and quality, and habitat openness. The areas where medium densities of Grevy's zebra were found had open water sources but the water pans held water for a period of 3-4 months and had open formation habitats (personal observation).

5.7 Vegetation association of Grevy's zebra

Chi-squared test and measures of association showed an association between Grevy's zebra and vegetation types in the Tsavo ecosystem. Results from this study showed that shrubs with herbaceous layer were common vegetation characteristics found in the vegetations that Grevy's zebra associated with. According to Rowen and Ginsberg (1992), Grevy's zebra live in arid and semi arid areas where shrubs and grassland is the main vegetation. Although Grevy's zebra are grazers and feed mainly on grasses, browsing comprise up to 30% of their diet during drought

conditions. Herbaceous vegetation provided diet for the Grevy's zebra because grasses and forbs are the main primary components of herbaceous vegetation. Eline (2009) did analysis of habitat types which Grevy's zebra preferred in Laikipia-Samburu ecosystem and found that Grevy's zebra preferred vegetation types which had herbaceous layer as the main cover.

5.8 Grevy's zebra association with water pans

The results of this study show that Grevy's zebra distribution was dependent on water availability. In the ranches and Tsavo East National Park the distribution of zebras was positively correlated with the distance from watering points. Utilization of habitat by wildlife has been shown to vary with species and distance from a water point. Western (1975) studied the distribution and abundance of 15 species around natural and artificial water sources in the area around Amboseli and found that water dependent mammals were concentrated within 10 km of water during the dry season, whereas species not dependent on water were distributed more-or-less uniformly up to 35 km from a water point. Though there was a positive correlation between Grevy's zebra locations and distances to water pans in all land parcels, Grevy's zebra densities were more concentrated in the ranches than in the national park. This was because most natural water pans in the national park were shallow and silted (personal observation) which dried up quickly, while in the ranches the water pans were artificial wells, which held water for a longer period in a year. The ability of water pans in the ranches to sustain water for a longer period might be one of the reasons why Grevy's zebra preferred the ranches than the National Park. Zoe Nyssa (Personal communication, 2009) projected Grevy's zebra locations in relation to water pans in Kenya in her final GIS project. The findings of her study revealed that water access was a primary factor affecting distribution of Grevy's zebra.

The results of this study showed that distances of Grevy's zebra locations to water pans in all land parcels was less than 10,000 meters showing that Grevy's zebra stayed closer to water. These results agreed with those of Rubenstein (1986) who found that Grevy's zebra in Samburu travel 10,000-15,000 meters daily looking for resources especially water. However, there was a significant difference in distances of Grevy's zebra locations to water pans in different land parcels. In Taita, Rukinga and Tsavo East National Park Grevy's zebra were found further away from water pans compared to Wangala and Bachuma ranches. The reason why the zebras stayed further away from water pans was probably to avoid predation by lions.

The main predator of Grevy's zebra is lion; zebras are most attacked during the night at waterholes (Grzimek, 1972). Animals modify their habitat preferences and movement patterns to reduce their likelihood of being encountered or captured by predators (Bowyer *et al.*, 1999; Fortin *et al.*, 2005) while at the same time meeting their resource needs. Prey species' responses to predation threat shape many of their ecological processes like population distribution (Lima and Dill 1990; Heithaus and Dill 2006), resource exploitation by prey (Fortin *et al.*, 2005), and vital rates (Bleich 1999). Zebras, as a species that experience high predation (Grange *et al.*, 2004), modify their behavior in ways that reduce their exposure to predators like staying further away from water pans. Lions hunt principally at night and rest at day time (Schaller 1972). When lions do hunt during the day, they do so in bushier habitat that offers cover to hide behind especially in water pans areas. (Elliott *et al.*, 1977). Predations by lions have been found to have a significant impact on Grevy's zebra numbers at Lewa Wildlife Conservancy (Rubenstein, 2004; Rubenstein *et al.*, 2004; Njonjo, 2005; King and Malleret-King, 2006). Ongoing predator

research in the Samburu landscape indicates predation by lions may be one of the limiting factors in Grevy's zebra population dynamics (KWS 2008).

The high numbers of lions in Tsavo National Park, Taita and Rukinga ranches might have caused Grevy's zebra to avoid staying close to the water pans. In Wangala and Bachuma ranch there were no lion populations as the ranches were stocked with livestock (personal observation). Lions do well in protected areas but poorly outside (Woodroffe, 2001). Lion densities outside protected areas are low because of them being poisoned by local people to protect livestock predation (Williams, 1998). The absence of Lions in Wangala and Bachuma ranch made the Grevy's zebra to stay close to water pans since there was no fear of predation.

Other factors that might greatly influence the distribution of Grevy's zebra in the Tsavo ecosystem and needs to be studied in details are competition with livestock, other wildlife and predation. In East Africa, the majority of the populations of most large mammal species occur outside protected areas, although this proportion is declining (Mbugua, 1986; Western, 1989; Ottichilo *et al.*, 2000). These populations mostly occur on land that is also being used for the production of livestock, either by traditional pastoralists or by large-scale ranching enterprises. There is a widespread belief that grazing wildlife, particularly zebras (*Equus* spp.) and wildebeests (*Connochaetes taurinus*), compete with cattle for grass in Africa (Pratt and Gwynne, 1977). The competition for resources between Grevy's zebra and other wild animals may be prominent in areas where plains zebra (*Equus burchellii*) are in higher density than Grevy's zebra (Rubenstein, 2004; Rubenstein *et al.*, 2004). According to Rubenstein (2004), competition with other ungulates can also affect Grevy's zebra space use. For instance, plains zebras can out

number the Grevy's zebra in good grazing areas, forcing the Grevy's zebra to use less appropriate areas. During this study, it was found that the plain zebra density was much higher in the national park compared to the ranch lands (personal observation). This high density of plain zebra might have caused competition for resources (grass and water), forcing the Grevy's zebra to move to the ranches where there is less competition.

