USING TELEMETRY DATA TO STUDY BEHAVIOURAL RESPONSES OF GREVY’S ZEBRA IN A PASTORAL LANDSCAPE IN SAMBURU, KENYA

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SEPTEMBER 2013

“A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE AND THE DIPLOMA OF IMPERIAL COLLEGE LONDON”
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# Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AIC</td>
<td>Akaike’s Information Criteria</td>
</tr>
<tr>
<td>CITES</td>
<td>Convention on International Trade in Endangered Species of Wild Fauna and Flora</td>
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<tr>
<td>DD</td>
<td>Daily Displacement</td>
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<tr>
<td>DOP</td>
<td>Dilution of Precision</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HDOP</td>
<td>Horizontal Dilution of Precision</td>
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<tr>
<td>NDVI</td>
<td>Normalised Difference Vegetation Index</td>
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<tr>
<td>HWC</td>
<td>Human Wildlife Conflict</td>
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<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
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<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>NIR</td>
<td>Near-Infrared Light</td>
</tr>
<tr>
<td>QGIS</td>
<td>Quantum Geographic Information System</td>
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<td>RED</td>
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**Abstract**

Pastoral communities have lived alongside wildlife for hundreds of years around the world and are generally seen as being in harmony with their environment. In the last three decades, however, wildlife in pastoral areas of East Africa has undergone dramatic declines which have been linked to changes in the land use changes and urban development. The Grevy’s zebra is an endangered equid which inhabits the arid landscape of northern Kenya and Ethiopia. Only 3% of the Grevy’s zebra range is formally protected. As a result, it has been suggested that they are in competition with humans and their livestock for limiting resources such as forage, water and space. For the conservation of the Grevy’s zebra, it is vital to understand their behaviour and how they respond to living within a pastoral landscape. This project aims to assess the behavioural changes of Grevy’s zebra due to the proximity of humans. The study site is situated in southern Samburu, Kenya and encompasses three conservancies: Meibae, West Gate and Kalama. GPS collar data from 10 female Grevy’s zebra were analysed with respect to their environment. Firstly, Grevy’s zebra visited water almost exclusively at night when in areas high settlement density. However, in areas of low settlement densities, Grevy’s zebra drinking events occurred throughout the day and night indicating that Grevy’s zebra are excluded from water by human presence in the day. Secondly, Grevy’s zebra travel significant shorter distances when in areas of high settlement density compared to Grevy’s zebra in areas of no human presence. Possible reasons for this are that zebra are restricted in terms of space availability suggesting the presence of competition or that humans choose to live in areas where forage and water are closer together and so making the distance between these two resources shorter for Grevy’s zebra. Finally, to link Grevy’s zebra behaviour to human activities, an analysis of NDVI values around water points was conducted. Water points in areas of high human settlement density had lower NDVI values for the surrounding areas. Although this was conducted on a small scale, it implies that areas where humans are present could be subject to land degradation. Overall, the observed differences in behaviour suggest that there are signs of competition between humans, their livestock and Grevy’s zebra. To conclude this study, these results are placed into the broader context and recommendations on future research of the Grevy’s zebra and management options for the study site within the Samburu region of northern Kenya are discussed.

**Word Count:** 13,677
ACKNOWLEDGEMENTS

Firstly, I would like to thank all of my supervisors for their hard work and dedication to this project. To Nathalie Pettorelli for her invaluable insights into movement ecology, remote sensing and data analysis; for reading through endless drafts of my project and providing much needed comments. Especially to Belinda for her insights into the world of Grevy’s zebra and the Grevy’s Zebra Trust for allowing me access to the data and for supporting me and the team while in the field. Thanks also go to Zeke Davidson and Siva Sundaresan for their contribution to the project, its design and advice on data analysis.

Additional thanks to Denver Zoological Foundation and Grevy’s Zebra Technical Committee for their support, for proving the GPS collars and for access to the collar data; to Shivani Bhalla (Ewaso Lions) for providing settlement data for West Gate conservancy and Daniel Letoiye (North Rangelands Trust) for access to his data for the Meibea conservancy.

My fieldwork in Samburu would not have been possible without the help and hard work from Andrew Letura who acted as, not only my field assistant but also my guide, translator and friend throughout my time in Kenya. Ropi Lekwale, our driver was also invaluable, providing me with the opportunity to access the most remote settlements in Samburu. My thanks also go to Peter Lalampaa for being on hand to smooth out all the small issues fieldwork brings. Finally thanks to all the staff and guards at Meibae, West Gate and Kalama conservancies for allowing us to use their facilities while in the field.

I am grateful to all those who helped me with my data analysis and R: Billy for his modelling skills, Dom for his coding wizardry and to Clare and Judith for helping with my NDVI analysis which without them would have taken me weeks.

I would like to thank all of John Smith ground floor for providing amazing friendship, constant support and hours of pure entertainment in the kitchen. A special thanks to Christina for providing constant provisions of food and cake to get us all through the last few weeks.

Last but not least, to all my friends and family back home for supporting me during my years at university, without all your support it would not have been possible to pursue my dreams. Finally, a special thank you to my parents for always believing in me and to my Granddad for his contributions to my savings which made this all possible.
1. INTRODUCTION

1.1. PROBLEM STATEMENT

Humans now dominate the landscape in which they live and have changed their environment on a massive scale (Vitousek et al. 1997; Foley et al. 2005). Today, this is particularly true in developing counties where land use change is occurring at a significant rate and ranges from changes in land management practices to wide scale urbanisation. Current land use change is one of the biggest threats to wildlife as it results in habitat loss, fragmentation and land degradation (Allen 2012).

Biodiversity loss is currently one of the prominent threats facing East Africa. Wildlife in this area has gone through rapid declines in pastoral areas over the last thirty years which has been associated with livelihood changes in the local communities, current land use changes and urban development of wild areas (Okech 2011). Land use changes in the area include increase in land use intensity, transition to a more sedentary lifestyle and diversification of livelihoods (Bhola et al. 2012; Ogutu et al. 2010). Furthermore land use changes are likely to continue to increase in the future as more pressure is put on natural resources from a growing human population.

Wildlife is important in East Africa for many reasons: it provides critical ecosystem services and functions, has socio-cultural and aesthetic values and, most importantly, provides significant economic benefits through tourism (Butt & Turner 2012; Okech 2011). In 2006, wildlife accounted for 70% of the gross tourism earning and 25% of the Gross Domestic Product for Kenya alone (Okech 2011; Ministry of Tourism and Wildlife 2007). However, despite national and international importance, wildlife is still declining over much of Africa and so is a conservation priority.

The majority of wildlife in East Africa occurs outside of protected areas (Young et al. 2005) and so faces indirect and direct conflict with local communities. Conflicts between people and wildlife can result in negative attitudes towards wildlife and the role they play in a human dominated environment. Communities affected by conflict are likely to become a major threat to wild species. These issues have made human wildlife conflict (HWC) a hot topic within the conservation community. However, in order to create the much needed win-win solutions to conflicts, where both groups benefit, more research is needed to help understand the issues and problems faced by both the wildlife and the local people living alongside it.

Conservation management options aim to reduce the impact of HWC and could include mitigation, education or compensation depending on the extent and peoples tolerance of the conflict (Sillero-Zubiri et al. 2009). Specifically, competition can be reduced by improving livestock management,
alternating grazing areas or by providing alternative water points. Management decisions need to be based on scientific research if they are to be successful in resolving conflicts. Furthermore research into HWC will contribute to the wider conservation issues currently surrounding conflict between humans and wildlife.

To first understand conflict, it is important to understand how species respond to changes in their environment. This has become an important issue in conservation and has fuelled a large amount of research in this area. In order to study this, we first need to understand how wildlife move in relation to resources in the environment (Papworth et al. 2012). Changes in the environment can alter an animal’s behaviour including how animals move in their environment and how they utilise resources. Although these changes can appear to be minimal, they can affect an individual’s fitness overtime and can especially threaten vulnerable individuals or groups.

This field of spatial ecology has been growing over the last decade (Holyoak et al. 2008) in response to advancements in Global Positioning System (GPS) and remote sensing technologies and through developments in how to analyse the resulting data. Understanding how animals respond to their environment is important in conservation science for several reasons. Firstly, it can give us insights into aspects of ecology which have been previously hard to study, including how animals move in the landscape, how they utilise resources and how they interact with their environment. Secondly, and more importantly in conservation, it can help us to understand and predict how species will respond to future changes in their environment.