Williams (1998) found that Grevy's zebra compete for critical resources with pastoralists and their livestock. Cattle diets are more similar to Grevy's zebra diets than the diets of many other wildlife species (Casebeer and Koss, 1970; Voeten, 1999), and cattle and zebra have considerable overlap in habitat use (Voeten and Prins, 1999). Pratt and Gwynne (1977) report that "(zebras) compete with cattle for grass and water and often concentrate on areas that are nominally being rested from grazing." The seasonal limitation of forage in pastoralist areas, and predators were found to be important factors determining use of space (Williams, 1998). Over-exploitation and monopolisation of resources across the Grevy's zebra range and the resulting competition with domestic livestock remain a critical conservation challenge (Kingdon, 1997; Williams, 2002; Williams and Low, 2004). During this study, it was noted that ranches with lots of livestock had no Grevy's zebra. These ranches were all intensively managed and over-stocked with cattle and this could be one of the reasons why Grevy's zebra avoided them as a way of avoiding competition with livestock. According to Sundaresan *et al.*, (2007) Grevy's zebra may avoid areas close to humans and their livestock because of direct disturbance, or due to indirect competition with domestic ungulates over forage. Most Grevy's zebra were found on Taita and Rukinga Ranches, which actively excluded or limited cattle for most of the study period.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Information on species distribution patterns is crucial for effective conservation and management of biodiversity (Margules and Pressey 2000). Animals make their habitat selection to satisfy vital requirements concerning food, shelter and reproduction (Bond *et al.*, 2002). Activities that lead to habitat loss may threaten the persistence of wildlife (Berland *et al.*, 2008). Conservation and management planning require not only an understanding of how wildlife use habitat in space and time, but how habitat use changes in response to landscape disturbances and modifications (Berland *et al.*, 2008). Thirty different habitat types were found in Tsavo East National Park and in the ranchland. This showed that Tsavo East National Park and the surrounding ranchlands have diversity of vegetation types that supports different wildlife species. These vegetation needs to be protected and conserved for wildlife survival especially the endangered species like Grevy's zebra.

Grevy's zebra in Tsavo East National Park and the surrounding ranchland preferred seven vegetation types. The names of vegetation preferences by Grevy's zebra were closed to very open herbaceous with sparse trees and shrubs (2H(CP)78), open shrubs with closed to open herbaceous and sparse trees(2SOJ67), open general shrubs with closed to open herbaceous (2SP6), very open shrubs with closed to open herbaceous (2SV6), very open shrubs with closed to open herbaceous and sparse trees (2SVJ67), closed to very open herbaceous with sparse shrubs on temporarily flooded land (4H(CP)F8) and rainfed herbaceous (HM4) . Vegetation selection index results showed that four out of the seven vegetation types where Grevy's zebra were found had a selection index of >1 indicating the vegetations which were mostly preferred by the zebras and these vegetations were open general shrubs with closed to open herbaceous, very open shrubs

with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees, closed to very open herbaceous with sparse shrubs on temporarily flooded land. This study concluded that Grevy's zebra has vegetation preferences in Tsavo East National Park and the surrounding ranchlands.

Grevy's zebra were found in vegetations which had the following characteristics shrubs with herbaceous layer, with crown covers of 60-100%, shrub cover of 14-40% and shrub height ranging from 0.3-5m high. Those habitats were closed to very open herbaceous with sparse trees and shrubs, open shrubs with closed to open herbaceous and sparse trees, open general shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous, very open shrubs with closed to open herbaceous and sparse trees, closed to very open herbaceous with sparse shrubs on temporarily flooded land and rainfed herbaceous. This study concluded that Grevy's zebra prefer open formation vegetation and avoid thick bushes.

Grevy's zebra occurred in groups of 1-4, 5-12 and 13-22 individuals respectively in different vegetation types with 85% of occurrences being in groups of 1-4 individuals. The mean distribution pattern of Grevy's zebra in their preferred vegetation types was 9.5 ± 3.08 . High densities in Tsavo East National Park were found in very open shrubs with closed to open herbaceous and sparse trees and lowest density was found in closed to very open herbaceous with sparse trees and shrubs. In the ranchlands high density of Grevy's zebra were found in closed to very open herbaceous with sparse shrubs on temporarily flooded land and lowest density was found in open shrubs with closed to open herbaceous and sparse trees. The study

concluded that in Tsavo East National Park and the surrounding ranchlands Grevy's zebra were distributed in small groupings and densities of individuals in their preferred vegetation types.

Grevy's zebra were distributed in groups, 95% of the locations were found in the ranchlands and 5% in the national park, the densities of Grevy's zebra were high in the ranchlands than the national park showing that Grevy's zebra preferred ranchlands than the national park.

Water was found to be a factor affecting the distribution of Grevy's zebra in Tsavo East National Park and in the ranchlands and all Grevy's zebra were within easy reach of watering points. There is need to desilt water pans which are silted so that they can hold water for a longer period and more water pans should be dug to provide sufficient supply of water to Grevy's zebra and other wildlife at large.

The null hypotheses were rejected and conclusion drawn that Grevy's zebra associated with vegetation types. (During analysis, the vegetation that Grevy's zebra preferred were considered as the vegetation which they associated with), the distribution of Grevy's zebra in different land parcels were clustered and there was a positive significant relationship between Grevy's zebra GPS locations and the water pans.

6.2 RECOMMENDATIONS

6.2.1 Conservation and management action

Grevy's zebra is an endangered species. Using the International Union Conservation for Nature (IUCN) categories of threat, Grevy's zebra (*Equus grevyi*) is listed as Endangered A1a and 2c in the *IUCN 1996 Red List of Threatened Animals*. Its range and number have been declining

steadily since 1970's. This study recommends that both total and aerial counts of Grevy's zebra in Tsavo ecosystem should be conducted to ascertain the exact population status of Grevy's zebra. Since their introduction from Isiolo in 1964 population count of this species has not been done. Understanding the population of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands will help the management of Kenya Wildlife Service in devising conservation and management strategies of Grevy's zebra.

6.2.2 Further research

Factors like competition with livestock, other ungulates and predation have been found to affect the distribution of Grevy's zebra in Laikipia-Samburu ecosystem. There is need to conduct detailed research in Tsavo East National Park and the surrounding ranchlands to determine whether predation, competition with livestock and competition with other ungulates are impacting on the survival and distribution of Grevy's zebra. Information generated from this research will help in effective management of Grevy's zebra and their habitats in Tsavo region.

Food is a factor affecting the survival and distribution of species. Detailed research on the type of food Grevy's zebra feeds on in Tsavo East National Park and in the ranchlands needs to be investigated so that the habitats where Grevy's zebra food is found can be saved from degradation, fragmentation and loss.

In 1977, 30 Grevy's zebra were introduced in Tsavo West National Park. Research should also be extended to Tsavo West National Park to assess the population dynamics of Grevy's zebra and their vegetation association

REFERENCES

- Ackerman, W. V. and Murray, A. T. (2004). Assessing spatial patterns of crime In Lima, Ohio. *Cities*, 21(5), 423-437.
- Araujo, M.B. and Williams, P.H. (2000). Selecting areas for species persistence using occurrence data. *Conservation Biology*, 96, 331–345.
- Bauer, I.E.; McMorrow, J. and Yalden, D.W. (1994). The historic ranges of three equid species in northeast Africa: a quantitative comparison of environmental tolerances. *Journal of Biogeography*, 21,169-182.
- Beauchamp, G. (1999). The evolution of communal roosting in birds: origin and secondary losses. *Behavioral Ecology*, 10, 675–687.
- Becker, C.D. and Ginsberg, J.R. (1990). Mother infant behavior of wild Grevy's zebra: adaptations for survival in semi-desert East Africa. *Animal Behaviour*, 40, 1111-1118.
- Berland, A.; Trisalyn, N.; Gord, S.; Karen, G. and Jerome, C. (2008). The impact of landscape disturbance on grizzly bear habitat use in the Foothills Model Forest, Alberta, Canada. *Forest Ecology and Management*, 256, 1875–1883.
- Bian, L. (2001). The Geographical information system representation of wildlife movements: a framework. In: Millington, A.C., Walsh, S.J., Osborne, P.E. (Eds.), *Geographical Information System and Remote Sensing Applications in Biogeography and Ecology*. Kluwer Academic Publishers, Boston.
- Bleich, V.C. (1999). Mountain sheep and coyotes: patterns of predator evasion in a mountain ungulate. *Journal of Mammals*, 80,283–289.
- Bond, B.T.; Burger, L.W. Jr.; Leopold, B.D.; Jones, J.C. and Godwin, K.D. (2002). Habitat use by cotton tail rabbits across multiple spatial scales in Mississippi. *Journal of Wildlife Management*, 66, 1171–1178.
- Bonnicksen, T. M. and Stone, E. C. (1981). The Giant Squoia-mixed conifer forest community characterized through pattern analysis as a mosaic of aggregations. *Forest Ecology and Management*, 3, 307-328
- Bos, D.G. and Carthew, S.M. (2003). The influence of behaviour and season on habitat selection by a small mammal. *Ecography*, 26, 810–820.
- Bowers, K. and Hirschfield, A. (1999). Exploiting links between crime and disadvantage in northwest England: an analysis using geographical information systems. *Geographical Information Science*, 13(2), 159 – 184.
- Bowyer, R.T.; Van Ballenberghe, V.; Kie, J.G. and Maier J.A.K. (1999). Birth site selection by