There are few studies which have addressed competition between livestock and ungulates for water and forage (Prins 1992; Butt & Turner 2012) and there are no studies looking into this competition at the individual scale in East Africa. This project will help fill this current gap in knowledge. Determining the scale and impact of competition between livestock and wildlife is important for conservationists. If negative effects can be highlighted for either group then appropriate conflict management options can be implemented. Furthermore this research will contribute to the wider conservation issues currently surrounding conflict between humans and wildlife.

In this study Grevy’s zebra (Equus grevyi) in northern Kenya will be used as a case study into resource competition arising between pastoral people, their livestock and native wildlife. Protected areas form less than 0.5% of Grevy’s zebra current range (Moehlman et al. 2008) and so individuals spend most of their time in pastoral areas. As a result, Grevy’s zebra are likely to compete with local communities and their domesticated livestock. Furthermore Grevy’s zebra have been classified as endangered by the IUCN and so are a research priority to provide recommendations for their
conservation. Current declines of Grevy’s zebra in the Rift Valley, Kenya have been attributed to low juvenile recruitment as a result of competition for resources with pastoral people and their livestock (Moehlman et al. 2008; Williams 1998). Therefore research into the role of competition between Grevy’s zebra and livestock is critically important in the conservation of this species in Kenya.

1.2. AIM AND OBJECTIVES

The aim of this project is to use movement data from Grevy’s zebra as a case study to explore livestock-wildlife competition in a pastoral landscape.

**Objective 1:** To assess behavioural responses of Grevy’s zebra in relation to the presence of human settlements

**Objective 2:** To identify signs of overgrazing or degradation around water points using NDVI data

**Objective 3:** To identify potential threats to Grevy’s zebra from livestock-wildlife competition

**Objective 4:** To provide recommendations on future research to inform management options and to enhance the conservation of Grevy’s zebra

1.3. HYPOTHESES

In this study, the following hypotheses will be tested:

\( H_1 \) **Water points in areas of higher human density will be used by wildlife more at night in comparison to water points in areas of lower human density which will be used more during the day**

\( H_2 \) **Daily distance travelled for Grevy’s zebra inhabiting areas of higher human density will be higher than daily distance travelled by zebras occupying areas of lower human density**

\( H_3 \) **Areas around water will have more bare ground and lower plant biomass if in a region of higher settlement density in comparison to water in regions of lower human density**
2. BACKGROUND

The following section will introduce the Grevy’s zebra and provide a background to the ecology of this species. Human-wildlife conflict will then be introduced with an emphasis on wildlife-livestock competition and how this fits into the East African pastoral landscape. Following this will be a brief overview of the study area.

2.1. FOCAL SPECIES: GREVY’S ZEBRA

The Grevy’s zebra (*Equus grevyi*) is a large, endangered equid adapted to arid savannas (Low et al. 2009) and is currently found in northern Kenya and southern Ethiopia. Grevy’s zebra occupy the narrow niche between the water-dependant plains zebra and the more arid adapted wild ass. Within this range, it inhabits Acacia-Commiphora thorn bush country and barren plains (Estes 1991).

The Grevy’s zebra is classified as endangered by the IUCN (Moehlman et al. 2008). The species had gone through an estimated 80% population decline in the past three decades and one of the largest range declines of any African mammal (Moehlman et al. 2008; Grevy’s Zebra Trust n.d.). It is estimated that there are only 2,500 individuals in the wild confined mostly to the eastern Rift Valley in Kenya with several isolated populations in Awash National Park, Ethiopia and a reintroduced population around Tsavo East National Park, Kenya (Moehlman et al. 2008; Grevy’s Zebra Trust n.d.). Past declines have been attributed to hunting for its skin (Moehlman et al. 2008) however hunting pressure has reduced since being listed on CITES Appendix I in 1979. Principal threats to Grevy’s zebra now include limited access to water and grazing resources, hunting for subsistence meat and medicinal products, predation and disease (Williams 1998; Williams 2002; Grevy’s Zebra Trust n.d.).

At present, protected areas form less than 0.5% of the range of the Grevy’s zebra (Moehlman et al. 2008). As a result they mostly live alongside people in a pastoralist dominated landscape. Current declines in Rift Valley, Kenya have been attributed to low juvenile recruitment as a result of competition for resources with pastoral people and their livestock (Moehlman et al. 2008; Williams 1998). Therefore research into the role of competition between Grevy’s zebra and livestock is critically important in the conservation of this species.

2.1.1. ECOSYSTEM

Equids have less efficient digestive systems than ruminants such as antelopes and bovids. To compensate for this, equids have high intake rates and so favour quantity over quality when choosing grazing areas (Williams 2002; Estes 1991). As a result, Grevy’s zebra can be forced to graze
in areas of poor quality vegetation when food is limiting and will be the first to move out of an overgrazed area (Kingdon 1979; Williams 2002). Although they are primarily grazers, they will browse in stressed conditions when grass has gone (Williams 2002). Permanent water sources are an important part of their diet. Although adults can survive without water for up to 5 days, lactating females must drink at least every other day so they can keep producing milk (Williams 2002; Rowen 1992).

Grevy’s zebra have large and variable home ranges which differs by class (Moehlman et al. 2008). Stallions maintain territories as large as 10-15km². However this is small compared to the home ranges of females and bachelors who can utilise hundreds of kilometres during a year (Estes 1991). Grevy’s zebra live in open membership groups in a polygynous mating system where males and females frequently change partners (Rubenstein 2010). This social behaviour can be explained by the habitat as food is scarce and located far from water. Dominant males hold large territories close to water so as to attract females with foals who must drink daily and those who come to drink every few days. Subordinate males establish their territories farther away in areas of abundant vegetation and so attract females without foals (Rubenstein 2010). As a result neither class of male is able to attract all females resulting in unstable social associations.

Most breeding occurs in the early rains and gestation lasts about a year. Mares can reproduce yearly under favourable conditions (Estes 1991). Mothers with new foals tend to associate in nursery herds. During droughts mothers may leave young foals in these nursery groups or alone as they travel long distances to find water (Estes 1991). Foals lack any instinct to hide and so if left unguarded, pose an easy meal for any passing predators. Young become independent after 6 months but will follow their mothers for up to three years (Estes 1991). Females are able to breed at three but males won’t breed before 6 years old.

### 2.2. Human-Wildlife Conflict

Human wildlife conflict is one of the biggest drivers of biodiversity decline worldwide (Woodroffe et al. 2005). It occurs when the needs and behaviours of humans negatively impacts wildlife or vice versa (IUCN 2005). HWC has occurred since humans and wildlife have lived side by side and shared resources (Lamarque et al. 2009). Nowadays it occurs worldwide with all nations being affected by conflict in one way or another. However the negative impacts that HWC can cause varies with the type of conflict, where they occur and its intensity. People in developing nations are more vulnerable to HWC as they are less able to mitigate against the negative effects it causes (Lamarque
et al. 2009). As a result conflicts in these counties are likely to escalate if left unmanaged and can have severe impacts on the local people.

The most well known examples of conflict include predation of livestock by carnivores, crop-raiding by elephants and attacks on humans by dangerous animals (Woodroffe et al. 2005). In extreme cases conflicts can lead to the death of both wildlife and humans. These examples have been relatively well studied as they have a high profile in both the news and scientific research (Lamarque et al. 2009; Newmark et al. 1994).

2.2.1. Livestock-Wildlife Competition as a Type of Conflict

Competition between organisms is a fundamental concept in ecology but can be defined in many different ways. For this study inter-specific competition will be defined as “the interaction between individuals from two different species who share resources such as food, water and space. This resource exploitation leads to a reduction in fecundity, growth or survivorship on one or both the species involved” (Begon et al. 2009).

In comparison to the other types of HWC, competition between humans, their livestock and wildlife has received only limited attention in the scientific literature and yet can be a significant area of conflict for local communities who live alongside wildlife. Competition between livestock and wild herbivores occurs for shared resources such as space, food and water.

Although the negative impacts of competition are not as obvious as other forms of HWC, it can still have detrimental effects on both wildlife and livestock. Competition can lead to the exclusion of one or both groups from critical resources such as water or food and so reduce the fitness for either group. This competition can be exacerbated if any of these resources become limiting. Furthermore conflict can occur if wildlife is seen or perceived to be in competition with livestock as this could directly affect a pastoralist’s livelihood.