- Alaskan moose: maternal strategies for coping with a risky environment. *Journal of Mammals*, 80, 1070–1083.
- Boyce, M.S. and McDonald, L.L. (1999). Relating populations to habitats using resource selection functions. *Trends in Ecology and Evolution*, 14, 268–272.
- Bronner, G. (1990). *Vegetation and land use in the Matthews Range area, Samburu District*. Dissertationes Botanicae. J. Cramer, Berlin.
- Carroll, C.; Zielinski, W.J. and Noss, R.F. (1999). Using presence–absence data to build and test spatial habitat models for the fisher in the Klamath region, United States of America. *Conservation Biology*, 13, 1344–1359.
- Casebeer, R.L.; Koss, G.G. (1970). Food habits of wildebeest, zebra, hartebeest and cattle in Kenya Masailand. *East African Wildlife Journal*, 8, 25–36.
- Churcher, C.S. (1993). *Equus grevyi*. *Mammalian Species* 453:1-9
- Cody, M.L. (1981). Habitat selection in birds: The roles of vegetation structure, competitors and productivity. *Bioscience*, 31, 107-113.
- Dash, S.B.; Clevers, J.; De Graaf, R. and Chapagain, R. (2004). Mapping Equus kiang (Tibetan Wild Ass) habitat in Surkhang, Upper Mustang, and Nepal. *Mountain Research and Development*, 24, 149–156.
- Dirschl, H.J. and Wetmore, S.P. (1978). Grevy's zebra abundance and distribution in Kenya, 1977, In Rep. No. 4. Kenya Rangeland Ecological Monitoring Unit, Nairobi, Kenya.
- Duncan, P. (1992). *Zebras, Asses and Horses, An Action Plan for the Conservation of Wild Equids*. IUCN, Gland.
- Dussault, C.; Ouellet, J.P.; Courtois, R.; Huot, J.; Breton, L. and Jolicoeur, H. (2005). Linking moose habitat selection to limiting factors. *Ecography*, 28, 619–628.
- Eline, H. (2009). *Modelling the migration of Grevy's zebra in function of habitat type using remote sensing*. (Unpublished master's thesis). University of Gent, Belgium.
- Elliott, J.P.; Cowan, I.M. and Holling, C.S. (1977). Prey capture by African lion. *Canadian Journal of Zoology*, 55, 1811–1828.
- Fischhoff, I. R.; Sundaresan, S. R.; Cordingley, J. and Rubenstein, D. (2007). Habitat use and movements of plains zebra *Equus burchelli* in response to predation danger from lions. *Behavioral Ecology*, 18(4), 725–729.
- FitzGibbon, C. D. and Lazarus, J. (1995). Antipredator behavior of Serengeti ungulates: Individual differences and population consequences. *In Serengeti II: Dynamics*,

Management, and Conservation of an Ecosystem (ed. A. R. E. Sinclair and P. Arcese). The University of Chicago Press, Chicago.

Food and Agriculture Organisation (2002). Kenya Africover Landcover Dataset, FAO, Rome, Italy.

Fortin, D.; Beyer, H.L.; Boyce, M.S.; Smith, D.W.; Duchesne, T. and Mao, J.S. (2005). Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. *Ecology*, 86, 1320-1330.

Freedman, B. (1989). Environmental ecology: The impacts of pollution and other stresses on ecosystem structure and function. Academic Press, San Diego, California.

Gatrell, C. A.; Bailey, T. C.; Diggle, P. J. and Rowlingson, S. B. (1996). Spatial point pattern analysis and its application in geographic epidemiology. *Transactions of the Institute of British Geographers.*, 21: 256-274.

Ginsberg, J.R. (1989). The ecology of female behaviour and male mating success in the Grevy's zebra. *Symposia of the Zoological Society of London*, 61, 89-110.

Grange, S.; Duncan, P.; Gaillard, J.M.; Sinclair, A.R.E.; Gogan, P.J.P.; Packer, C.; Hofer, H. and East, M. (2004). What limits the Serengeti zebra population? *Oecologia*, 140, 523-532.

Greenway, P. J. (1969). A check list of plants recorded in Tsavo National Park, East. *Journal of the East African Natural History Society and National Museum*, 3, 168-209.

Grooves, C.P. (1974). Horses, asses and zebras in the wild. David and Charles, Newton Abbott and London, 192 pp.

Grunblatt, J.; Said, M.Y. and Nutria, J.K. (1989). Livestock and wildlife summary 1987-1988 for Kenya Rangelands. Department of Resource Surveys and Remote Sensing, Ministry of Planning and National Development, Nairobi, Kenya.

Grunblatt, J.; Said, M. and Wargute, P. (1996). Summary of Population Estimates for Wildlife and Livestock: Kenyan Rangelands 1977-1994. Department of Resource Surveys and Remote Sensing, Nairobi, Kenya.

Grzimek, B. (1972). Het leven der dieren. deel Zoogdieren 3. Spectrum.

Guisan, A. and Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling*, 135, 147-186.

Hack, M.A. and Rubenstein, D.I. (1998). Zebra Zones, *Natural History* 3: 28-29

- Hansen, M.J.; Franklin, S.E.; Woudsma, C. and Peterson, M. (2001). Caribou habitat classification and fragmentation analysis of old growth cedar and hemlock forests in British Columbia using Landsat TM and Geographical information system data. *Remote Sensing of Environment*, 77, 50–65.
- Heithaus, M.R. and Dill, L.M. (2006). Does tiger shark predation risk influence foraging habitat use by bottlenose dolphins at multiple spatial scales? *Oikos*, 114, 257–264.
- Herlocker, D.J. 1992. Vegetation types in: *Range Management Handbook of Kenya, Volume II, 2: Samburu District* (eds. S.B. Shaabani, M. Walsh, D.J. Herlocker, and D. Walther). Republic of Kenya, Ministry of Livestock Development, Nairobi, Kenya.
- Heupel, M. R. and Simpfendorfer, C. A. (2005). Quantitative analysis of aggregation behavior in juvenile blacktip sharks. *Marine Biology*, 147(5), 1239 – 1249.
- Honnnavalli, N.K.; Mohammed, I.U. and Shanthala, K. (2009). Mapping potential distribution of slender loris sub species in peninsular India. *Endangered Species Response* 7, 29-38.
- Horn, H.S. (1968). Adaptive significance of colonial nesting in Brewers Blackbird (*Euphagus cyanocephalus*). *Ecology*, 49, 682.
- IUCN, (2002). *Equids: Zebras, Asses and Horses*. IUCN, Gland, Switzerland and Cambridge.
- Jeganathan, P.; Greer, R.E.; Norris, K.; Vogiatzakis, J.N.; Bartsch, A.; Wotton, S.R.; Bowden, C. G.R.; Griffiths, G.H.; Pair, D. and Rahmani, A.R. (2004). Modelling habitat selection and distribution of the critically endangered Jerdon’s courser *Rhinoptilus bitorquatus* in scrub jungle: an application of a new tracking method. *Journal of Applied Ecology*, 41, 224–237.
- Johnson, D.H. (1980). The comparison of usage and availability measurements for evaluating resource preference. *Ecology*, 61, 65–71.
- Johnson, C.J.; Seip, D.R. and Boyce, M.S. (2004). A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. *Journal of Applied Ecology*, 41, 238–251.
- Johnson, G. D.; Eidson, M.; Schmit, K.; Ellis, A. and Kulldorff, M. (2006). Geographic Prediction of Human Onset of West Nile Virus Using Dead Crow Clusters: An Evaluation of Year 2002 Data in New York State. *American Journal of Epidemiology*, 163(2), 171 – 180.
- Keast, A. (1965). Inter relationships of two zebra species in an overlap zone. *Journal of Mammalogy*, 46:53-66.
- Kenya Wildlife Service (2008). Conservation and management strategy for Grevy’s zebra (*Equus grevyi*) in Kenya 2007-2011. Kenya: Kenya Wildlife Service.

- Kinahan, A.; Pimm, S. and van Aarde, R. (2007). Ambient temperature as a determinant of landscape use in the savanna elephant, *Loxodonta africana*. *Journal of Thermal Biology*, 32(1), 47-58.
- Kingdon, J. (1979). *East African mammals, an atlas of evolution in Africa*. University of Chicago Press, Chicago 3B (Large mammals), 436pp.
- Kingdon, J. (1997). *The Kingdon Guide to African Mammals*. Academic Press, San Diego.
- King, J. and Malleret-King, D. (Eds.) (2006). *The Ewaso Landscape Planning Workshop: January 25th-29th 2006*. Mpala Research Centre, Laikipia, Kenya.
- Kivai, S. M. (2006). *Feeding ecology and diurnal activity pattern of the Grevy's zebra (*Equus grevyi*, Oustalet, 1882) in Samburu Community Lands, Kenya*. MSc Thesis, Addis Ababa University, Addis Ababa.
- Klingel, H. (1969). Zur Soziologie des Grevy's zebras, *Zoologischer Anzeiger, Supplemental Band*, 33, 311-316.
- Klingel, H. (1972). Social behaviour of African Equidae. *Zoologica Africana*, 7, 175-185
- Klingel, H.; Geist, V. and Walther, F. (1974a). A comparison of the social behaviour of the Equidae, in *The Behaviour of Ungulates and its Relation to Management*. International Union for Conservation of Nature Publications. New Service: Morges, Switzerland. p. 124-132.
- Klingel, H. (1974b). Social organisation and behaviour of the Grevy's zebra. *Zeitschrift für Tierpsychologie*, 36, 37-70.
- Klingel, H. (1977). Observation on social organization and behaviour of African and Asian wild asses (*Equus africanus* and *E. hemionus*). *Zeitschrift für Tierpsychologie*, 44, 323-331.
- Klingel, H. (1980). *Survey of African Equidae*. International Union for Conservation of Nature Survival Service Commission, Gland, Switzerland.
- Kotler, B.P. (1997). Patch use by gerbils in a risky environment: manipulating food and safety to test four models. *Oikos*, 78, 274-282.
- Krebs J. C. (1985b). *Ecological Methodology*. Second edition. Addison – Welsey Educational Publishers, New York.
- Lack, D. (1933). Habitat selection in birds, with special reference to the effects of a forestation on the Breckland avifauna. *Journal of Animal Ecology*, 2, 239-262.
- Lancaster, J. and Downes, B. J. (2004). Spatial point pattern analysis of available and exploited resources. *Ecography*, 27, 94-102.

- Laurence, F.; McLellan, S.; Hazzah, L.; Bonham, R. and Tom, H. (2006). Lion Killing in the Amboseli and Tsavo Ecosystem, 2001-2006, and its Implications for Kenya's Lion Population. Unpublished report to Kenya Wildlife Service.
- Lee, J. and Wong, D. W. S. (2001). Statistical Analysis with Arc View Geographical Information System. John Wiley and Sons, New York.
- Leimgruber, P.; McShea, W.J.; Brookes, C.J.; Bolor-Erdene, L.; Wemmer, C. and Larson, C. (2001). Spatial patterns in relative primary productivity and gazelle migration in the Eastern Steppes of Mongolia. *Biological Conservation*, 102, 205–212.
- Leuthold, W. and Sale, J.B. (1973). Moments and Patterns of Habitat Utilization of Elephants in Tsavo National Parks, Kenya. *East African Journal*, 11, 369-384.
- Lima, S.L. (1998). Stress and decision making under the risk of predation: recent developments from behavioral, reproductive and ecological perspectives. *Advances in the Study of Behavior*, 27, 215–290.
- Lima, S.L. and Dill, L.M. (1990). Behavioral decisions made under the risk of predation: a review and prospectus. *Canadian Journal of Zoology*, 68, 619–640.
- Low, B.; Sundaesan, S.R.; Fischhoff, I.R.; Rubenstein, D.I. (2009). Partnering with local communities to identify conservation priorities for endangered Grevy's zebra. *Biological Conservation* 142 (7): 1548-1455.
- Manyibe, T.; Low, B. and Chege, G. (2006). *Mass Vaccination of Grevy's zebra Against Anthrax in Northern Kenya. April 2006*. Kenya Wildlife Service, Northern Rangelands Trust on Lewa Wildlife Conservancy.
- Margules C.R. and Pressey R.L. (2000). Systematic conservation planning. *Nature*, 405,243 253.
- Mbugua, S.W. (1986). Monitoring livestock and wildlife in Kenya. In: Hansen, R.M.; Woie, B.M. and Child, R.D. (Eds.), Range Development and Research in Kenya. Winrock International Institute for Agricultural Development, Morrilton, Arizona, pp. 413–430.
- McClain, B.J. and Porter, W.F. (2000). Using satellite imagery to assess large-scale habitat characteristics of Adirondack Park, New York, United States of America. *Environmental Management*, 26, 53–561.
- McKendry, J.E. and Machlis, G.E. (1991). The role of geography in extending biodiversity gap analysis. *Applied Geography*, 11, 135-152.
- McPeck, M.A. (1996). Trade-offs, food web structure, and the coexistence of habitat specialists and generalists. *American Naturalist*, 148, S124–S138.
- Mladenoff, D.J.; Haight, R.C.; Sickley, T.A. and Wydeven, A.P. (1997). Causes and implications