Providing evidence for competition between two or more species can be challenging. As a result, the presence of livestock-wildlife competition has not been extensively studied yet its existence has been much debated in the literature (Butt & Turner 2012; Young et al. 2005). Overlap of habitat and diet between livestock and ungulates has been used as evidence for the co-existence between these species. On the contrary, widespread displacement of wildlife has been used to show there is competition with livestock causing exclusion. Due to this uncertainty, there is still little known about the extent to which livestock and wild grazers actually compete and if this competition negatively affects either group.
2.2.2. The Pastoral Landscape

A pastoralist can be defined as someone living in a household which obtains more than 50% of their total gross income from mobile livestock rearing in unimproved, communal pastures (Rass 2006). Pastoral communities have existed for thousands of years and are still found around the world today. There are an estimated 120 million pastoralist living worldwide and over 40% of these are in Sub-Saharan Africa (Rass 2006). This nomadic or semi-nomadic lifestyle provides a successful strategy in harsh and variable environments such as the savannas and grasslands of Africa and the Asian steppes as it allows communities and their livestock to follow resource availability. Mobile pastoralism contributes to food security, livelihoods and income of these communities and could help mitigate against negative impacts of climate change (Shanahan 2013).

Pastoralists are one of the poorest population sub-groups worldwide and so are extremely vulnerable. Pastoral communities themselves are being threatened by ideas of modernisation and are sometimes seen by governments as obstacles to national development (Anderson & Grove 1987). Pastoral herders rarely benefit from the growing economies of the countries they live in and are often marginalised by governments (Rubenstein 2010). In East Africa, nomadic communities are becoming more sedentary as infrastructure, schools and shops are built making moving away from these areas less desirable.

Although pastoralists are generally seen as being in harmony with nature (Butt & Turner 2012), these land use changes can affect the native wildlife by increasing competition and by making resources limiting. In addition, conflict is likely to increase as the proximity between humans and wildlife decreases. An increase in human and livestock numbers can lead to the displacement of wildlife, first through competition and then through development, urbanisation and the resulting habitat loss (Prins 1992). Overgrazing of areas by cattle and other livestock can result in land degradation and desertification. Although to what extent is still debated within the literature (Anderson & Grove 1987). Disturbance from humans such as noise or the presence of dogs can also alter a wild animal’s natural behaviour.

Factors which affect resource availability will also affect competition. Anthropogenic pressures such as human population growth, land use changes and urbanisation are all exacerbating competition between humans and wildlife. A further threat to pastoral people in arid environments is climate change. Predicted rises in temperature, increase in droughts and changes to precipitation levels over much of Africa (Mitchell 2012; Duncan et al. 2012) will affect resource availability not just for humans and livestock but also for the wildlife. These predicted changes are likely to make the
current conflicts more intense. Due to the current and future pressures on pastoral landscapes, it is important to study current competition issues so that future conflicts can be managed proactively.

2.3. **Grevy’s Zebra and Livestock Interactions**

As Grevy’s zebra live in a pastoralist-dominated landscape, they are likely to interact with livestock on a regular basis. Using data collected by scouts, Low et al. (2009) found that Grevy’s zebra are observed in proximity to livestock in approximately 40-50% of all zebra observations (Low et al. 2009). Grevy’s zebra were seen less with donkeys and cattle than with small stock (sheep and goats) and camels. The results suggest that Grevy’s zebra avoidance of cattle and donkeys is high in this area which increases closer to water. Furthermore different classes of zebra behaved differently. Territorial males and non-lactating females were unlikely to be observed within close proximity to livestock which could be explained by their ability to travel further from water to find better foraging areas not used by cattle. In contrast, bachelors’ who defend water sources and lactating females who are dependent on water are more often seen with livestock.

Williams (1998) aimed to test the hypothesis that Grevy’s zebra compete for critical resources with pastoral people and their domestic livestock. He studied the spatial patterns of Grevy’s zebra away from water and found that zebra grazing in areas used by pastoral people were recorded at a mean distance of 5.9km from permanent water, nearly 3 times the distance of zebras grazing in Buffalo Springs Nature Reserve where no humans are present (Williams 1998). This suggests that Grevy’s zebra are forced to travel further between resources when humans are present. However it is unclear whether this displacement is due to settlement avoidance, exclusion from resources or a reduction in resource availability.

2.3.1. **Drinking Patterns of Grevy’s Zebra**

The cost for animals to move to water is affected by many factors at both the individual and wider environmental levels. Normal drinking patterns of ungulates is a trade-off between the avoidance of predation at night and reducing thermoregulation costs during the day (Williams 1998). Therefore the time of day at which ungulates choose to drink can tell us what forces are driving this decision. If free to choose, Grevy’s zebra prefer to drink in the mid-morning (Rubenstein 2010; Williams 1998) to avoid predation risks. However Grevy’s zebra have been observed drinking at night when there are humans and cattle present around water during the day (Sundaresan et al. 2012; Williams 2002). Drinking at night presents an increased vulnerability of Grevy’s zebra, especially of foals, to
predation as this is when lions are most active. Therefore this exclusion of wildlife from water can present a conflict between humans, their livestock and wildlife that compete for water use.

2.4. **Study Site: Samburu, Kenya**

The research will be conducted within the Samburu district in the Rift Valley Province of northern Kenya (figure 2.1). This area is a typical arid savannah system and a stronghold for the Grevy’s zebra. Acacia trees dominate the area with ground cover made up of mixed forbs and grasses (Low et al. 2009). The average rainfall is 375mm with occasional droughts (Low et al. 2009).

In this area, the Grevy’s zebra are seen as a flagship species (Low et al. 2009). The habitat is mostly owned by pastoral communities comprised of Samburu and Maasai people with only 2% of the area is formally protected (Sundaresan et al. 2012). There are several conservancies in the area which are comprised of one or more community owned group ranches who agree to manage their land collectively for both livestock and wildlife conservation (Low et al. 2009). Each group ranch has four to six thousand inhabitants (Low et al. 2009). There are also commercial ranches in the area which are typically owned by wealthy individuals or cooperations. Some of these have formed conservancies where wildlife conservation is an explicit goal (Sundaresan et al. 2012). The study area is made up of three conservancies: Kalama, West Gate and Meibae. They form a total of 202,350 hectares with a population of approximately 21,500 people (NRT 2013).

![Figure 2.1: Situation of study site within the rift valley, northern Kenya. Study site encompasses three conservancies of Meibae, West Gate and Kalama and Samburu National Reserve.](image-url)
2.4.1. Samburu Manyattas

Pastoralist communities in the Samburu district are semi-nomadic, moving every few years to follow resource availability for their livestock. Pastoralists keep a mixture of chickens, small livestock, including goats and sheep, cattle and camels. Pastoralists live in temporary structures called manyattas (figure 2.2). These are made up of a number of small houses which surround a number of central bomas. The bomas hold small livestock such as goats and sheep where as larger livestock such as cattle and camels stay within the perimeter fence during the night. This perimeter fence is made from thorny acacia branches with movable branches acting as gates (Samburu Trust 2013).

![Figure 2.2: Typical layout of a manyatta](image)
3. Methods

3.1. Methodological Framework

This study analyses the behaviour of Grevy’s zebra in relation to their habitat specifically water use and movement. To provide a link to possible causes of any behavioural changes in relation to human settlement density, degradation around water sources was assessed using remote satellite data. The study thus combines remote sensing methodology, spatial analysis and movement ecology in order to infer behavioural changes in Grevy’s zebra. All analysis was carried out using Microsoft Office Excel 2007, R version 3.0.1 (R Core Team 2013) and QGIS version 1.8.0 (QGIS Development Team 2013).

3.2. Data Collection

GPS collars were fitted to ten adult female Grevy’s zebra in October 2010 and April 2011. The zebra were tranquillised by experienced vets before a general health check was carried out and GPS collars were fitted. Out of the ten zebra, five were collared in Meibae, one in West Gate and four in Kalama. All GPS data was collected between October 2010 and December 2012 and GPS positions were recorded automatically every hour. Data was downloaded using Savannah Data Management software. Approximately 105,000 GPS data points were collected from the ten collared zebra.