- of species restoration in altered ecosystems. A spatial landscape projection of wolf population recovery. *Bioscience*, 47, 21–31.
- Moehlman, P.D.; Rubenstein, D.I. and Kebede, F. (2008). *Equus grevyi*. In: International Union Conservation for Nature 2011. *International Union Conservation for Nature Red List of Threatened Species*. Version 2011.2. Gland, Switzerland.
- Morris, D.W. (2003). Toward an ecological synthesis: a case for habitat selection. *Oecologia*, 136, 1–13.
- Muoria, K. P.; Oguge, N. and Rubenstein, D. (2004). Conservation of Grevy's zebras (*Equus grevyi*) in Samburu Kenya. *Samburu Conservation Research Initiative Annual report 2004*. Earthwatch Institute, Nairobi.
- Muoria, K.; Boru, A.H.; Dominic, M.; Nicholas, O.; Philip, M. and Waititu, K. (2007). Anthrax outbreak among Grevy's zebra (*Equus grevyi*) in Samburu, Kenya.
- Mwasi, S. and Mwangi, E. (2007). Proceedings of the National Grevy's zebra Conservation Strategy Workshop 11 -14 April 2007. Kenya Wildlife Service Training Institute, Naivasha, Kenya.
- Naylor, J.A. and Herlocker, D.J. (1987). *Criteria for range condition classification, Central Rangelands Development Project*. Mogadishu, Somalia. Technical Report 6. pp 26
- Nelson, A.P.W. (2003). *Status, distribution and structure of Grevy's zebra populations in northern Kenya*. MSc thesis. University of Oxford, Oxford.
- Nelson, A.P.W. and Williams, S.D. (2003). Grevy's zebra Survey: Kenya 2000. Final report. Kenya Wildlife Service, Nairobi, Kenya.
- Njonjo D. (2004). *Predator Project report. Unpublished report*. Lewa Wildlife Conservancy
- Orians, G.H. and Wittenberger, J.F. (1991). Spatial and temporal scales in habitat selection. *American Naturalist*, 137, S29–S49.
- Osborne, P.E.; Alonso, J.C. and Bryant, R.G. (2001). Modelling landscape-scale habitat using Geographical information system and remote sensing: a case study with great bustards. *Journal of Applied Ecology*, 38, 458–471.
- Ottichilo, W.K.; Grunblatt, J.; Said, M.Y. and Wargute, P.W. (2000). Wildlife and livestock trends in the Kenya rangeland. In: Prins, H.H.T.; Grootenhuis, J.G. and Dolan, T.T. (Eds.). *Wildlife Conservation by Sustainable Use*. Kluwer Academic Publishers, Boston, pp. 203–218.
- Palma, L.; Beja, P. and Rodrigues, M. (1999). The use of sighting data to analyze Iberian lynx habitat and distribution. *Journal of Applied Ecology*, 36, 812–824.

- Patterson, B. D.; Kasiki, S.M.; Selempo, E. and Kays, R.W. (2004). Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighboring Tsavo National Parks, Kenya. *Biological Conservation*, 119, 507-516.
- Pratt, D.J. and Gwynne, M.D. (1977). *Rangeland Management and Ecology in East Africa*. Hodder and Stoughton, London.
- Ramp, D.; Caldwell, J., Edwards, K. A., Warton, D. and Croft, D. B. (2005). Modeling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological conservation*, 126(4), 474 – 490.
- Raxworthy, C.J.; Martinez-Meyer, E.; Horning, N.; Nussbaum, R.A.; Schneider, G.E.; Ortega Huerta, M.A. and Peterson, A.T. (2003). Predicting distributions of known and unknown reptile species in Madagascar. *Nature*, 426, 837–841.
- Read, B.; Kelly, C.; Bueler, M. and Junge, R. (1988). Grevy's zebra management survey. American association of Zoological Parks and Aquariums, Species survival plan, St. Louis Zoological Park, St. Louis, Missouri, 169 pp.
- Rettie, W.J. and Messier, F. (2000). Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. *Ecography*, 23, 466–478.
- Ripple, W.J.; Lattin, P.D.; Hershey, K.T.; Wagner, F.F. and Meslow, E.C. (1997). Landscape composition and pattern around northern spotted owl nests sites in southwestern Oregon. *Journal of Wildlife Management*, 55, 316–318.
- Roosevelt, T. and Heller, E. (1914). Life histories of African game animals, Volume 2, New York, 2:698-700.
- Rosenzweig, M.L. (1991). Habitat selection and population interactions: the search for mechanism. *American Naturalist*, 137(suppl), 5-28.
- Rotenberry, J.T.; Preston, K.L. and Knick, S.T. (2006). Geographical information system based niche modeling for mapping species habitat. *Ecology*, 87, 1458–1464.
- Rowen, M. (1992). *Mother-infant behavior and ecology of Grevy's zebra, Equus grevyi*. Ph.D. dissertation, Yale University, New Haven.
- Rowen, M. and Ginsberg, J.R. (1992). Grevy's zebra (*Equus grevyi*) in: *International Union for Conservation of Nature/Status Survey and Conservation Action Plan for the Conservation of Wild Equids* (Ed. P. Duncan). International Union for Conservation of Nature, Gland, Switzerland.
- Rubenstein, D.I. (1986). Ecology and Sociality in Horses and Zebras. In *Ecological Aspects of Social Evolution* (Eds D.I. Rubenstein and R.W. Wrangham), Princeton University Press, Princeton. pp. 282-302.

- Rubenstein, D.I. (2004). Why are Grevy's zebra numbers not increasing? Potential impacts of interspecific competition and Predation. *In Grevy's Zebra Workshop: Proceedings of a Workshop*. Mpala Research Centre, 22-24 March 2004. 20-21.
- Rubenstein, D.; Kirather, J. and Oguge, N. (2004). Competitive relationships between Grevy's and Plains zebras. *In Samburu Conservation Research Initiative Annual Report 2004*. 13-22.
- Sanchez-Zapata, J.A. and Calvo, J.F. (1999). Raptor distribution in relation to landscape composition in semi arid Mediterranean habitats. *Journal of Applied Ecology*, 36, 254-262.
- Schaller, G.B. (1972). *The Serengeti lion: a study of predator-prey relations*. Chicago Illinois: University of Chicago Press.
- Scott, J.M.; Davis, F.; Csuti, B.; Noss, R.; Butterfield, B.; Groves, C.; Anderson, H.; Caicco, S.; D'Erchia, F.; Edwards Jr., T.C.; Ulliman, J. and Wright, R.G. (1993). Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs*, 123, 1-41.
- Stamps, J.A. and Swaisgood, R.R. (2007). Some place like home: experience, habitat selection and conservation biology. *Applied Animal Behavioral Science*, 102, 392-409.
- Sundaresan, S.R.; Ilya, R.F.; Helen, M.H.; Patrick, A. and Daniel, R. (2007). Habitat choice of Grevy's zebra in Laikipia, Kenya. *African Journal of Ecology*, 46, 359-364.
- Swayne, H.G.C. (1900). *Seventeen trips through Somaliland*. Second edition, Rowland, London pp385.
- Thouless, C.R. (1995a). Aerial Surveys for Wildlife in Eastern Ethiopia. London: Ecosystem Consultants.
- Thouless, C.R. (1995b). Aerial Surveys for Wildlife in Omo Valley, Chew Bahir and Borana areas of Southern Ethiopia. London: Ecosystem Consultants.
- Trisalyn, N. and Barry, B. (2005). Identifying insect infestation hot spots: an approach using conditional spatial randomization. *Journal of Geographical Systems*, 7(3-4), 291 - 311.
- Verlinden, A. and Masogo, R. (1997). Satellite remote sensing of habitat suitability for ungulates and ostrich in the Kalahari of Botswana. *Journal of Arid Environments*, 35, 563-574.
- Vickery, W.L.; Giraldeau, L.A.; Templeton, J.J.; Kramer, D.L. and Chapman, C.A. (1991). Producers, scroungers, and group foraging. *American Naturalist journal*, 137, 847-863.
- Voeten, M.M. (1999). Coexistence of wildlife and livestock in an East African system. Tropical Resource Management Papers, No. 29. Wageningen, Netherlands.

- Voeten, M.M.; Prins, H.H.T. (1999). Resource partitioning between sympatric wild and domestic herbivores in the Tarangire region of Tanzania. *Oecologia* 120, 287–294.
- Wall, G.; Dudycha, D. and Hutchinson, J. (1985). Point pattern analysis of accommodation Toronto. *Annals of tourism Research*, 12: 603-618.
- Western, D. (1975) Water Availability and its Influence on the Structure and Dynamics of Large Mammal Community. *East African Wildlife Journal*, 13: 265-286.
- Western, D. (1989). Conservation without parks: wildlife in the rural landscape. In: Western, D. and Pearl, M.C. (Eds.). *Conservation for the Twenty-first Century*. Oxford University Press, Oxford, pp.158–165.
- Wiegand, T. and Moloney, K. A. (2004). Rings, circles, and null-models for point pattern analysis in ecology. *Oikos*, 104(2), 209-229.
- Wiens, J.A. (1989). Spatial scaling in ecology. *Functional Ecology*, 3, 385-397.
- Wilcove, D.; Rothstein, D. and Losos, E. (1998). Quantifying threats to imperiled species in the United States. *Bioscience*, 48: 607-612.
- Williams, S.D. (1998). *Grevy's zebra: Ecology in a Heterogeneous Environment*. Ph.D. dissertation, Zoological Society of London, London.
- Williams, S.D. (2002). Status and action plan for Grevy's zebra (*Equus grevyi*). In *Equids: Zebras, Asses, and Horses: Status Survey and Conservation Action Plan* (Ed P.D. Moehlman), pp. 11-27. International Union for Conservation of Nature/Survival Service Commission Equid Specialist Group, Gland, Switzerland.
- Williams, S.; Nelson, A. and Kebede, F. (2003). *Grevy's zebra Survey: Ethiopia 2003* <http://www.stlzoo.org/downloads/EthiopiaSurveyResults.pdf>
- Williams, S.D. and Low, B. (Eds.) (2004). *Grevy's zebra Conservation: Proceedings of a Workshop*. Mpala Research Centre, Kenya, 22-24 March 2004.
- Willoughby, D.P. (1974). *The empire of Equus*. A. S. Barnes and Co., South Brunswick, 475 pp.
- Wijngaarden, W. V. (1985). *Elephants - Trees - Grass - Grazers; Relationships between climate, soil, vegetation and large herbivores in a semi-arid savanna ecosystem (Tsavo, Kenya)*. Wageningen, The Netherlands: ITC Publication.
- Woodroffe, R. (2001). Strategies for carnivore conservation: Lessons from contemporary extinctions. In *Carnivore Conservation* (eds. Gittleman, J. L.; Funk, S.; Macdonald, D. W. and Wayne, R. K.) 61-92. Cambridge University Press, Cambridge.