<table>
<thead>
<tr>
<th>Zebra Name</th>
<th>Date Collared</th>
<th>Area Collared</th>
<th>Collar End Date and Time</th>
<th>% Time Spent in Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sambasa Safari</td>
<td>11th November 2010</td>
<td>Meibae</td>
<td>28/12/2010 03:00</td>
<td>71%</td>
</tr>
<tr>
<td>Kiba</td>
<td>11th November 2010</td>
<td>Meibae</td>
<td>21/10/2012 09:00</td>
<td>94%</td>
</tr>
<tr>
<td>Nchoro</td>
<td>10th November 2010</td>
<td>West Gate</td>
<td>05/12/2012 09:00</td>
<td>93%</td>
</tr>
<tr>
<td>Meibae</td>
<td>9th November 2010</td>
<td>Meibae</td>
<td>17/08/2011 21:00</td>
<td>71%</td>
</tr>
<tr>
<td>Barsalinga</td>
<td>9th November 2010</td>
<td>Meibae</td>
<td>04/11/2011 15:00</td>
<td>35%</td>
</tr>
<tr>
<td>Leslie</td>
<td>9th November 2010</td>
<td>Meibae</td>
<td>03/06/2012 03:00</td>
<td>82%</td>
</tr>
<tr>
<td>Kalama</td>
<td>28th April 2011</td>
<td>Kalama</td>
<td>07/12/2012 03:00</td>
<td>68%</td>
</tr>
<tr>
<td>Saruni</td>
<td>28th April 2011</td>
<td>Kalama</td>
<td>26/11/2012 09:00</td>
<td>99%</td>
</tr>
<tr>
<td>Samburu</td>
<td>28th April 2011</td>
<td>Kalama</td>
<td>29/08/2011 21:00</td>
<td>90%</td>
</tr>
<tr>
<td>Waso</td>
<td>28th April 2011</td>
<td>Kalama</td>
<td>04/12/2012 21:00</td>
<td>0.7%</td>
</tr>
</tbody>
</table>
Settlement data for the study area was collected remotely using Google Earth software. Active manyattas were distinguished from abandoned ones by presence of houses, clear paths around the manyatta, intact outer fence and any other signs of use (see appendix A for a comparison between an active and abandoned manyatta). The main disadvantage of collecting settlement data remotely is that abandoned manyattas and living manyattas can be hard to distinguish especially if local Google Earth data is of poor quality. Only active manyattas were recorded for analysis. In this study, settlements were used as a proxy for livestock presence in the area. To improve the quality of the settlement data, 10 days fieldwork in Samburu, Kenya was carried out to ground truth the remote data. During fieldwork, a random 10% sample of recorded manyattas were selected and visited to confirm their status.

Additional manyatta data was collected by Ewaso Lions in West Gate in 2012. They carried out a full census of the area by visiting each individual manyatta and recording its coordinates.

For each settlement identified the following data was recorded: type of settlement, date when the image was taken and latitude and longitude coordinates. The final settlement map contained Google Earth data for Meibae and Kalama and Ewaso Lion data for West Gate. A map was produced using QGIS and contained over 900 living manyattas for the study area (see Appendix B for study site map). It was assumed that manyatta density remained constant throughout the study period. Although the Samburu are semi-nomadic, there have been reports that settlements are becoming increasingly permanent and therefore unlikely to move (B. Low, pers. comm. 2013). This assumption therefore was deemed likely to be valid for the duration of this study.

Water point data was collected for the study area by the Grevy’s Zebra Trust using handheld GPS units. The main assumption here is that water remained in water points and was accessible to humans and wildlife throughout the year. Therefore only permanent water points were included in the analysis as the study area is an arid environment. A GIS layer containing water points for the study area was produced using QGIS (see Appendix B for map).

MODIS tiles for the study site were downloaded from Reverb website (National Aeronautics and Space Administration 2013c). The tiles used for analysis were 250m in resolution and were taken at 16 day intervals between July 2010 and March 2013. A two month buffer either side of the study period was included to allow for any contaminated values to be smoothed correctly. The tiles were then clipped to the study site using the HEG Tool (National Aeronautics and Space Administration 2013b).
3.3. **Data Analysis**

3.3.1. **Data Screening**

GPS collar data was screened for errors before analysis began. There are two types of error inherent in animal location data: inaccuracy in location and missing data (Frair et al. 2004).

Failed location attempts result in missing data and occur when GPS transmitters are unable to find enough satellites to produce a location fix. Models can be used to fill in missing data gaps by estimating the likely trajectory of an animal (Horne et al. 2007; Morales et al. 2004). The zebra GPS data used in this study was missing 6% of its data points through failed location attempts. As this study does not involve the analysis of continuous animal trajectories, however, it was not necessary to estimate missing points.

Inaccuracy in the locations acquired is the difference between an animal’s actual location and the location recorded by the GPS (Frair et al. 2004). There are two ways to measure the accuracy of a GPS location. First is the number of satellites used to record a data point and the second is satellite geometry. Satellite geometry is measured by the dilution of precision (DOP) where the lower the value, the higher the chance of accuracy (Langley 1999). Grevy’s zebra GPS collars recorded horizontal dilution of precision (HDOP). However other determinants of GPS accuracy, such as sky availability, number of satellites and tree cover was not recorded. HDOP values associated with successful fixes were found to explain only 21% of the variation in location error when tested (Recio et al. 2011). When using only HDOP values to screen for location errors there is a trade off between data accuracy and data reduction and it has been suggested that filtering based on HDOP values will yield only limited reduction of GPS errors while discarding a large number of accurate fixes (Lewis et al. 2007; Recio et al. 2011). To try and retain a high proportion of data while still improving accuracy, a threshold HDOP value of 20 was used in this study. Although this is a higher value than used by other studies (Recio et al. 2011; D’Eon & Delparte 2005), the data set doesn’t include number of satellites for a location fix so a threshold HDOP value lower than 20 is likely to discard a higher proportion of accurate fixes. This screening removed 0.37% of the data points leaving a total of 103,333 points in the data set.

Conservancy boundaries which made up the study site were supplied by GZT. Further screening occurred to remove any data points outside of the study area which left approximately 70% of all GPS data points for the Grevy’s zebra and a total of 45 water points and 922 settlement points.
3.3.2. Drinking Patterns of Grevy’s Zebra

In Samburu, water is only a limiting factor during the dry season when there are a handful of available water sources for both humans and animals. To account for this, the Grevy’s zebra GPS points was analysed in relation to the season. Seasons have been defined as either wet season, encompassing the long rains from March to May and the short rains from November to December, or dry season as the months in between (Journey by Design 2013). The water point data was restricted to those sources which are known to contain water throughout the year and are available to both wildlife and livestock.

A buffer zone around each GPS zebra and water point was made in QGIS. A buffer radius of 3km was chosen as the area needed to be large enough to provide a wide range of settlement densities while still being a reasonable area for Grevy’s zebra to roam within an hour. This decision is further supported by Williams (1998) who found that manyattas in a different part of Samburu were found on average between 2 km and 3.6 km from usable water. The Points in Polygon package in QGIS was used to count the number of settlements within each buffer zone. This was then converted into settlement density by dividing by the area of the buffer. Finally the densities were split into four classes as defined in Error! Reference source not found.. The boundaries were selected to give an even spread of points within the low, medium and high density classes as there were no appropriate natural breaks in the data to provide density boundaries.

<table>
<thead>
<tr>
<th>Settlement Density Class Boundaries</th>
<th>Within 3km of GPS Point Settlement Count</th>
<th>Density per km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>1 - 8</td>
<td>0.03 – 0.30</td>
</tr>
<tr>
<td>Medium</td>
<td>9 - 18</td>
<td>0.30 – 0.67</td>
</tr>
<tr>
<td>High</td>
<td>&gt;19</td>
<td>&gt;0.67</td>
</tr>
</tbody>
</table>

Using the distance matrix function in QGIS, the distance to the nearest water source for each Grevy’s zebra GPS point was calculated. Water visits were then identified as any GPS point recorded within a set distance from water. As there is no confirmed methodology in the literature on how to define drinking events using GPS points, a distance of 500m from water was used as the threshold for this analysis. Low et al. (2009) used a threshold of 100m to define Grevy’s zebra drinking events in their study; however they used field observations of the Grevy’s zebra rather than collar data. Therefore a larger threshold was selected for this study to account for the data being collected only every hour while still maintaining a high probability that Grevy’s zebra were likely to drink within this event. This threshold, therefore, was based on the average distance travelled by the study zebra of...
0.4km in an hour. There are several assumptions with using this method. Firstly is the chance of identifying false drinking events, when a zebra is close to water but doesn’t drink. Secondly is the chance of missing drinking events which could occur if drinking events are shorter than an hour and Grevy’s zebra are not within 500m of the water source on the hour before or after drinking.

Each water visit event was identified as a water visit by an individual zebra if they remained within 500m of the same water point or subsequent visits to this water source occurred within 2 hours of the previous point. A gap of longer than two hours is likely to mean that these are independent drinking events however there is no set threshold within the literature (S. Sundaresan, pers. comm. 2013)

The first analysis was initially visualised by plotting histograms of the frequency of time of unique water visit for each of the four settlement classes. The data was further split into the wet and dry seasons to account for seasonal differences in water use and availability. In this analysis, to account for drinking events which lasted longer than one hour, only the hour at which the zebra was recorded closest to water was used so that the results were not skewed by individuals that stayed close to water for long periods of time. The closest distance to water was chosen over the first record for each event as it is a better representation of when the zebra was likely to have visited the water to drink rather than first approaching water.

To assess the importance of time of day, settlement density, season and year in determining the probability of zebra drinking at water points, general linear mixed models were considered using the lme4 and car packages in R. A full model was built with the following proposed variables:

\[
\text{Probability of drinking event} \sim \text{Settlement class of water} + \text{Time} + \text{Season} + \text{Year} + \text{Zebra ID}
\]

A number of models with different combinations of variables and interactions were run and the model which had the best fit was selected using Akaike’s Information Criterion (AIC) values. AIC allows for the comparison between models by uses deviance as a measure of fit while taking into account complexity (Bolker et al. 2008; Burnham & Anderson 2002). For the models, zebra ID was included as a random effect to account for any individual behavioural differences. Time (day or night), season (wet or dry) and year (2010, 2011 or 2012) were factors included as fixed effects in the model. The response variable was the proportion of hours an individual spent drinking for each combination of explanatory variables. The main assumption of the proposed approach is that zebras are able to visit all water sources within the study site. As there are no barriers to dispersal throughout the study site and female zebras are not territorial, the individuals in this study are able to visit all water sources and so this assumption is likely to hold true.
3.3.3. **Daily Distance Travelled by Grevy’s Zebra**

To test for the second hypothesis, the daily distance travelled by each zebra on each day needed to be calculated. Firstly, a trip number was given to each zebra for each day. Any trips whose duration was less than 21 hours were discarded as this represents a GPS fix rate of less than 80% and would not provide enough points to provide an accurate estimate for the distance travelled in a day. To calculate hourly displacement, the great-circle distance between sequential locations was calculated using Haversine’s formula with Earth’s radius set as 6371km (Polansky et al. n.d.). This method gives the minimum distance an individual travels between two points assuming the individual walks in a straight line and the ground is flat. Although this is a simple approach to calculate distance travelled, it is sufficient for this analysis as hourly displacement is likely to be small and it allows for comparisons between these distances to be made.

The cumulative distance travelled for each day or daily displacement (DD) was calculated by summing hourly displacement over 24 hours. For each unique trip the following information was extracted: daily displacement, average density for the area in which they travelled during that day, the date and the season. From this data, the cumulative distance per day was plotted for the four density classes and split between wet and dry season. Further analysis of this data was carried out by using general liner mixed models with the following proposed variables:

\[
\text{Daily Displacement } \sim \text{ Settlement Class + Season + Year + Zebra ID}
\]

A number of models were run with different combinations of variables and the best fitting model was selected using the AIC method (Bolker et al. 2008). For the models, zebra ID was a random effect to account for individual differences in movement. Settlement class was a fixed factor in the model. It was calculated by taking the average settlement density for each Grevy’s zebra GPS point per trip and then assigning a settlement class using the boundaries as set out in table 3.2. Season (wet or dry) and year (2010, 2011 or 2012) were included as fixed effects within the models. The response variable was the total daily distance travelled by each zebra.

3.3.4. **Degradation and Overgrazing**

The third hypothesis, that amount of vegetation round water in areas of high settlement density would be lower than around water in areas of low settlement density, was tested using remote sensing data. The Moderate Resolution Imaging Spectroradiometer (MODIS) takes high resolution images of the Earth’s surface from the Terra and Aqua satellites (National Aeronautics and Space Administration 2013a). These images provide a range of data on different aspects of the Earth’s processes. One of the products of MODIS is the Normalised Difference Vegetation Index (NDVI).
NDVI is calculated using the following formula: \( \text{NDVI} = \frac{(\text{NIR}-\text{RED})}{(\text{NIR}+\text{RED})} \), where NIR is the amount of near-infrared captured by the satellite and RED is the amount of red light captured. NDVI ranges from -1 to +1 and directly correlates with vegetation productivity where a negative value represents absence of vegetation (Pettorelli et al. 2005). NDVI is rapidly becoming a powerful tool for scientists and has a wide range of uses in conservation. In this study NDVI will be used to assess if there is a difference in plant productivity around water points due to the presence of humans. The following processes were carried out using R. Firstly every 250m\(^2\) cell within a 2km buffer around a water point in the study area was identified. Then the cells which contained the water points were removed as the presence of water will cause contamination of the NDVI values. This left between 220 and 230 cells per water point. NDVI data was extracted for all these cells to give a total of 56 NDVI data values from October 2010 to February 2013 for each of the cells around the 48 water points. To get comparable data, all the NDVI values were multiplied by 10,000 to get a range between -10,000 and +10,000. Next the NDVI values were examined for contamination by looking for anomalies in the values. Contamination is usually caused by large bodies of water or cloud cover in the cell (Pettorelli et al. 2005) and can be pinpointed by looking for any negative values or extreme peaks in subsequent values (Garonna et al. 2009). Once anomalies were pinpointed in the data they were ‘smoothed’ by replacing the contaminated value with the average of the previous and following values (Garonna et al. 2009). Finally the NDVI data was averaged across 2011 and 2012 for each water point.

Each of the water points was given a settlement density class using a 3km buffer and using the boundaries as defined in table 3.2. To visualise the results, a box plot including all the cells was produced. Next a number of general liner models were run to test which variables were significant in explaining variation in NDVI values around water point. The response variable was the average NDVI for each water point; calculated by averaging the NDVI values of the cells around each water point across the study period. This produced one NDVI value for each water point. Location was a fixed factor depending on which conservancy (Meibae, West Gate or Kalama) the water point was in. Water point type was also included as a fixed factor with the following categories: dam, permanent pan, river, trough, pools, well, seepage and seepage/wells and was recorded when the GPS points were collected. The proposed model had the following formula and the best fitting model was chosen using the AIC method (Bolker et al. 2008).

\[
\text{Average NDVI} \sim \text{Settlement Class} + \text{Location} + \text{Water Point Type}
\]
4. RESULTS

4.1. GREVY’S ZEBRA DRINKING PATTERNS

Grevy’s zebra drinking events during the study period were not evenly distributed throughout the season or in relation to the settlement class given to the area (table 4.1). There were less water visits to water points in the study area during the wet season than in the dry season and highest number of visits occurred in areas of high settlement density.

<table>
<thead>
<tr>
<th>Settlement Density Class</th>
<th>Number of Drinking Events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet Season</td>
</tr>
<tr>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>121</td>
</tr>
<tr>
<td>Medium</td>
<td>45</td>
</tr>
<tr>
<td>High</td>
<td>135</td>
</tr>
<tr>
<td>Total</td>
<td>303</td>
</tr>
</tbody>
</table>

Firstly the water visits for all zebra were split into day (from 06:00 to 18:00) and night (from 19:00 to 05:00). This initial analysis shows a general increase in proportion of visits occurring at night as the settlement density increases (table 4.2). Despite the difference in water availability during the dry and wet seasons, the results show similar trends in water use in areas of low, medium and high settlement density.

<table>
<thead>
<tr>
<th>Time</th>
<th>Wet Season</th>
<th>Dry Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>Day</td>
<td>100%</td>
<td>51%</td>
</tr>
<tr>
<td>Night</td>
<td>0%</td>
<td>49%</td>
</tr>
</tbody>
</table>

The frequencies of drinking events were then plotted for each of the four settlement densities in each season (figure 4.1). These graphs show clear patterns in drinking times which change with settlement density. In areas of low settlements Grevy’s zebra visit water throughout the day, although this varies with the season. In the dry season water visit frequency remains constant throughout the night but increases steadily through the day, peaking at 4pm. In the wet season, water visits remain relatively constant between midnight and 4pm with a drop in frequency in the evening before rising at midnight. In contrast in areas of medium and high settlement density,
frequency of water visits peak during the night in both seasons (peaking between 19:00 and 01:00). Although water visits in both medium and high settlement density areas drop during the day, this drop is more prominent in areas of high settlements where only a small number of visits occur in daylight. Water visits to areas of no settlements in the dry season are unusual as they do not follow the general trend expressed by the rest of the results. Instead they also show a peak in drinking times at night, similar to that of high settlement areas. However these results are inferred from a smaller sample size.