Yalden, D.W.; Lagen, M.J. and Kock, D. (1986). Catalog of the Mammals of Ethiopia .6. Perissodactyla, Proboscidea, Hyracoidea, Lagomorpha, Tubulidentata, Sirenia and Cetacea. *Monitore Zoologico Italiano- Italian Journal of Zoology*, 21, 31-103.

Zuberbuhler, K.; Noe, R. and Seyfarth, R.M. (1997). Diana monkey long distance calls: messages for conspecifics and predators. *Animal Behaviour*, 53, 589–604.

APPENDIX

Appendix 1: Distribution of Grevy's zebra in Tsavo East National Park and the ranchlands

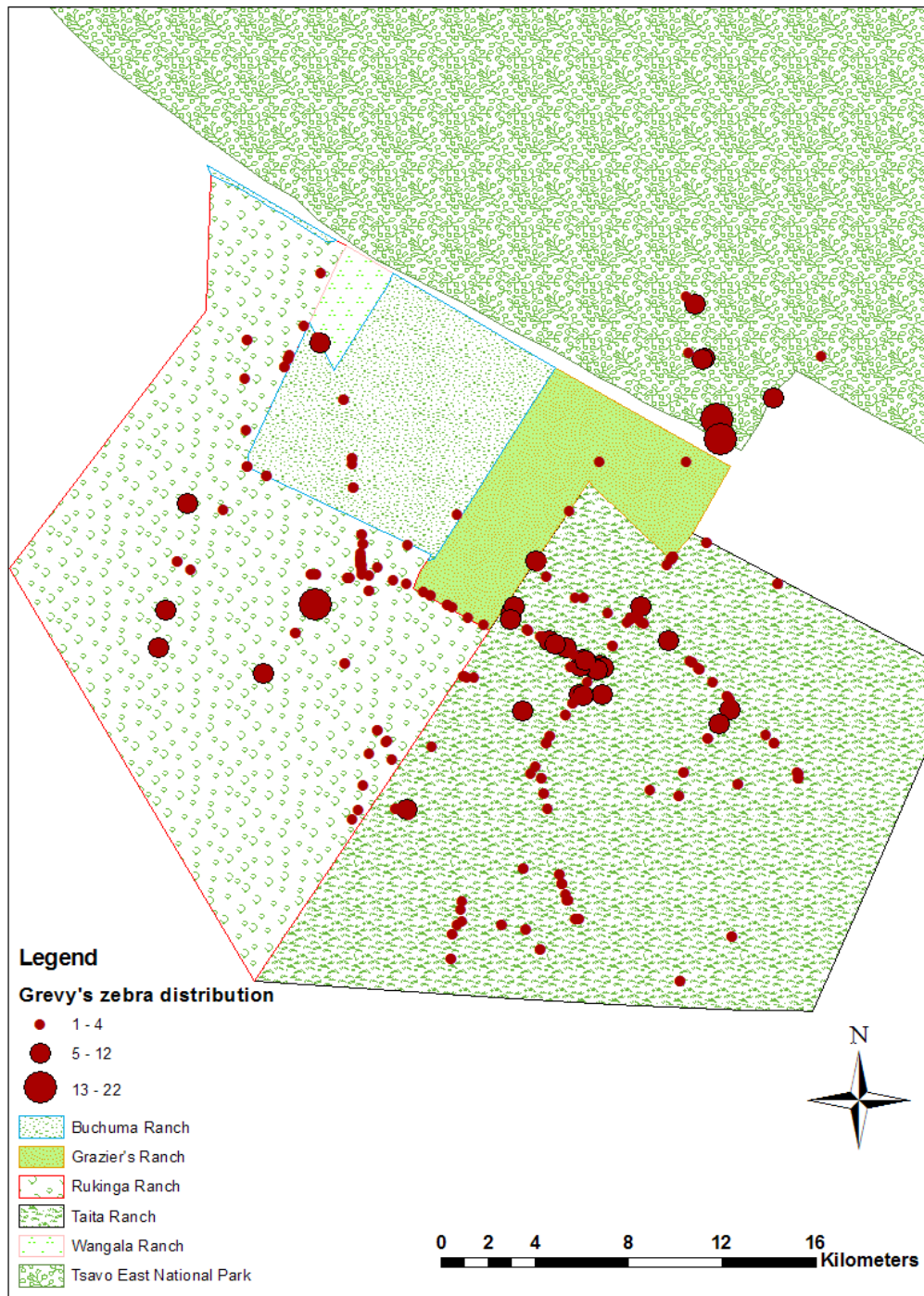


Figure 8. 1: Distribution of Grevy's zebra in Tsavo East National Park and the surrounding ranchlands.