**Figure 4.1**: Frequency of water visiting times for Grevy’s zebra in the dry and wet seasons for each settlement density class. The graph for area of no settlement in the wet season has been excluded due to low sample size. Dark green bars denote night time and light green bars denote daylight hours.
To further test the significance of these results a number of general linear mixed models were run and figure 4.3 shows the AIC values for the five models tested.

**Table 4.3:** AIC values of competing models to explain the probability of drinking events. Zebra ID is a random effect and time, density, season and year are fixed factors. In models 4 and 5, time and density are interactions.

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>AIC value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Probability ~ Time + Density Class + Zebra ID</td>
<td>-915.1</td>
</tr>
<tr>
<td>2</td>
<td>Probability ~ Time + Density + Year + Zebra ID</td>
<td>-895.4</td>
</tr>
<tr>
<td>3</td>
<td>Probability ~ Time + Density + Season + Year + Zebra ID</td>
<td>-886.5</td>
</tr>
<tr>
<td>4</td>
<td>Probability ~ Time * Density Class + Season + Year + Zebra ID</td>
<td>-878.9</td>
</tr>
<tr>
<td>5</td>
<td>Probability ~ Time * Density Class + Year + Zebra ID</td>
<td>-887.9</td>
</tr>
</tbody>
</table>

The following model was selected as the model with the best fit as shown by an AIC value of -886.5:

**Probability of Drinking Event ~ Time * Density Class + Season + Year + Zebra ID**

The results from this model (table 4.4) show that probability of drinking events significantly differs with time of day. Furthermore, probability of drinking events can be explained as the interaction between time of day and density of the area. Hence as density increases, the drinking patterns of Grevy’s zebra changes. Season and year also have an effect on the frequency of drinking events however these variables are not significant. Zebra ID was included in the model as a random effect and it explained 11.87% of the variation within the data. Overall these results support the hypothesis that Grevy’s zebra are more likely to drink at night in areas of higher settlement density. In contrast in areas of lower settlement density Grevy’s zebra are more likely to drink during the day.

**Table 4.4:** Results of the fixed effects from the linear mixed model with the formula Probability ~ Time * Density + Season + Year + (1 | Zebra ID) with 231 degrees of freedom. Significance codes = ***p<0.001, **p<0.005

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Standard Error</th>
<th>t-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.003314</td>
<td>0.009674</td>
<td>0.342591</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>(Time)Night</td>
<td>0.042519</td>
<td>0.008476</td>
<td>5.016707</td>
<td>0.0000</td>
<td>***</td>
</tr>
<tr>
<td>(Density)Low</td>
<td>0.000458</td>
<td>0.008417</td>
<td>0.054409</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>(Density)Medium</td>
<td>0.00453</td>
<td>0.008417</td>
<td>0.538236</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>(Density)No</td>
<td>-0.013017</td>
<td>0.008417</td>
<td>-1.54657</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>(Season)Wet</td>
<td>0.006494</td>
<td>0.004694</td>
<td>1.383392</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>(Year)2011</td>
<td>0.006860</td>
<td>0.00575</td>
<td>1.043364</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>(Year)2012</td>
<td>0.011290</td>
<td>0.007107</td>
<td>1.588626</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>(Time)Night:(Density)Low</td>
<td>-0.045143</td>
<td>0.011894</td>
<td>-3.7955</td>
<td>0.0002</td>
<td>***</td>
</tr>
<tr>
<td>(Time)Night:(Density)Medium</td>
<td>-0.046561</td>
<td>0.011894</td>
<td>-3.91474</td>
<td>0.0001</td>
<td>***</td>
</tr>
<tr>
<td>(Time)Night:(Density)No</td>
<td>-0.041245</td>
<td>0.011842</td>
<td>-3.48279</td>
<td>0.0006</td>
<td>***</td>
</tr>
</tbody>
</table>
4.2. **Daily Distance Travelled by Grevy’s Zebra**

From the dataset, 6772 unique daily trips were identified for use in analysis. Overall the greatest distance an individual Grevy’s zebra travelled in a day was 51.66km and the shortest distance travelled was only 0.3km which shows there is a large amount of variation between individual journeys. The cumulative distance travelled was visualised graphically by season and by settlement density (figure 4.2). From these graphs there are no significant trends in increasing or decreasing DD with increasing settlement density. However the graphs do show that Grevy’s zebras travel further in a day during the wet season than in the dry season.

On average Grevy’s zebra travel around 9.99 (±4.81) km per day and around 0.4km in an hour. DD was shortest in areas of high settlement density (9.07km) and furthest in areas of no settlement (11.32km) (table 4.5). The general trend suggests that DD decreases with increasing settlement density although there is a large amount of deviation within the data. There is also a decreasing trend in DD through the years (11.31km in 2010 to 9.09km in 2012) and there is very little difference between seasons (9.99km in dry compared to 9.96km in the wet season).

<table>
<thead>
<tr>
<th>Settlement Density Class</th>
<th>Average Daily Displacement (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>NA</td>
</tr>
<tr>
<td>Low</td>
<td>14.14</td>
</tr>
<tr>
<td>High</td>
<td>10.59</td>
</tr>
</tbody>
</table>

To determine the effect of settlement density, season and year on daily displacement of Grevy’s zebra, four linear models were run with varying variables used to explain daily distances travelled. The models and their respective AIC values are displayed in table 4.6.

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>AIC value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distance ~ Density Class + Season + Year + Zebra ID</td>
<td>16406.38</td>
</tr>
<tr>
<td>2</td>
<td>Distance ~ Density Class + Season + Zebra ID</td>
<td>16477.48</td>
</tr>
<tr>
<td>3</td>
<td>Distance ~ Density Class + Year + Zebra ID</td>
<td>16477.48</td>
</tr>
<tr>
<td>4</td>
<td>Distance ~ Density Class + Zebra ID</td>
<td>16474.47</td>
</tr>
</tbody>
</table>
Figure 4.2: Cumulative distances travelled (in km) by Grevy’s zebra in a day for the dry (above) and wet (below) seasons split for: A areas of no settlements, B areas of low settlement density, C areas of medium settlement density and D areas of high settlement density.
Using the AIC values to compare the models, the following model was selected as the best fit to the data:

\[
\text{Daily Distance} \sim \text{Density Class} + \text{Year} + \text{Season} + \text{Zebra ID}
\]

The output from this model is summarised in table 4.7 below. All three factors were included in the model which best fit the data; however, only density and year produced significant results. Zebra ID was a random effect in the model and explained 17.1% of the variance. The model shows no significance difference in DD between areas of no and low, and areas of medium and high settlement densities. Grevy’s zebra move significantly shorter distances in areas of high settlements than in areas of no or low settlements. Overall, there is a negative correlation between DD and increasing density class as shown by the model. This provides support for the previous results using average DD. Although these results do show significant trends, they were not the results hypothesised and the second hypothesis has not been supported. Year was also a significant factor and Grevy’s zebra travelled significantly shorter distances in 2012 than in either 2010 or 2011. There was no significant difference between DD in 2010 and 2011. There was no significant difference between DD in the wet and dry season. Therefore although there are some environmental factors which are affecting DD, Grevy’s zebra do respond to the presence of settlements.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Standard Error</th>
<th>t-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>11.22893</td>
<td>0.483886</td>
<td>23.20576</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>(Season)Wet</td>
<td>-0.21614</td>
<td>0.194953</td>
<td>-1.10868</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>(Year)2011</td>
<td>-1.42425</td>
<td>0.366014</td>
<td>-3.89124</td>
<td>0.0001</td>
<td>***</td>
</tr>
<tr>
<td>(Year)2012</td>
<td>-2.7998</td>
<td>0.381313</td>
<td>-7.34251</td>
<td>0.0000</td>
<td>***</td>
</tr>
<tr>
<td>(Density Class)Low</td>
<td>1.513632</td>
<td>0.238416</td>
<td>6.348708</td>
<td>0.0000</td>
<td>***</td>
</tr>
<tr>
<td>(Density Class)Medium</td>
<td>0.312085</td>
<td>0.228804</td>
<td>1.363985</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>(Density Class)No</td>
<td>1.375588</td>
<td>0.642582</td>
<td>2.14072</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

4.3. **Evidence of Degradation and Overgrazing**

In total, 46 water points were included in analysis. As indicated by figure 4.3, cells around water in areas of no settlement density had a lower average NDVI (2682.02 ±402.62) in comparison to areas of low, medium and high settlement density classes (2317, 2259 and 2386 respectively).
Using the average NDVI values per water point, a number of general linear models were run using different combinations of fixed variables. The AIC values for these models are shown in table 4.8.

**Table 4.8: AIC Values of Competing Models to Explain Variance in Average NDVI with Density Class, Location and Water Point Type as Fixed Variables**

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>AIC value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average NDVI ~ Density Class + Location + Water Point Type</td>
<td>508.07</td>
</tr>
<tr>
<td>2</td>
<td>Average NDVI ~ Density Class + Location</td>
<td>516.20</td>
</tr>
<tr>
<td>3</td>
<td>Average NDVI ~ Density Class + Water Point Type</td>
<td>525.36</td>
</tr>
<tr>
<td>4</td>
<td>Average NDVI ~ Location + Water Point Type</td>
<td>519.14</td>
</tr>
</tbody>
</table>

From the AIC values, the model with the following formula was selected:

Average NDVI ~ Density Class + Location + Water Point Type

Results from this model show that all three variables, density class, location and water type were significant in explaining the variation of NDVI values around water points (table 4.9). Location came out as the most significant in the model. Water points in Meibae had the highest average NDVI value of 2545 (±354), followed by water points in West Gate (2344 ±121) and Kalama (2159 ±134). Water point type came out as a significant although this may be skewed by the inclusion of dams in the data set which had an unusually high NDVI value of 2608 (±289) and was significantly higher than...
four of the other water point types (pools, seepage, wells and seepage/wells). Finally settlement density also came out as significant. NDVI around water points in areas of no settlements was significantly different to areas of low, medium and high settlement areas. Overall this result supports the hypothesis that NDVI around water would be smaller in areas of lower settlement densities in comparison to areas of higher settlement densities.

### Table 4.9: Results of the fixed effects from the linear mixed model with the formula Average NDVI ~ Density Class + Location + Water Point Type with 37 degrees of freedom. Significance codes = ‘***’ p<0.001, ‘**’ p<0.01, ‘*’ p<0.05

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2324.81</td>
<td>130.99</td>
<td>17.748</td>
<td>4.74e-16</td>
<td>***</td>
</tr>
<tr>
<td>(Location)Meibae</td>
<td>445.06</td>
<td>119.87</td>
<td>3.713</td>
<td>0.000984</td>
<td>***</td>
</tr>
<tr>
<td>(Location)Westgate</td>
<td>175.31</td>
<td>108.64</td>
<td>1.614</td>
<td>0.118681</td>
<td></td>
</tr>
<tr>
<td>(Class)Low</td>
<td>174.87</td>
<td>109.77</td>
<td>1.593</td>
<td>0.123239</td>
<td></td>
</tr>
<tr>
<td>(Class)Medium</td>
<td>-39.52</td>
<td>74.91</td>
<td>-0.528</td>
<td>0.602285</td>
<td></td>
</tr>
<tr>
<td>(Class)No</td>
<td>269.95</td>
<td>89.61</td>
<td>3.013</td>
<td>0.005707</td>
<td>**</td>
</tr>
<tr>
<td>(Type)Permanent pan</td>
<td>-176.5</td>
<td>229.78</td>
<td>-0.768</td>
<td>0.449338</td>
<td></td>
</tr>
<tr>
<td>(Type)Pools</td>
<td>-424.08</td>
<td>121.38</td>
<td>-3.494</td>
<td>0.001723</td>
<td>**</td>
</tr>
<tr>
<td>(Type)River</td>
<td>-114.77</td>
<td>109.15</td>
<td>-1.051</td>
<td>0.302705</td>
<td></td>
</tr>
<tr>
<td>(Type)Seepage</td>
<td>-485.8</td>
<td>203.43</td>
<td>-2.388</td>
<td>0.024489</td>
<td>*</td>
</tr>
<tr>
<td>(Type)Seepage/Wells</td>
<td>-251.54</td>
<td>110.61</td>
<td>-2.274</td>
<td>0.031451</td>
<td>*</td>
</tr>
<tr>
<td>(Type)Wells</td>
<td>-257.78</td>
<td>94.82</td>
<td>-2.719</td>
<td>0.011515</td>
<td>*</td>
</tr>
</tbody>
</table>
5. DISCUSSION

Results from this study have revealed differences in Grevy’s zebra behaviour in areas of varying settlement density; fulfilling the first objective of the study. The second objective has also been accomplished with the finding that NDVI around water in areas of no settlements is significantly higher than the NDVI around water in areas where settlements are present. The following section will provide a discussion of the results by putting them in the broader conservation context. Finally, recommendations for future studies and implication for management of the Grevy’s zebra and other wildlife in the Samburu region will be presented to fulfil the final objectives.

5.1. RESPONSES OF GREVY’S ZEBRA TO HUMAN PRESENCE

5.1.1. DRINKING PATTERNS

Grevy’s zebra drinking patterns are significantly affected by the presence of human settlements. Williams (1998) found that if away from the presence of humans, Grevy’s zebra will tend to drink during the hottest part of the day but when humans are present, Grevy’s zebra will drink at night. In this study, Grevy’s zebra drank at night independent of settlement density, implying that even at low settlement density, normal drinking patterns are disturbed. Unfortunately there were only few water points in areas of no settlement and Grevy’s zebra rarely visited them so this study did not allow for a strong comparison between areas of no human presence and areas with human presence. Although the unusual behaviour of the Grevy’s zebra who did visit water in areas of no settlements could be explained by the small sample size, there is another explanation. There have been reports that two of these water points are heavily used by humans and their livestock from both Meibae and neighbouring conservancies despite the fact that there are no settlements in the proximity (B. Low, pers. comm. 2013). This would result in drinking patterns similar to those individuals in areas of high settlements density as supported by the results in this study. This also hints at the explanation behind the disturbance of drinking patterns.

Williams (1998) had two explanations for Grevy’s zebra night time visits to water. First is the presence of cattle at water during the day. This is supported by the finding that Grevy’s zebra actively avoided cattle corrals (Sundaresan et al. 2007). However Low et al. (2009) found that co-occurrence of Grevy’s zebra and livestock was particularly common around water holes. A second explanation by Williams was that activity around settlements during the day formed a barrier to Grevy’s zebra, preventing them from accessing water until activity ceased at dusk. However this is
not supported in this study as the settlements rarely from a ring around water points to prevent access by Grevy’s zebra (see Appendix B for map).

The main assumption of this analysis is the use of a 500 metre threshold to determine an individual drinking event. As there is no literature on this subject the threshold was based on the average distance travelled by the study zebra within an hour. It is possible that a number of false drinking events were used in the analysis or that a number of true drinking events were missed. However as the results do show significant patterns in water use, it can be assumed that this threshold was appropriate for the study. However this assumption could be further backed up by research using field observations of Grevy’s zebra drinking patterns.

There are several possible implications of these results for the Grevy’s zebra. Firstly, lions and other predators prefer to visit water holes at night in this area (Williams 1998; Fischhoff et al. 2007). Therefore drinking in the night could represent an increased predation risk for Grevy’s zebra. Secondly, dominate male Grevy’s zebra defend territories around water points (Rubenstein 2010). If zebra are excluded by humans then dominant males in particular could be unable to hold these territories, reducing mating opportunities of these more dominant males. Thirdly, Williams (1998) has shown that foal survival was lower in areas of human presence due to reduced water availability. It is likely that this reduction in fitness is due to disruption in drinking patterns. Finally, as other wildlife in the area will also be disrupted by human presence, it is possible that, once water becomes available at night, there will be increased competition for access between wild species.

In the broader context, water availability will affect more than just Grevy’s zebra. The plains zebra are also excluded by humans presence in Kenya (Williams 1998). Furthermore, impala and warthog both live within close proximity to water in this area and also do not drink when cattle are present at water (Williams 1998). Outside of Kenya, African elephants have also been found to be restricted by water availability in Zimbabwe (Chamaille-Jammes et al. 2007) and have been a source of HWC throughout Africa (Newmark et al. 1994; Lamarque et al. 2009). Desertification is already affecting between 1% and 6% of people living in drylands and climate change is expected to decrease water availability into the future (Secretariat of the Convention on Biological Diversity 2010). Both humans and wildlife are vulnerable to changes in water availability and so finding ways in which water can be provided to wildlife without decreasing availability to humans is a vital problem which needs solving.

5.1.2. Daily Distance

It has been documented that human settlements can form a barrier to wildlife trying to access water or forage (Williams 1998) however there have been no studies on if these barriers alter Grevy’s
zebra movement on a daily basis. In this study, it was hypothesised that at high settlement density, wildlife would have to travel further to move around these barriers. The majority of Grevy’s zebra in this study travelled within 3km of at least one active manyatta on a daily basis. Although the distance travelled by Grevy’s zebra did change with settlement density, the results were not as expected. Overall the results suggest that DD and therefore Grevy’s zebra movements are restricted by human presence rather than amplified by it.

One explanation for this restriction is that Grevy’s zebra in areas of higher settlement density are excluded from certain areas by the presence of humans and therefore are unable to travel as far. This is supported by findings that Grevy’s zebra do actively avoid humans and cattle (Williams 1998; Sundaresan et al. 2007). If this explanation is correct then the results imply that Grevy’s zebra and humans are in competition for space and that as human presence increases, the area an individual zebra can exploit decreases. However a second explanation for the decrease in DD when humans are present could be to do with the landscape. It is possible that humans will choose to inhabit areas with good availability of both water and forage. If this is true then Grevy’s zebra moving in this area would have less distance to travel between water and forage which in turn will result in a smaller daily range. This is supported by the results from this study as the highest proportion of visits to water occurred in areas of high settlement density. To further explore this, further analysis of more detailed zebra movements could be carried out using the same data.

There are a number of limitations with the methods used. Firstly, DD maybe skewed by short migrations within the study site in response to changes in resource availability. This was hard to account for within this study as there is no set threshold distance which separates normal daily movement from migration patterns in Grevy’s zebra. Secondly, travel distances were recorded using hourly displacement and this method is likely to have underestimated the true distance travelled within a day. A more extensive study into Grevy’s zebra movements would be useful and provide further insights into this topic.

Overall these results suggest that there is unlikely to be an increased cost to Grevy’s zebra in areas of higher settlement densities through increased travel distances. Williams (1998) found that Grevy’s zebra juvenile survival was related to the distance their mothers travelled and survival was lowest in areas used by pastoralists. This study eliminates distance as a possible cause of increased juvenile mortality in areas where humans are present suggesting there are other factors at play here, such as stress from disturbance, limited resource availability or exclusion from water.
Although these results are specific to Grevy’s zebra, the techniques used here can be applied to other studies using telemetry data. For example Polansky et al. (unpublished) used a similar methodology to show that daily displacement of African elephant’s changed in response to resource availability and NDVI. Therefore is another analysis tool in a growing area of movement ecology.

5.2. **Evidence of Overgrazing/Degradation**

The results from analysis of NDVI around water points support the hypothesis that plant productivity is higher in areas of low settlement density when compared to areas of high settlement density. However, in this study there was no significant difference between areas of low, medium and high settlement densities which suggest that NDVI does not follow a decreasing trend with increasing human density as expected. There could be several explanations of these findings. Firstly, this could provide some evidence for degradation of water points close to human settlements. Land degradation in this area could be due to overgrazing, clearing of vegetation or trampling by large numbers of cattle. However, environmental factors such as annual rainfall have been shown to have a significant effect on NDVI. It has been shown that variation in NDVI due to land degradation is hard to distinguish from variation due to rainfall (Wessels et al. 2007) and often this variation masks any underlying trends from land degradation (Pickup et al. 1998). An alternative explanation could be that other variables are more significant in explaining variation in NDVI. This is supported in this study where both location and water point type were significant factors within the model explaining average NDVI around water. However other variables such as average rainfall and vegetation type will also affect NDVI and should be included in further studies using this data.

Due to time limitations, this study only focused on areas around water points. Further research in this area is needed and should encompass the whole study area and compare areas of high human use verses areas of low human disturbance. This could be measured by counting numbers of cattle using an area, by asking cattle herders to map their general movements throughout the year or by taking counts of cattle tracks throughout the study area. This could also be factored into the model in this study.

Overgrazing has become an increasing problem for pastoralist around the world and can lead to loss of vegetative cover and sedimentation of water points (Secretariat of the Convention on Biological Diversity 2010). To provide solutions to overgrazing, conservationists and land managers need to be able to identify areas which are either overgrazed or are likely to become so. This can lead to appropriate interventions such as planting vegetation or restricting use of the land. However
identifying areas of degradation on a large scale is challenging; one solution to this would be to use remote sensing tools such as NDVI. Therefore it is important that future research efforts are focused on this topic.

5.3. **Future Recommendations**

This study shows dramatic changes in water use with changing presence of human settlements and from the results, it is clear that this is an important issue for the Grevy’s zebra and should be a key area for future research efforts. Following on from this research, the main question to be answered is if these behavioural changes, especially in water use, have an effect on Grevy’s zebra fitness similar to those shown in Williams (1998). To study this, life history characteristics, such as survival and fertility of Grevy’s zebra should be compared for individuals in differing areas of human presence. If there is an effect on Grevy’s zebra fitness then a second important question to address is whether the underlying causes of these differences in water use is it due to active disturbance from humans, increasing presence of cattle, restricted access to water or another factor which has not yet been identified. From the results of this, more specific management options can be suggested.

Management options which could be considered include creating separate water points for use by wildlife or limiting times at which livestock can visit water points. However these two options may be controversial and cause more conflict between humans and wildlife especially as water is limiting and human perception of wildlife is somewhat negative in this area (Sundaresan et al. 2012). As settlements in the Samburu region are semi-nomadic, a further management option could be to advise local people on where to move in order to reduce to competition between wildlife and livestock. This approach has the possibility to benefit both humans and wildlife although it would require a great amount of research into how to determine where is best to move. Furthermore, as people are becoming increasing sedentary in this area (B. Low, pers. comm. 2013), this approach may also be problematic.

Further research could also include analysis of cattle and human movements at a finer scale. The same methods used here could be applied to human, cattle and other livestock movements within the same area. This would provide more conclusive evidence on the presence of competition as it will show overlap in habitat and resource use. Currently we only have one side to the story and cattle movement data has widely been ignored within the literature and so is a key area of study.
Another important research question in terms of the Grevy’s zebra is to determine if there are differences in behaviours from different classes of zebra. All the individuals in this study were female and previous studies have shown there is a behavioural difference between different classes of zebra (Sundaresan et al. 2007; Low et al. 2009; Williams 1998). Therefore it would be interesting to find out if there are similarities or differences between different classes of zebra with regards to both water use and DD. As the individual’s reproductive status throughout this study period was unknown, this factor was also omitted from analysis but could be included if the data on the reproductive status of individuals was collected. As female Grevy’s zebra are highly dependent on water during lactation (Rowen 1992), it is likely that they will respond differently to the presence of humans in contrast to non-lactating females.

Season and year were both included as factors in the models run to account for seasonal or annual differences in Grey’s zebra behaviour. Out of these variables, only year was significant in explaining the DD of Grevy’s zebra. As the study period only spanned two whole years, it is hard to make any assumptions based on these observations. Although wet and dry seasons were also included, the boundaries were defined as the typical monthly patterns for the area. A more accurate measure would be to use monthly rainfall for the area during the study period. Environments conditions, such as rainfall and temperature were not taken into account due to the lack of official meteorological data for the area but are factors which would be useful to include into future studies. Including this would also help to develop methods to predict behavioural changes in animals in response to future weather patterns. This would provide advance warning for conservationists about especially vulnerable groups, species or area and helping management options become proactive rather than responsive.

GPS collars have become increasingly popular in conservation by providing fine scale data on the movements of individuals; especially useful when species are elusive or hard to follow (Cagnacci et al. 2010). They remove the need for extensive periods of fieldwork by tracking day and night for long periods of time. Telemetry data was successfully used in this study to infer changes in behaviours of Grevy’s zebra in relation to aspects of their environment. Using field observations for a study such as this would have involved a huge amount of effort, time and resources to gather the same quality and quantity of data. The use of field staff would have also introduced human bias into the data as human presence was one of the factors being measured. In conclusion, although the high cost of GPS collars can be problematic, especially in small conservation organisations, they are a powerful tool which should be utilised to understand species behaviour, ecology, how they respond to their environment, and most importantly, to inform future conservation efforts.
6. REFERENCES


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APPENDIX A

Example of an abandoned (left) and an active (right) manyatta and their distinguishing features:

**ABANDONED:**
- No houses visible
- Outer fence deteriorated

**ACTIVE:**
- Houses visible
- Paths around manyatta
- Fences clearer
- Ground darker inside
APPENDIX B

Map of study site showing presence of manyattas and water points in the study area: