HABITAT USE AND ECOLOGICAL CARRYING CAPACITY FOR THE EASTERN BLACK RHINOCEROS (*Diceros bicornis michaeli*) IN RUMA NATIONAL PARK, KENYA

BY

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DECLARATION

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

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DEDICATION

I dedicate this work to my loving twin sister Lydia Achieng Oginah.

ABSTRACT

The population of black rhinoceros has declined in African range states since 1960s due to poaching and habitat loss. In Kenya the species population declined from an estimated 20,000 in 1970 to less than 500 animals by 1990. However, through increased security and translocation, Kenya has witnessed a modest increase in population of this critically endangered species. The current population size is 623. Kenya like other range countries conserves black rhinoceros sub-populations as a meta-population, which employs conservation translocation as its primary conservation tool. However, translocation is a complex process that requires knowledge of habitat suitability and carrying capacity for each reserve. Knowledge of carrying capacity is important in determining whether the current population of black rhinoceros in Ruma National Park is within the ecological carrying capacity. Furthermore, knowledge of both habitat and diet preference and how this differs between the sexes is crucial for determining the absence or presence of competition for ecological resources. Between 2011 and 2012 Kenya Wildlife Service re-introduced twenty-one black rhinoceros to Ruma National Park. However, habitat use and carrying capacity of black rhinoceros in the park has not been determined since their translocation. The general objective of this study was to investigate habitat use and ecological carrying capacity for the black rhinoceros population in Ruma National Park. The specific objectives of the study were to determine whether level of elevation, rockiness, shade, distance to fence, roads, and human settlements predict habitat use by black rhinoceros; determine differences in habitat and diet preference between female and male black rhinoceros; and to determine the ecological carrying capacity of black rhinoceros in Ruma National Park. Data on environmental and anthropogenic factors were collected in 30 sampling plots each measuring 20 m by 20 m and analyzed using binomial logistic regression. Indices of habitat preference were estimated separately for the sexes by dividing the total number of locations in all habitats by the total area of kernel home range. Difference in diet between the sexes was determined using Jaccard's coefficient. Carrying capacity was estimated using the habitat use method. The results of the study show, first, that none of the environmental and anthropogenic factors predict habitat use by black rhinoceros. Second, there was no significant difference in habitat preference between female and male black rhinoceros $U = 16.50$, $p = 0.306$. However, there was a 60 % dissimilarity in diet selection between the sexes. Third, Ruma National Park can sustain a maximum of 65 black rhinoceros. The results that suggest that there is available space for black rhinoceros population growth and that the current population is within ecological carrying capacity will be beneficial to Ruma Park management team in decision making and conservation planning for this critically endangered species. However, future conservation plans for black rhinoceros population in Ruma National Park should include reintroduction of more female black rhinoceros so as to address the male-biased sex ratio.

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LIST OF ABBEVIATIONS AND ACROYNMS

RNP: Ruma National Park

KWS: Kenya Wildlife Service

AFNP: Augrabies Falls National Park

LSV: Least square cross validation

DEFINITION OF TERMINOLOGIES

Anthropogenic factors: These are factors arising from human activities and include human settlements, roads and park boundary fence.

Diet: The range of food plants consumed by herbivores.

Ecological carrying capacity: The maximum number of black rhinoceros that can be sustainably supported by resources of Ruma National Park.

Environmental factors: Are factors in the rhinoceros surrounding. In this study, environmental factors were rockiness, shade, elevation and distance to water

Habitat: An area with a combination of resources (food, water) and environmental conditions (temperature, precipitation, presence of predators) that promotes occupancy by individuals of a given species (or population) and allows those individuals to survive and reproduce.

Habitat use: This is the way black rhinoceros use the physical and biological resources at the habitat which incorporates diet selection.

Habitat preference: This is a process where a species chooses to use one habitat component over another when both are equally available.

Habitat selection: The process by which animals choose a habitat component to use i.e., available resources or condition.

Habitat types: Used to mean vegetation types in Ruma National Park.

Shade: This was defined as diameter of the canopy that is ≥4 m and was thus operationalized as a resource available to animals during hot periods of the day.

Vegetation type: The classes of vegetation types in Ruma National Park based on the dominant plant species.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The Eastern black rhinoceros (*Diceros bicornis michaeli)* are considered critically endangered by the International Union for Conservation of Nature (IUCN, 2017). The species population and distribution has declined throughout its African range states since 1960s (Coeverden *et al*., 2011; Otiende *et al*., 2015) due to intensive poaching and habitat destruction (Buk & Knight, 2012). Conservation plans for several African countries specify the need to establish new breeding populations and increase meta-population growth rates of the species, as many populations' growth rates are slowing down due to high densities of rhinoceros (Morgan, Mackey, & Slotow, 2009).

In Kenya, increased security and translocation enabled recovery of the population to a total of 623 black rhinoceros by the end of 2011 from less than 500 individual in 1990s (KWS, 2012). Translocation has received considerable attention and still remains a powerful tool in conservation of endangered species (Ebrahimi, Ebrahimie, & Bull, 2015). To control poaching and recover the species population from decline, surviving black rhinoceros are translocated into high security sanctuaries (Muya, Bruford, Osiemo, Mwachiro, & Goossens, 2011). Subsequently, new sanctuaries have been established forming meta-population. For instance Kenya Wildlife service (KWS) re-introduced twenty-one individuals of the free-ranging population from Mugie Ranch and Solio Game Reserve to Ruma National Park (RNP) between December 2011 and January 2012, (KWS, 2012).

A part from re-introduction of species into their historical ranges, translocation has been used to solve human–wildlife conflict and reduce overexploitation at the source site (Pinter-wollman, Isbell, & Hart, 2009). Besides these functions of translocation, translocation has been associated with the following challenges: tendency of translocated animals to return back to the site of capture (Villasenor, Escobar, & Estades, 2013), demographic stochasticity, and inbreeding (Cain *et al*., 2014; Greaver, Ferreira, & Slotow, 2014). Furthermore, translocation yields mixed results for species recovery when management plan fail to account for the interaction between translocated individuals and the environment (IUCN/SSC, 2013).

Several factors constrain or promote black rhinoceros occupancy of an area (Buk & Knight, 2012; Morgan *et al*., 2009). The species avoids areas closer to roads, rockiness, human presence and higher slopes that could cause injury (Graham, Adams, Douglas-Hamilton, & Lee, 2009). The species visits water points at night, moves faster and spends less time in highly fragmented landscape to minimize contact with humans (Graham *et al*., 2009; Ochieng, 2015). However, black rhinoceros prefer areas with shade, closer to water points, (Buk & Knight, 2012) and nutritionally important geo-elements (Augustine, McNaughton & Frank, 2003; Ayotte, 2004; Baptista, Pinto, Freitas, Cruz, & Palmeirim, 2012).

Factors that ‘pull’ animals result in aggregation of animals in relatively small spaces ultimately leading to con-specific competition for ecological resources and increases opportunities for disease transmission (Mccallum & Dobson, 2002). On the other hand factors that constrain habitat availability, which for the most part derive from edge effects due to roads and park boundary may results in habitat degradation and may thus limit sustainable conservation of a given species in a given area. Although a number of studies have shown that slope, rockiness, distance to water, roads, boundary fences, and human presence influence distribution and movement of black rhinoceros (Buk & Knight, 2012; Graham *et al*., 2009; Lush, Mulama, &

Jones, 2015; Morgan *et al*., 2009; Ochieng, 2015). However, whether these factors predict habitat use by black rhinoceros in Ruma National Park still remains unknown.

Generally, black rhinoceros has a broad range of plant diet (Oloo, Brett, & Young, 1994). The species prefers habitats dominated by *Spirostachys africana*, *Acacia*, *Croton dichogamus* as well as plants in the family's *Euphobiacea*, *Acanthaceae*, *Papilionacea*, *Compositae*, *Mimosaceae*, *Verbenaceae*, *Anacardiaceae* and *Rhamnaceae* (Oloo *et al*., 1994). However, the species selectively browses on plants with low phenol and alkaloid and high fibers (Muya & Oguge, 2000). Black rhinoceros have been shown to select patches within the landscape with highly preferred forage but not with abundance of browsable species (Buk & Knight, 2012; Buk &Knight, 2010; Morgan *et al*., 2009). Black rhinoceros is a selective browser, whose habitat use is influenced by factors such as browse availability, density of vegetation, (Lush *et al*., 2015). Black rhinoceros browse can be identified from other species browse by a characteristic prune at 45^0 they made on plant stems and they also feed on plants within 2 m high (Hutchins & Kreger, 2006).

The species prefers open woodlands and closed shrub-lands more than closed woodland habitat, which reduces browse accessibility (Lush *et al*., 2015). Forage selection hypothesis proposes that male and female differ in diet due to different nutritional and energy requirements. Males opt for abundance forage and food plants that are rich in fibers than females. However, reproducing females have higher energy requirements due to gestation and lactation; hence they select higher quality food plants rich in nitrogen, sodium, or calcium (Ruckstuhl & Neuhaus, 2000).

Niche partitioning at the diet level is important for species survival (Griffin & Silliman, 2011). This is because by consuming same or different resources, individuals of different species compete less with one another (interspecific competition) than individuals of the same species (intraspecific competition). Species therefore limit their own population growth more than they can limit the growth of sympatric competitors. Therefore resource partitioning acts to promote long-term coexistence of competing species (Griffin & Silliman, 2011). Taken together, the two sexes prefer different habitat types and or diets deriving in part from inherent sex differences in nutrition and energetic needs (Ruckstuhl & Neuhaus, 2000). However, whether male and female black rhinoceros in Ruma National Park differ in habitat and diet preferences is not known.

Factors or processes that influence habitat use together influence the carrying capacity of a given conservation area (Tregenza, 1995). Carrying capacity per unit area is inversely proportional to body size of species as does home-range size due to individual energy demand such that larger animals require more food and thus a larger area to forage (Braithwaite, Meeuwig, & Jenner, 2012). Furthermore, carrying capacity is related to the total amount of resource each individual needs (Braithwaite *et al*., 2012). Consequently, the number of individuals in an area increases up to a point beyond which growth in population is limited by resource availability (Amin *et al*., 2006).

According to McLeod (1997), carrying capacity is not a measurement of long–term equilibrium density but of short-term potential density as a function of resource availability. However, Amin *et al*. (2006), demonstrated that maximum sustainable yield (MSY) commonly called maximum productivity carrying capacity (MPCC) is an estimate of long term ecological carrying capacity. Nonetheless, according to Lush *et al*. (2015); Steenweg, Hebblewhite, Gummer, Low, and Hunt, (2016), browse availability and distribution of vegetation particularly that of preferred browse are important in assessing carrying capacity.

According to the Kenya Wildlife Service the aim of the current conservation strategy for the critically endangered black rhinoceros is to repopulate vacant reserves, such that each reserve is treated as a patch within a meta-population (KWS, 2012). Nevertheless, in order to achieve and maintain a high meta-population growth rate, areas that maintain rhinoceros populations are not to be overstocked relative to available habitat resources (Amin *et al*., 2006). However, the ecological carrying capacity of black rhinoceros in Ruma National Park is not known and therefore how the park fits in with the country's meta-population strategy is not clear.

1.2 Statement of research problem

Environmental factors such as slope, rockiness, distance to water points, protected area fences, and anthropogenic factors such as human settlements and roads are the primary determinants of large scale distribution of wildlife. Moreover, these factors may either promote or constrain habitat use. However, whether these factors constrain or promote habitat use by black rhinoceros in Ruma National Park is not known yet how different anthropogenic and environmental factors predict habitat use is important in assessing RNP suitability. In addition, whether female and male black rhinoceros differ in habitat and diet preference remains unknown yet such differences point to whether there is presence or absence of competition for browse between the sexes. Lastly, the maximum number of black rhinoceros the park can support is not known and so it is not clear whether the number of animals that was reintroduced exceeds or is below the park's carrying capacity. These three major gaps in knowledge make it difficult to carry out evidence-based conservation action plan for the black rhinoceros in Ruma National Park. Thus the aim of the proposed study was to investigate habitat use and carrying capacity for the black rhinoceros population in Ruma National Park.

1.3 Justification of the study

Black rhinoceros is a critically endangered herbivore that contributes to the biodiversity of wildlife populations in Kenya and a major source of tourist attraction that earns the country foreign exchange. Therefore, concerted effort must be employed to prevent this animal species from extinction. First, systematic feasibility and risk assessment was not done prior to the species re-introduction and therefore it still remains to be determined how suitable Ruma National Park is for the sustainable conservation of the species. Second, the absence or presence of competition for ecological resources e.g. food is relevance in determining the sustainability of RNP. Third, whether the current population of black rhinoceros in RNP is within or above the ecological carrying capacity is timely towards efforts to conserve the critically endangered black rhinoceros and the sustainability of the park.

1.4 Significance of the study

Empirical data on habitat use by the critically endangered black rhinoceros will inform the Ruma Park Management on how distance to different environmental and anthropogenic factors predicts habitat use by the species. Furthermore, habitat use empirical data will inform the translocation success since one of the primary factors in assessing the success of a re-introduction is the survival of the release stock and their ability to disperse throughout the release area and utilize their habitat. In addition, empirical data on difference in habitat and diet between the sexes will inform Ruma Park Management on the presence or absence of competition for ecological resources such as food and space between male and female black rhinoceros. Also empirical data on carrying capacity will potentially inform the Ruma Park Management on the maximum number of individuals the park can support sustainably. In summary, empirical data on habitat use and carrying capacity will be beneficial to Ruma National Park management, Rhino Programme and Kenya Wildlife Service in decision making, conservation planning for this critically endangered species and the meta-population management.

1.3 Study objectives

1.3.1 General objective

To investigate habitat use and ecological carrying capacity for the black rhinoceros population in Ruma National Park

1.3.2 Specific objectives

1. To determine the influence of rockiness, shade, elevation, human settlement, distance to the park boundary fence, roads, and distance to water points on habitat use by black rhinoceros in Ruma National Park.
2. To determine differences in habitat and diet preferences between male and female black rhinoceros in Ruma National Park.
3. To determine the ecological carrying capacity of black rhinoceros in Ruma National Park.

1.3.3 Research hypotheses and question

1. Rockiness, shade, elevation, human settlement, park boundary fence, roads, and distance to water points do not influence habitat use by black rhinoceros in Ruma National Park.
2. There is no difference in habitat and diet preference between male and female black rhinoceros in Ruma National Park.
3. What is the ecological carrying capacity of black rhinoceros in Ruma National Park?

CHAPTER TWO

LITERATURE REVIEW

2.1 Causes of world-wide species endangerment

World-wide species endangerment arises from overexploitation, climate change, pollution, invasive species, loss of genetic variation, and habitat loss (Hilton-taylor & Stuart, 2008). A loss of habitat can happen naturally but in most cases human activities such as deforestation contributes extensively to global habitat destruction (Coeverden *et al*., 2011; Walpole, Morgan-Davies, Milledge, Bett, & Leader-Williams, 2000). In Africa, mega-herbivores such as elephants and black rhinoceros endangerment are attributed to habitat loss and poaching (Buk & Knight, 2012).

2.2 Global trends in black rhinoceros population

The population and range distribution of black rhinoceros (*Diceros bicornis*) has declined in the African range since 1960s (Otiende *et al*., 2015; Coeverden *et al*., 2011) as a result of illegal killing to supply international trade and habitat destruction (Coeverden *et al*., 2011; Walpole *et al*., 2001). In addition, other factors that have contributed to decline in population of rhinoceros in the wild include ecological resource depletion and decrease in both survival and reproductive rates (Greaver *et al*., 2014). Furthermore, (Reid *et al*., 2007) links the decline in black rhinoceros population to negative habitat changes and reduction in carrying capacity of most conservation areas.

Kenya`s black rhinoceros population declined by more than 98% between 1970s and 1990s from 20,000 to less than 500 individuals in 1990 (Ryan, Flamand, & Harley, 1994). However, a report by the Kenya Wildlife Service showed that Kenya's black rhinoceros population has increased to approximately 623 animals (KWS, 2012). Conservation strategies employed in halting decline in black rhinoceros in Kenya include increased safety and extensive translocation of individuals, from areas of low rhinoceros density and from unprotected areas to those with heightened security (Oloo *et al*., 1994).

2.3 Conservation action plan for black rhinoceros

Kenya like most African range states has adapted translocation has a management tool such that the government aims at managing the country's black rhinoceros population as a meta-population (Okita-Ouma, Amin, van Langevelde, & Leader-Williams, 2009). Translocation has also been used to solve human-wildlife conflict and to introduce species outside its home range (Villasenor, Escobar, & Estades, 2013). Moreover, translocation has been used to reduce overexploitation at the source site, and for re-introducing animals that have become either globally or locally extinct in the wild to their historical ranges (Pinter-wollman *et al*., 2009).

Despite its popularity, wildlife translocations face several challenges. A common source of failure in wildlife translocations is the tendency of the animal to return to the site of capture (Villasenor *et al*., 2013). The tendency to return also referred to as homing has been reported in several taxa including mammals and reptiles. In addition, translocating a small population leads to reduced heterozygosity which affects population viability (Greaver *et al*., 2014). In addition, lower genetic variation depresses individual fitness, resistance to disease and parasites (Lacy, 1997) and is also vulnerable to demographic stochasticity and catastrophes (Cain *et al*., 2014).

However, before translocation is carried out, pre-translocation assessment is recommended (IUCN/SSC, 2013). Pre-translocation assessment focuses on both ecological surveys of the habitat (presence of competitors species, population density), security, epidemiological data, genetic consideration and climate requirements (IUCN/SSC, 2013). This is because it is important to ensure that there is adequate food and water as well as security at the release site (Lekolool, 2012). Furthermore, because habitat varies over space and time and that species' ranges also changes, it is essential to evaluate the current suitability of habitat in a proposed destination area (Emslie, 2012). However, a systematic feasibility and risk assessment study was not done prior to the re-introduction of black rhinoceros in Ruma National Park.

2.4 Factors influencing habitat use and distribution of black rhinoceros

2. 4.1 Environmental factors

Habitat selection and occupancy by black rhinoceros depends on environmental factors such as slope, rockiness, and distance to water points, availability of food and shade (Buk & Knight, 2012; Lush *et al*., 2015). These factors influence black rhinoceros movement, establishment of home ranges, resource selection, and social structure (Odendaal-Holmes, Marshal, & Parrini, 2014). Consequently, the impacts of these environmental factors are more pronounced in smaller reserve than larger reserves (Odendaal-Holmes *et al*., 2014).

It has been noted, for instance, that areas located on steep slopes receive less use by mega-herbivores (Bailey *et al*., 1996). For example elephants use higher elevations in dry seasons due to high abundance of high quality forage but avoid the same in the wet season as they become slippery thus risk of injury (Ochieng, 2015). In addition, slope avoidance could be explained by lack of water and because such areas are associated with high energy demands (Wall, Douglas-Hamilton, & Vollrath, 2006). Energy requirement and expenditure is one of the main factors why mega-herbivores avoid areas with high elevation (Wall *et al*., 2006). However, slope is a less significant factor in flatter reserves where species movement is not as energy expensive as it is on slopes (Buk & Knight, 2012; Odendaal-Holmes *et al.*, 2014). Consequently, selection of higher altitudes may be associated with other factors that limit availability of more conducive areas of a given conservation area.

Black rhinoceros like most ungulates use a variety of mechanisms to cope with challenging environmental conditions such as heat stress and dehydration (Cain, Jansen, Wilson, & Krausman, 2008). Site characteristics such as presence of shade affects where animals rest and browse (Bailey *et al*., 1996). The species seek shade under dense canopies and restricts high energy activities to conducive times of the day so as to maintain body heat and water budget in a hot dry climate (Buk & Knight, 2012; Cain *et al*., 2008). Normally the species is found wallowing in mud (Hutchins & Kreger, 2006) or under shade to avoid heat of midday (Buk & Knight, 2012).

Water points can either promote or constrain black rhinoceros occupancy of an area (Ballard, Devos, & Rosenstock, 1999). According to Odendaal-Holmes *et al*. (2014) concentration of other animals around water points constrains occupancy of such areas by black rhinoceros. Besides, water points are important areas for game-spotting which is a potential anthropogenic disturbance to wildlife by tourists. Furthermore, zones around water points are associated with poor quality or absent of resources as a result of vegetation removal, which ultimately leads to soil erosion (Strauch, Kapust, & Jost, 2009).

With regards to food availability, black rhinoceros shows preference for vegetation types dominated by *Spirostachys africana*, *Acacia nilotica*, *A. karoo*, *A. brevispica* and *Dichrostachys cinerea* (Reid *et al*., 2007; Muya & Oguge, 2000) and *Euclea divinorum* (Lush *et al*., 2015). Black rhinoceros also browse on *Grewia similis* and *Hibiscus fuscus*, thicket of mainly *Croton* *dichogamus*, as well as plants in the family *Euphobiacea*, *Acanthaceae*, *Papilionaceae*, *Compositae, Mimosaceae*, *Verbenaceae*, *Anacardiaceae* and *Rhamnaceae* (Oloo *et al*., 1994; Walpole *et al*., 2000).

Furthermore, black rhinoceros prefer landscapes with sufficient browse for forage and shade (Odendaal-Holmes *et al*., 2014). This includes recently burnt forage, which enhances regrowth of green forage biomass and reduces dead biomass (Coppedge & Shaw, 1998). The species preferences for burnt forage rather than mature forage is because fresh browse are more palatable and digestible (Coppedge & Shaw, 1998). According to Allred, Fuhlendorf, Engle, & Elmore, (2011), continual preference for burned areas is due to nutritional content in post fire regrowth. Ungulates primarily select recently burnt patches because they contain lowest amount of biomass but highest amount of proteins (Allred *et al*., 2011). Additionally, as plant biomass increases, quality and digestibility decline causing species to select recently burnt forage (Allred *et al*., 2011).

Apart from the preference for burnt forage, abundant vegetation cover also influence the distribution of black rhinoceros (Reid *et al*., 2007). For instance, high density of black rhinoceros in Ndumu National Park, South Africa is associated with high vegetation cover (Conway & Goodman, 1989). Furthermore, competition from other mega herbivore such as elephants, affects habitat selection by rhinoceros such that rhinoceros have been shown to avoid areas with such sympatric competitors (Lush *et al*., 2015).

A number of studies have demonstrated change in habitat use and spatial distribution of ungulates, in response to water availability as reviewed in (Rosenstock *et al*., 1999). This contradict Reid *et al*. (2007); Buk & Knight, 2012), who demonstrated that availability of water, does not influence the home range of black rhinoceros. The species drink water once after every 24 to 48 hours, but the frequency is less when they are feeding on succulent plants because of higher content of water from their forage (Carrera *et al*., 2015; Buk & Knight, 2012; Odendaal-Holmes *et al*., 2014). However, black rhinoceros need water to remain cool, especially during hot times of the day (Ballard *et al*., 1999). With regards to environmental factors, it is expected that black rhinoceros should use habitat that are less rocky, low elevation, closer to water points and highly shaded (Buk & Knight, 2012; Odendaal-Holmes *et al*., 2014). It can be expected that if these environmental factors do predict habitat use by black rhinoceros then they potentially would have repercussions on sustainable conservation in the park (Odendaal-Holmes *et al*., 2014). However, it remains to be determined whether these environmental factors predict habitat use of black rhinoceros in Ruma National Park.

2.4.2 Anthropogenic factors

Anthropogenic factors such as human settlement, protected area fences and roads constrain distribution of black rhinoceros, especially in areas where their range overlap with that of humans (Graham *et al*., 2009; Ochieng, 2015). Fences make expansion of range impossible (Steenweg *et al*., 2016). Black rhinoceros avoids areas close to roads where tourist activities negatively have impacts on their habitat and home ranges (Odendaal-Holmes *et al*., 2014). Black rhinoceros, like other animals develop survival mechanisms to co-exist with humans by altering their behavior accordingly (Graham *et al*., 2009). For example visiting water points at night, moving faster and spending less time in highly fragmented landscape to minimize contact with humans (Graham *et al*., 2009).

In the context of habitat suitability, it is expected that black rhinoceros should range in areas away from human disturbances such as human settlements, roads and boundary fence (Odendaal-Holmes *et al*., 2014). It can be argued that if human disturbances constrain habitat use by black rhinoceros then the area of RNP available for black rhinoceros and other animals would be much smaller than the actual area of 126 km^2 of the park (Odendaal-Holmes *et al*., 2014). Conversely, if distance to human disturbances does not predict habitat use by black rhinoceros then it may indicate low human population density and activities around the park and presence of other factors that may predict habitat use such as snaring and poaching. However, whether these anthropogenic factors predict habitat use by black rhinoceros in Ruma National Park is not known.

2.5 Habitat and diet preference

Ungulates' selection of productive patches within the landscape is related to both energy level and nutrient-related aspects of the forage quality (Augustine *et al*., 2003). The Optimal Foraging Theory predictions (OFT) often shows that large herbivores aim to maximize intake of energy or protein, while minimizing energetic and temporal costs of ecological resource search (Ceacero *et al*., 2015). Rhinoceros prefer open woodland and closed shrubs habitat (Lush *et al*., 2015), this contradicts Tatman, Stevens-wood, & Smith (2000), who found that rhinoceros avoid open woodlands since open woodlands allows for trees to grow taller, making browse inaccessible by rhinoceros (Lush *et al*., 2015). From the contradiction, black rhinoceros preference for open woodlands is because it can support understory of shrubs and herbaceous plants which they forage on. At the same time closed woodlands cast shade that protects the species from direct sun light.

Habitat selection by black rhinoceros results in changes in size of home ranges particularly between the dry and wet seasons (Buk & Knight, 2010). Proportion of rhinoceros home ranges being utilized is considerably greater during wet seasons, because of larger variety of palatable plants (Lush *et al*., 2015). However, the species concentrates seasonally around water sources or riparian zones, where woody vegetation maintains green foliage for longer into dry season (Odendaal-Holmes *et al*., 2014). According to Oloo *et al.* (1994), the species feed less on each plant in dry season than in wet season. This reduction in feeding during dry season is due to decreased palatability of food plants, resulting in part from wilting of leaves (Buk & Knight, 2010). Consequently, black rhinoceros travel further per day in dry season than in wet season in search of succulents used as hot-season water sources (Buk & Knight, 2010).

When translocation of endangered species occurs into small areas, mortality risks can be minimized by understanding patterns of intraspecific and interspecific interaction (Landman, Schoeman, & Kerley, 2013). Female black rhinoceros have been shown to have a high post-release mortality than male rhinoceros due to intersexual resource conflict (Landman *et al*., 2013). In the context of translocation and to the extent that both male and female black rhinoceros have different nutritional and energetic needs (Ruckstuhl & Neuhaus, 2000), it is expected that sexes should prefer different habitat types. It can be argued that such differences in habitat preference may also indicate whether a translocated population has settled at the release site. However, the absence of discernable differences in habitat preferences may be interpreted either as the presence of homogenous habitat types with limited choices or of the presence of factors that constrain habitat use by a translocated population. Potential factors that may constrain habitat selection by a translocated population include risks associated with edge effects in the form of park boundary and roads as well as other environmental factors such as rockiness, shade, water availability and level of elevation (Buk & Knight, 2012; Lush *et al*., 2015). Alternatively, translocation success can be interpreted using socio-ecological model, which postulates that female black rhinoceros selects habitat with available ecological resource while male black rhinoceros selection of habitat is predicted by the distribution of females (Genin & Masters, 2018).

Black rhinoceros have a broad range of plant diet (Oloo *et al*., 1994) such as twigs, woody shrubs, small trees, legumes and grass in various habitats that ranges from deserts to grasslands, both tropical and subtropical (Hutchins & Kreger, 2006). Availability of particular food plants affects black rhinoceros movement and distribution in a given habitat (Morgan *et al*., 2009; Oloo *et al*., 1994). For example a study in Ol Ari Nyiro, Laikipia, Kenya, showed that scattered *Euphorbia candelabrum* trees are highly preferred by black rhinoceros (Oloo *et al*., 1994). Two hypotheses explain patterns of food selection by herbivores. Herbivores select food in order to acquire adequate balance of nutrients (Winkel, 2004). Another hypothesis is that herbivores select forage in order to avoid plant secondary compounds, which are toxic (Winkel, 2004).

Black rhinoceros selectively browse on plants with low phenol and alkaloid contents and high fibers (Muya & Oguge, 2000). Avoidance of food plants by herbivores with high secondary metabolites is because of their toxicity, these metabolites reduce the digestive process in herbivores by inhibiting enzyme cellulase from functioning (Muya & Oguge, 2000). For example, black rhinoceros were observed to completely reject several plant species including *Pentzia incana*, *Elytropappus rhinocerotis*, *Eriocephalus ericoides* and *Tarchonanthus camphorathus* due to the presence of terpenes or phenols with antibacterial properties (Buk & Knight, 2010).

At the individual level it is expected that the sexes should prefer different browse because of differences in energy and nutritional requirements (Ruckstuhl & Neuhaus, 2000). This difference in diet selection is important in order to avoid competition for browse between the sexes. The absence of difference in diet preference between the sexes may be interpreted as presence of intersexual competition for food which might result into risks (Griffin & Silliman, 2011). However, whether male and female black rhinoceros differ in habitat and diet preference in Ruma National Park is not known.

2.6 Habitat availability and carrying capacity

The population size that a given habitat can support is important for conservation of an endangered species (Aryal, Brunton, Weihong, & Raubenheimer, 2014). This is more so the case for the meta-population strategy adapted by the Kenya Wildlife Service to conserve black rhinoceros in the country. Carrying capacity is often estimated based on available forage and energetic requirements of individuals (Steenweg *et al*., 2016; Braithwaite *et al*., 2012). Furthermore, Steenweg *et al*. (2016) defined ecological carrying capacity (K) as the nutritional-based number of animals that can be sustained with zero population growth.

Ecological space, which is a species home range is related to availability of ecological resources that limit species density (Braithwaite *et al*., 2012). Species density in an area is primarily determined by preferred browse availability, habitat heterogeneity, slope and water (Hansen, Phillips, Flather, & Robison-cox, 2011). However, common use of range does not alter species diet preference because foraging is proportional to herbivore density (McLeod, 1997).

Generally, decline in habitat quality results in larger home ranges (Reid *et al*., 2007), because of the need to range wider to meet resource needs (Reid *et al*., 2007). There is a proportional relationship between time large herbivore spends in a habitat and the quantity and quality of available forage (Bailey *et al*., 1996). This proportional relationship has been observed in several species such as bison, cattle, feral horses, mule and deer. However, animals released into a new area explore the new environment as they look for favorable patches and respond to the presence of other animals in the same environment (Odendaal-Holmes *et al*., 2014). Therefore, their home ranges and resource use areas are expected to change as they habituate in the new environment (Odendaal-Holmes *et al*., 2014). If there is home range overlap between male and female black rhinoceros then it can be argued that they use same habitat hence no difference in habitat preference. But if there is no home range overlap between the sexes then it implies that they use different habitat hence differences in habitat preference between the sexes (Hutchins & Kreger, 2006).

Rapidly breeding healthy population provide an insurance against future poaching, preserve genetic diversity by ensuring maximum rate of gene transfer to the next generation (KWS, 2012). Black rhinoceros population growth has increased in most sanctuaries necessitating translocation to avoid density dependence effects (KWS, 2012). However, most of the established sanctuaries remain overstocked (KWS, 2012). In Kenya, the KWS's objective is to maintain rhinoceros population below the ecological carrying capacity of a reserve in order to increase reproduction in the donor population as well as the translocation of animals to create new populations with potential for rapid growth (Amin *et al*., 2006).

Simulation models and population models have been used to determine carrying capacity of species. These models cannot take into account large variations in habitat selection among individuals, making them a flawed approach in understanding habitat selection (Morgan *et al*., 2009). The assumption when using habitat selection approach to estimate ecological carrying capacity is that individual's selects habitat with available key resources and there is ideal free distribution of animals (Morgan *et al*., 2009). Previous prediction of carrying capacity have been based on species habitat use (Steenweg *et al*., 2016), productivity and quality of browse (Amin *et al*., 2006), how species use available space (Braithwaite *et al*., 2012) and the use of absolute density of animals per unit area (Okita-Ouma *et al*., 2009). All these approaches do not take into consideration the habitat preferred by the species.

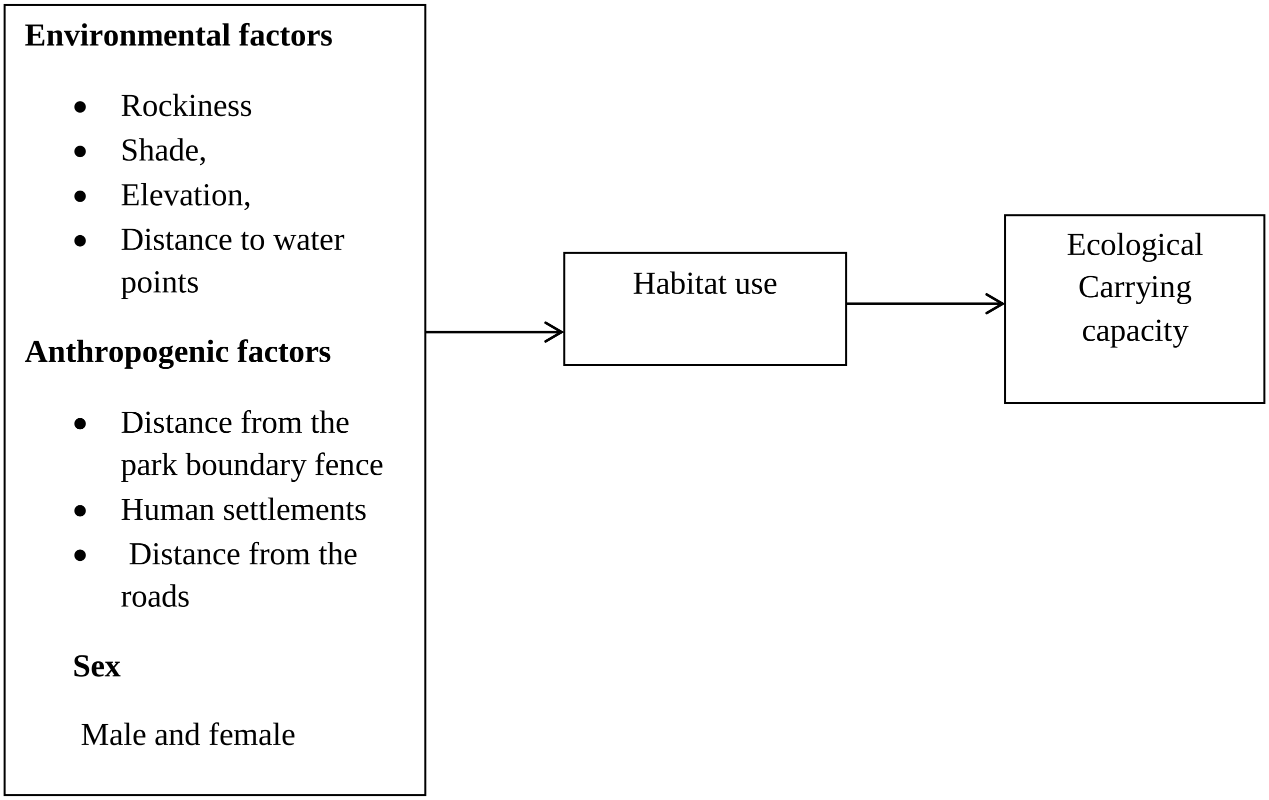
Sex ratio of 1:1 or bias towards the females is recommended at the time of translocation (Waweru, 1991) and in already established rhinoceros population. This is important especially in establishing a breeding population and for the recovery of population of a critically endangered black rhinoceros because adult sex ratio with more females increases reproductive potentials. However, adult sex ratio with more males reduces the population growth rate and levels of genetic heterozygosity and this can result in injuries and death to reproductive age females as well as other males (Okita-Ouma *et al*., 2009; Hutchins & Kreger, 2006). A apart from skewed sex ratio in favor of females, high breeding success of black rhinoceros can be achieved by increasing contact between opposite sexes especially during oesterus, high food availability and enhanced security against poachers (Waweru, 1991).

For most of large mammals such as rhinoceros maximum sustainable yield commonly called maximum productivity carrying capacity is 75% of the estimated long term ecological carrying capacity (Amin *et al*., 2006). Management of population at or below 75% of ecological carrying capacity minimizes the risk of density-dependent effects (Amin *et al*., 2006). However, upon translocation of species, population size grows with increasing pressure on the vegetation until a point of equilibrium is reached between herbivore number and forage resources.

As reviewed by Okita-Ouma *et al*. (2009), ECC varies from one protected area to another. For example Ol Pajeta conservancy can support 120 rhinoceros and it measures 365 km^2, Meru National Park 39 individuals and it measures 74 km^2, and Ngulia Rhino Sanctuary 90 individuals and it measures 92 km^2. This variation largely depends on availability of ecological resources and the size of a protected area (Okita-Ouma *et al*., 2009). Nevertheless, it is not known the ecological carrying of black rhinoceros in Ruma National Park.

In the context of RNP, it is predicted that the park has capacity to allow for black rhinoceros population growth. If the estimated carrying capacity is below the number of black rhinoceros that was translocated then it can be argued that RNP cannot sustain the reintroduced species and future population growth. However if the estimated carrying capacity is above the number that was translocated then RNP can sustain the reintroduced black rhinoceros and future population growth.

2.7 Conceptual frame work



CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site: Ruma National Park

Ruma National Park is located to the southern shores of Lake Victoria in Homa Bay County between 0^0 33′-0^0 44′ S, and 34^0 10′-34^0 22′ E, about 23 km south- west of Homa Bay Town and 425 km west of Nairobi (Figure 3.1). The park lies at the bottom of Lambwe Valley between the Kanyamwa Escarpment and Gwasi Hill. The park experiences bimodal rainfall annually with peaks between March and May and between October and December with annual rainfall of between 1200 mm-1600 mm. The climate is warm and humid and is classified as sub-humid to semi-arid. The park covers an area of 126 km^2 and it is dominated by seven vegetation types: *Combretum* grassland association, *Balanites* grassland association, *Acacia* grassland associations, *Acacia* woodland, dense continuous thicket, isolated thicket clumps and grassland. All roads in RNP are seasonal roads and the park is almost completely isolated from its former surrounding by the fence and dense human settlement (Kimanzi, 2011). The park is drained by Lambwe River which flows across the park into Lake Victoria and there are also water springs in Kanyamwa escarpments where a number of seasonal streams originates (Kimanzi, 2011). The park is rich in wildlife species such as the Roan antelope (*Hippotragus equinus*) which is endemic to park , Rothschild giraffe (*Giraffa camelopardalis Rothschildi*), Jackson's hartebeest (*Alcelaphus bucelaphus jacksonii*), Impala (*Aepyceros melampus*), cape buffalo (*Syncerus caffer*), spotted hyaena (*Crocutta crocutta*), leopard (*Panthera pardus*) bush pig (*Potamochoereus porcus*), olive baboon (*Papio Anubis Nenmmani*)and the vervet monkey (*Cercopithecus aethiops Johnstoni*), bush buck (*Tragelaphus scriptus*), white rhinoceros

(*Ceratotherium simum simum*) and black rhinoceros (*Diceros bicornis michaeli*) which was re-introduced between 2011 and 2012 (Njoka, Muriuki, Reid, & Nyariki, 2003).

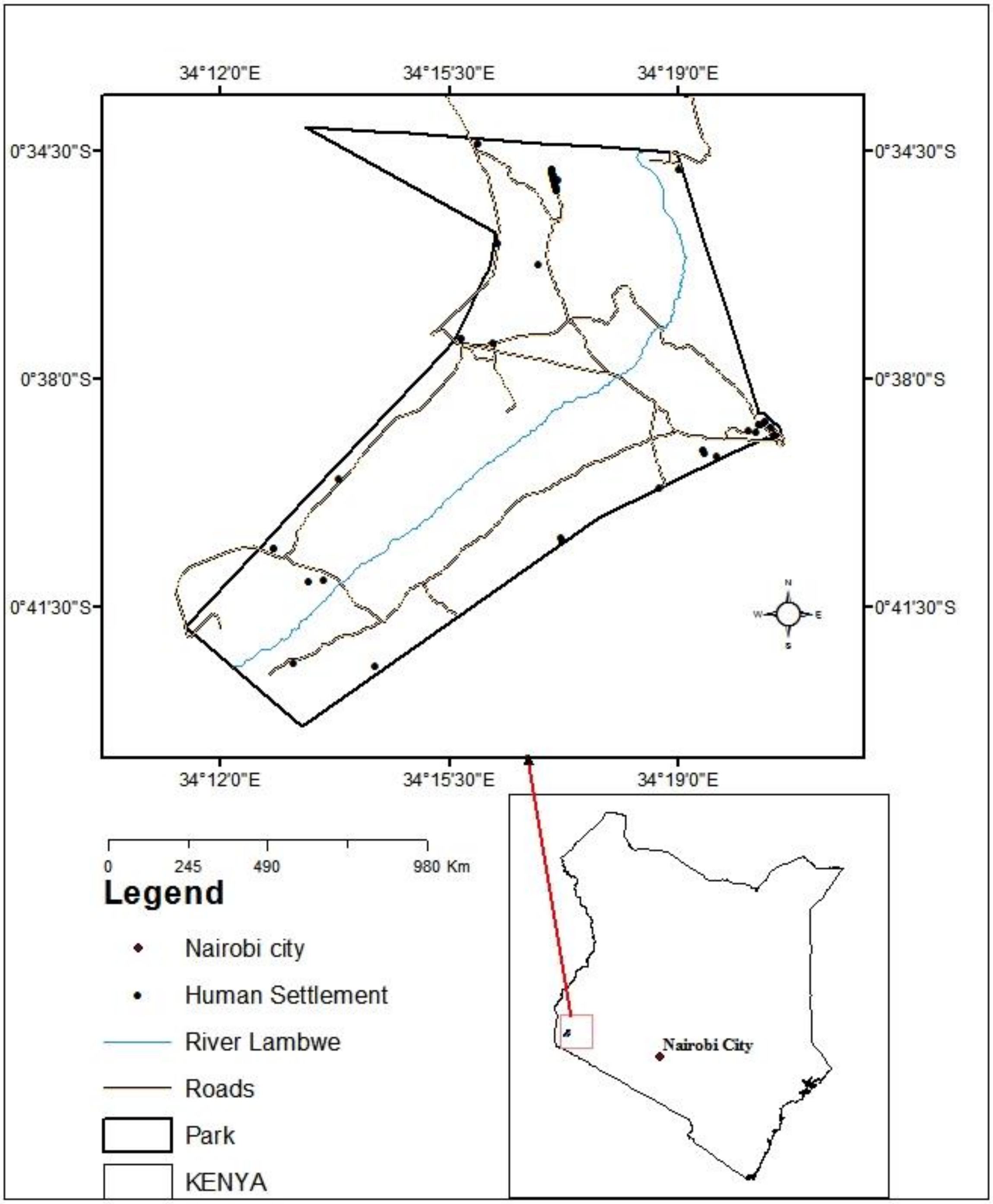


Figure 3.1 Map of Kenya showing the location of Ruma National Park

3.2 Study species

Black rhinoceros, the focus of the present study, is a critically endangered species with a population of 4880 in Africa (Emslie, 2012) and approximately 623 in Kenya (KWS, 2012) Appendix 3.1. The species is primarily a browser and feeds on plant items such as twigs, woody shrubs, small trees, and legumes within 2 m high with a characteristic prune of 45^0 (Hutchins & Kreger, 2006). Currently the total number of black rhinoceros in RNP is 19 (eight adult male, one sub adult male, five adult females, one sub adult female and four juveniles). Proposed definitions of biological life stages for demography of black rhinoceros used include: Calf from birth to separation from the mother, sub adult from ceasing to be a calf until becoming an adult, female adult; female rhinoceros age seven years and above and adult male; male black rhinoceros age eight years and above.

3.3 Data Collection

3.3.1 Sampling plot determination

Using vector grid method in Qgis, thirty sampling plots were established on a map Ruma National Park as shown in Figure 3.2. The sampling points were marked 1 km apart both vertically and horizontally across the map to ensure that the plots were spatially independent. A Global Positioning System (Garmin etrex 30) was used to navigate to each sampling point and a 20 m × 20 m square sampling plot was marked out from the centre of each sampling point using a tape measure and its boundary set using polyethylene string.

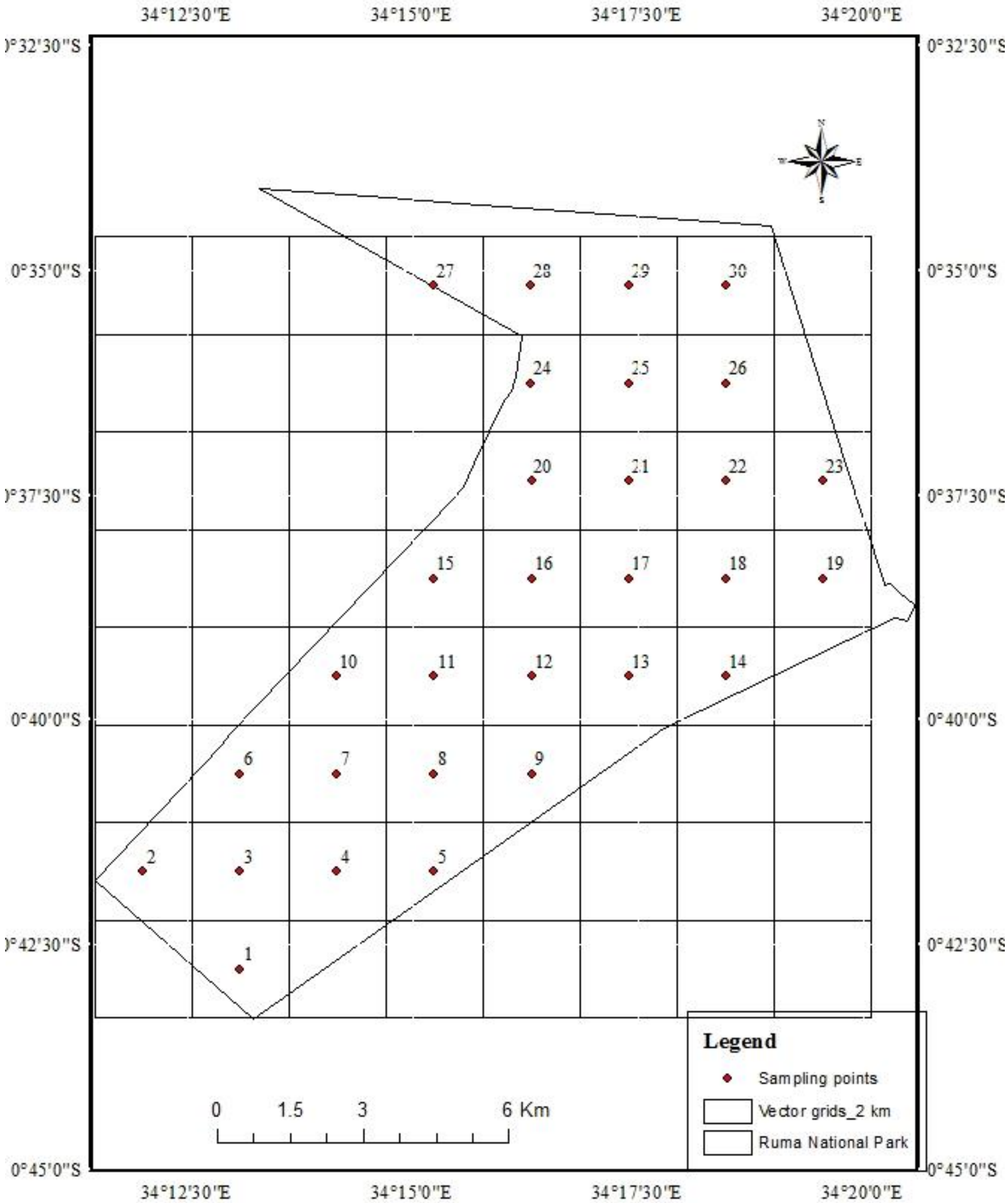


Figure 3.2 Map showing all sampling locations in the study area. Numbers indicate sampling identity for each sampling plot

3.4 Vegetation mapping and identification of habitat types

Cloud free Sentinel 2A Images were downloaded from Copernicus Science Data hub (https://sentinel.esa.int/web/sentinel/sentinel-data-access). QGIS 2.10 was used for map layout and Semi-Automatic Classification Plugin for digital image processing (Nguyen *et al*., 201) Table 3.1.

Table 3.1 Different spatial resolution bands and their respective colors

Band types	Spatial resolution (m)	Color
Band 2	10	Blue
Band 3	10	Green
Band 4	10	Red
Band 5	20	Vegetation Red Edge
Band 6	20	Vegetation Red Edge
Band 7	20	Vegetation Red Edge
Band 8	10	NIR
Band 8A	20	Vegetation Red Edge
Band 11	20	SWIR
Band 12	20	SWIR

The images underwent atmospheric correction using DOS 1 method. This was done to compensate for interference of electromagnetic waves by atmospheric constituents (Nguyen *et al*., 2015). The images were then clipped to area of interest, Ruma National Park. The bandset tool was used to combine band 8, 4 and 3 to give standard color composite which is appropriate for vegetation studies. In order to classify imagery into vegetation types a classification scheme was used based on (Allsopp & Baldry, 1972). The system used is as shown in Table 3.2.

Ground-truth spatial and attribute data obtained during fieldwork and the output of the unsupervised classification were used to perform a supervised classification on the images, using the maximum likelihood classification algorithm. The algorithm was used because it is able to incorporate the statistics of the training samples before assigning the vegetation types to each pixel. From the recommendation by Lillesand, Kiefer, & Chipman (2008), the vegetation type maps generated were filtered with the majority filter, a post-classification tool in Semi-Automatic Plugin, to remove the "salt-and-pepper appearance" and to enhance the cartographic presentation after the image classification. Lastly, map accuracy assessment was done using kappa statistics tool in QGIS 2.10 (Kimanzi, 2011).

Table 3.2 Vegetation types classification scheme

Vegetation type	Description of vegetation type
Acacia grassland association	The dominant tree is *Acacia drepanolobium* and *Setaria spacelata* or *Themeda triandra*.
Acacia woodland	Dominated by acacia species such as *A. seyal, A. kirkii, A Xanthophloea, A. hockii and A tortilis.*
Balanites grassland association	Dominated by mature trees of *Balanites aegypticum* and *Hyparrhenia fillipendula or Themeda triandra.*
Combretum grassland association	Dominant tree is *Combretum* species and *Hyparrhenia fillipendula*.
Dense continuous thicket	Dominated by trees such as *Rhus natalensis*, *Grewia spp, and Euphorbia candelabrum.*
Isolated thicket clumps	Dominated by trees such as *Rhus natalensis*, *Grewia spp*, *Euphorbia candelabrum.* Located at the periphery of the main continuous thicket or in grassland or woodland vegetation type.
Grassland	Dominant grass includes *Hyparrhenia* species, *Setaria* species and *Themeda* species.

Adopted from Allsopp & Baldry (1972)

3.5.1 Habitat use

Distance from each plot to the nearest road, settlement, boundary fence and water sources was calculated using near feature table analysis tool in Arc GIS 9.2 with maximum near feature set at 1 to determine how proximity to these factors affect black rhinoceros habitat use (Buk & Knight, 2012). Elevation of each sampling points was determined from the handheld GPS device. Habitat rockiness was visually assessed as zero percent or fifty percent or greater than fifty percent loose rock or bed rock at 25 pinpoints in each of the 30 sampling plots (Buk & Knight, 2012). At the sampling plot level, shade was measured by measuring the diameter of the canopy ($\geq$ 4m indicate presence of shade and < 4 m indicate no shade) plant canopy cover $\geq$ 4 m would form shade because adult black rhinoceros measures 3.0 m -3.8 m in length. However, shade across the park was determined from vegetation mapping (Blandford, 2013) .

3.5.2 Habitat preference

Rhinoceros habitat preference was determined from the sightings data in Arc GIS 9.2. Each plot was classified into one of the habitat types used to classify vegetation types in Ruma National Park. Habitat preference index for each black rhinoceros was calculated by dividing proportion of rhinoceros sightings in a habitat by proportion of the habitat available within Ruma National Park. Habitat type not present within the home range was excluded from the individual analysis (Morgan *et al.*, 2009).

3.5.2.1 Home range

A total of 1033 locations of male and female black rhinoceros in RNP tracked between October to November 2107 were used. Kernel home ranges were estimated using the Hawths analysis tool extension to the geographic information system Arc GIS 9.2 (Mitchell, 2007).This involved following the software instructions to input the locations and input parameters were standardize as describe below Table 3.3. The 95 % kernel was used to estimate maximum home range size and 50 % for core areas of use within the home ranges (Reid *et al*., 2007).

Table 3.3 Hawths tool Kernel home range settings

Program	Rescale	Form	LSV	Href	Cell size	Scaling	Isopleth	Platform
Hawths tool	No	Gaussian (bivariate normal)	Yes	No	20	1000000	95, 50	ArcGIS 9.2

3.5.3 Diet differences between the sexes

Male or female black rhinoceros feeding trails were located early morning and the feeding trails followed until rhinoceros was spotted. Along the feeding trails freshly browsed plants were identified and recorded. Signs of feeding by rhinoceros were identified by 45˚ clean cut they make on the stem of browse species within 2 m high. Each focal animal was followed at a distance of 100 m and the focal animal identified using ear notch mark. Food plants were identified on the spot if possible and those that could not be identified in the field were collected, pressed and dried for identification at Maseno University Herbarium using a protocol by (Queensland Herberium, 2016).

3.5.4 Carrying capacity

To determine carrying capacity, data on the total area of all vegetation types and total area of each vegetation types was estimated from area calculation in Arc GIS 9.2. The Kernel home range of black rhinoceros at 50 % was used in calculating carrying capacity. To determine area of species home range overlap in each habitat, the generated home range estimates for the sexes and habitat type's shapefile were uploaded to Arc GIS 9.2 and using an intersect tool, geometric intersection between the input features were computed (Locher & Lindenberg, 2016). Habitat selection index of each vegetation class was obtained by dividing proportion of the habitat use by availability of the respective habitat in the home range and scales used include: 1.00-1.04 indicates neutral selection, >1.04 positive habitat selection and 0-0.90 indicates negative habitat selection (Nascimento & Schmidlin, 2011).

3.6 Data analysis and statistical tests

Binomial logistic regression was used to determine whether elevation, level of rockiness, distance to water points, distance from the boundary fence, distance from the roads, and distance from the human settlements predict habitat use by black rhinoceros. Habitat and diet preference between female and male black rhinoceros was calculated separately. Habitat preference was calculated using the formula by (Morgan *et al*., 2009):

$$\text{Habitat preference index} = \frac{[\#\text{ of locations in habitat type / total number of locations in all habitats}]}{[\text{Area of the habitat type / total area of Ruma National Park}]}$$

Mann-Whitney U test was used to determine whether there was a statistical difference in habitat preference between the sexes. Three categories of analyses for habitat preference used were 0-0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection. Statistical significance for the test was evaluated at $P < 0.05$. In addition to sex differences at the habitat level, diet difference between the sexes was calculated using Jaccard`s Coefficient; the closer the index is to 100% the more similar the diet between the two sexes (Waweru, 1991):

$$Isj = (c / a+b+c) \times 100$$

$$d = 1 - Isj$$

Where Isj is the Jaccard`s Index of similarity

a is the number of plant species unique to male black rhinoceros

b is number of plant species unique to female black rhinoceros

c is number of plant species common to both male and female black rhinoceros

d is the Jaccard`s Index of dissimilarity

Lastly, Proportions of the female and male black rhinoceros home range sizes were compared using the Mann-Whitney U test as the data was not normally distributed.

Carrying capacity was calculated using the formula by (Nascimento & Schmidlin, 2011);

$$K^{*} \text{ index} = \sum [(D_{cv} \times I_{cv}) / (A - S)]$$

Where

K^* is the carrying capacity

A is the area of 50 % kernel home range in each habitat type (ha)

S is home range overlap (ha)

Dvc is the total area (ha) of each vegetation class available

Ivc is the habitat selection index for each vegetation class

3.7 Ethics statement

Because the research did not involve invasive approaches such as capture and handling of rhinoceros, ethical approval was not necessary. However, in order to carry out the research, research authorization was obtained from the Kenya Wildlife Service, Appendix 3.2.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Environmental and anthropogenic factors that predict habitat use

The level of loose rocks in the park across all habitats ranged from 0 to < 50 %; 61 % of the park was shaded. Binomial logistic regression results shows that none of the environmental and anthropogenic factors influenced the habitat use by black rhinoceros (Table 4.1).

Table 4.1 Influence of environmental and anthropogenic factors on habitat use

Variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
Level of Rockiness	0.012	0.024	0.250	1	0.617	1.012	0.965	1.061
Shade	0.004	0.011	0.153	1	0.695	1.004	0.982	1.027
Slope	-0.016	0.026	0.386	1	0.535	0.984	0.936	1.035
Distance to fence	27.456	80.153	0.117	1	0.732	8.397E11	0.000	1.415E80
Distance to human settlement	-50.680	59.416	0.728	1	0.394	0.000	0.000	3.674E28
Distance to the roads	61.482	122.09	0.254	1	0.615	5.025E26	0.000	4.215E130
Distance to the water points	-52.281	89.973	0.338	1	0.561	0.000	0.000	7.584E53
Constant	19.436	31.388	0.383	1	0.536	2.760E8		

Df=Degree of freedom which depends on the number of specified dependable variable

Hosmer and Lemeshow Test**,** X^2 = 14.179, df = 8, P= 0.077; the model adequately fits the data

Ruma National Park is less rocky (0 to < 50 %), which might explain why rockiness did not predict habitat use by black rhinoceros. In contrast, in parks with high level of loose rocks accounting for more than 50 %, the movement of black rhinoceros are affected thus their habitat use (Buk & Knight, 2012). Similarly black rhinoceros activities were observed in both areas of low altitude and high altitude. This could be related to the generally flat terrain of the park.

Abundant shade and feeding habit of black rhinoceros in the park might explain why shade was not a predictor of habitat use by black rhinoceros; the species was observed to browse for food early in the morning and evening and sleep during the hottest part of the day. In contrast to Buk & Knight (2012), low shade in AFNP (97 % no shade) predicted habitat use by black rhinoceros. This makes shade only a predictor of habitat use in areas with limited shade.

Similarly, distance to water points did not predict habitat use by black rhinoceros. Given that ungulates like black rhinoceros require water or shade to cool their bodies from heat (Cain *et al*., 2008), abundant shade in the park which is required for osmoregulation just like water might explain why distance to watering points did not predict habitat use by black rhinoceros. With regards to anthropogenic factors, black rhinoceros habitat use in the park was not predicted by presence of human activities. The park is surrounded by human settlement, roads, farms, and population density around the park is high (Kenya National Bureau of Statistics, 2009). Therefore absence of anthropogenic factors that predict habitat use by black rhinoceros can be explained by presence of other anthropogenic factors such as snaring and poaching in the park which is not known. This is in contradiction to Morgan *et al*. (2009), where human settlement, protected area fence and roads constrained distribution of black rhinoceros and Odendaal-Holmes *et al.* (2014) where black rhinoceros avoids areas closer to roads where tourist activities negatively have impact on their habitat use. It is however important to state that role of anthropogenic factors on habitat use may change as human continue to return to Lambwe Valley in part because of the successful control of tsetse fly population in the region (Kimanzi, 2011).

4.2.0 Habitat and diet preference between the sexes

4.2.1 Habitat preference between the sexes

Vegetation classification results and both male and female rhinoceros home range results are presented first because they were necessary in determining the proportion of the habitat available within the individual Kernel home range which was to be used in calculating habitat preferred by different sexes.

4.2.1.1Vegetation classification

The final product of vegetation mapping provided an estimated area of each vegetation type in the park appendix 4.1 (Table 4.2). The area estimate for each vegetation type was calculated using geometry and basic statistics tools on the Qgis environment; for these analyses, overall map accuracy was 94.1 % and kappa coefficient of 0.90 (Appendix 4.2 and Appendix 4.3).

Table 4.2 Vegetation types and their respective area of Ruma Park 2017

Vegetation types	Area (Km^2)	Percentage
Acacia grassland association	34	27
Acacia woodland	25	20
Dense continuous thicket	17.9	14
Grassland	14.9	12
Isolated thicket clumps	13	10
Balanites grassland association	12.4	10
Combretum grassland association	8.7	7
Total	125.9	100

4.2.1.2 Home range size

There was no significant difference between male and female black rhinoceros kernel home range sizes (Mann-Whitney U= 23, p=0.897). However, on average male black rhinoceros home range size was larger (3565.00 ha) than female black rhinoceros (2407.95 ha). Also there were cases of home range overlap of 1215.80 ha between the sexes (Figure 4.1).

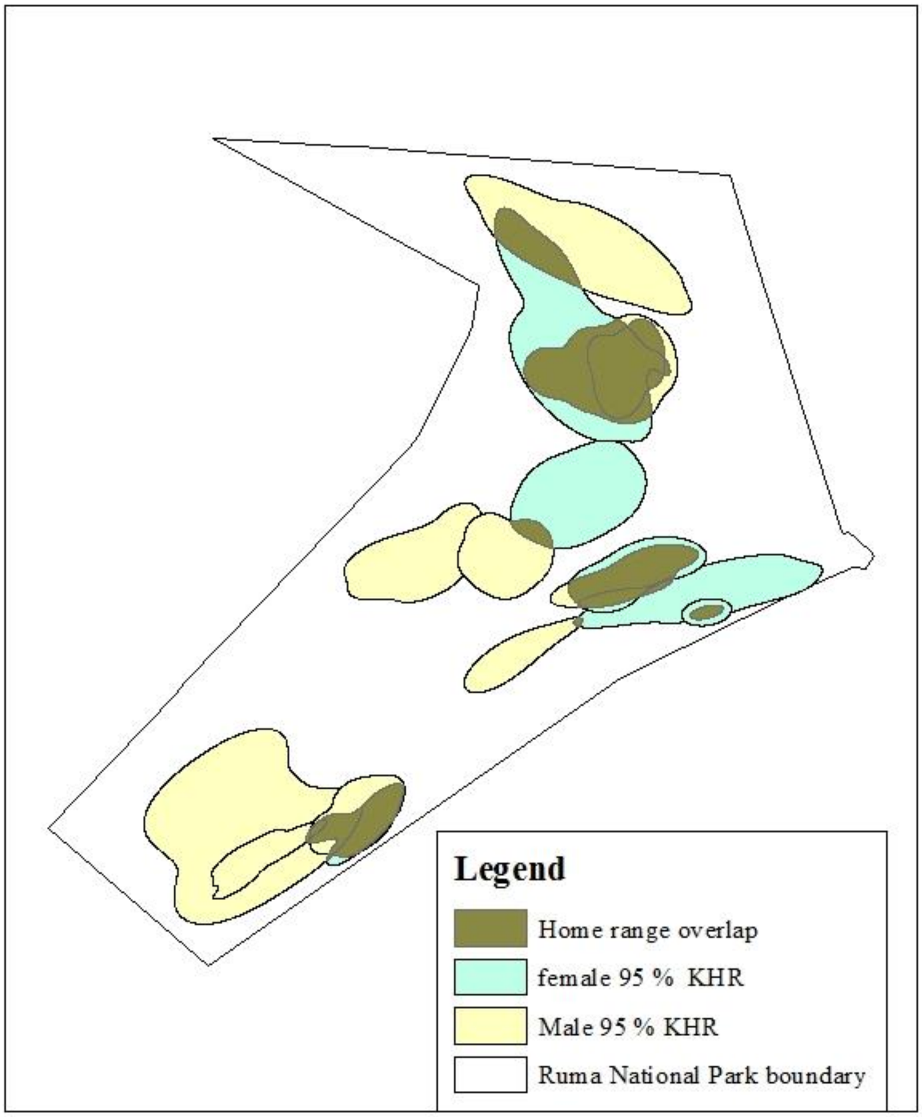


Figure 4.1 male and female black rhinoceros home range overlap

Habitat preference indices showed that *Acacia* grassland is most preferred by black rhinoceros with a habitat preference index of 1.44 followed by *Acacia* woodland with habitat preference index of 1.30 and lastly *Combretum* with a preference of 0.28 (Table 4.3).

Table 4.3 Black rhinoceros habitat preference index

Habitat type	Sightings in each	Area in KHR	Sightings Ratio	Area ratio	Habitat preference index
Acacia grassland	422	34.0	0.39	0.27	1.44
Acacia woodland	282	25.0	0.26	0.20	1.30
Grassland	124	14.9	0.11	0.12	0.97
Isolated thicket	95	13.0	0.09	0.10	0.84
Balanites	76	12.4	0.07	0.10	0.71
Dense thicket	66	17.9	0.06	0.14	0.43
Combretum	21	8.7	0.02	0.07	0.28

Note: KHR=Kernel home range; sightings ratio is the proportion of rhinoceros locations in a habitat; area ratio is the proportion of the habitat available within Ruma National Park; scale for habitat preference index of 0-0.75 is selection against, 0.76–1.25 no selection, and >1.25 positive selection.

From Mann- Whitney U test results, there was no statistical difference in habitat preferences between female and male black rhinoceros ($U= 16.50$, $p = 0.306$). However, habitat preference indices showed that male black rhinoceros prefer *Acacia* woodland and isolated thicket clumps as opposed to female black rhinoceros that prefer *Acacia* grassland (Table 4.4 and Table 4.5). In both sexes *Combretum* was the least habitat type preferred with a preference index of 0.40 and 0.13 respectively.

Table 4.4 Male black rhinoceros habitat preference index

Habitat type	Sightings	Area (km^2)	Sighting ratio	Area ratio	Habitat preference index
Acacia woodland	197	25.0	0.31	0.20	1.57
Isolated thicket	78	13.0	0.12	0.10	1.20
Grassland	71	14.9	0.11	0.12	0.96
Acacia grassland	156	34.0	0.25	0.27	0.92
Balanites	51	12.4	0.08	0.10	0.83
Dense thicket	56	17.9	0.09	0.14	0.63
Combretum	17	8.7	0.03	0.07	0.40

Note: KHR=Kernel home range; sightings ratio is the proportion of rhinoceros locations in a habitat; area ratio is the proportion of the habitat available within the park; scale for habitat preference 0-0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection

Table 4.5 Female black rhinoceros habitat preference index

Habitat type	Sightings	Area (km^2)	Sightings ratio	Area ratio	Habitat preference index
Acacia grassland	266	34.0	0.58	0.27	2.15
Grassland	53	14.9	0.12	0.12	0.98
Acacia woodland	85	25.0	0.18	0.20	0.92
Balanites	25	12.4	0.05	0.10	0.55
Isolated thicket	17	13.0	0.04	0.10	0.36
Dense thicket	10	17.9	0.02	0.14	0.15
Combretum	4	8.7	0.01	0.07	0.13

Note: KHR=Kernel home range; sightings ratio is the proportion of rhinoceros locations in a habitat; area ratio is the proportion of the habitat available within the park; scale for habitat preference 0-0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection

4.2.2 Diet differences between the sexes

Eighteen plants were browsed on by both male and female black rhinoceros (Table 4.6). Jaccard`s coefficient showed that there was a 60 % dissimilarity in diet selection between the sexes (Appendix 4.4).

Table 4.6 Common food plants to both male and female black rhinoceros

Plant species
Lantana camara
Venonia amygdalina
Acacia drepanolobium
Ormocarpum trichocarpum
Acacia seyal
Triumfetta rhomboidea
Acacia kirkii
Balanites aegyptiaca
Abutilon mauritianum
Combretum species
Harrisonia abyssinica
Solanium incanum
Grewia bicolor
Carrisa endulis
Aspilia pluriseta
Acacia hockii
Phyllanthus spp
Conyza Canadensis

At the habitat level, the absence of a difference in habitat preference index between female and male rhinoceros indicates that the sexes use same habitat. In accordance with the socio-ecological model (Genin & Masters, 2018), male black rhinoceros were found to occupy home ranges that were in proximity to those of females. However, core areas of all the male black rhinoceros remained exclusive representing territorial nature of male black rhinoceros during the current study. This results confirm previous report by Hutchins & Kreger (2006) where male black rhinoceros are territorial.

Female unlike male black rhinoceros have been shown to have a strong bond with their young ones (Tatman *et al*., 2000). Therefore presence of female black rhinoceros young ones may explain why female black rhinoceros preferred *Acacia* grassland associations while male preferred *Acacia* woodland. The calves in RNP were between the age of 1 and 2 months, thus *Acacia* grassland associations allowed for their free movement and most food is within reach (Tatman *et al*., 2000).

At the diet level, however, female and male black rhinoceros were found to show a 60% difference in diet selection, which suggest niche partitioning (Griffin & Silliman, 2011). This observation renders coarse support for the forage selection hypothesis. Consequently, even though the sexes shared or had home ranges in close proximity, sex differences in diet preferences may mollify inter-sexual competition for ecological resources. This dissimilarity in diet selection between the sexes may be attributed to sex differences in energy and nutritional requirements (Ruckstuhl & Neuhaus, 2000). In addition, and viewed in the context of the absence of sex differences in habitat preference, sex differences in diet preference may suggest niche partitioning between female and male black rhinoceros (Griffin & Silliman, 2011). All other factors being equal, the implication of the sex difference in diet selection is low competition for food between male and female black rhinoceros and thus potential for future population growth (Gedir, Law, Du Preez, & Linklater, 2018).

4.3 Carrying capacity

Habitat selection by both sexes was determined first so as to control for the fact that some parts of the park may not be available for black rhinoceros (Table 4.7).

Table 4.7 Habitat selection by black rhinoceros in Ruma National Park

Habitat type	Proportion of use	Availability in KHR	Habitat selection Index
Acacia grassland	0.39	0.34	1.14
Acacia woodland	0.26	0.24	1.09
Balanites	0.07	0.08	0.83
Combretum	0.02	0.04	0.47
Dense thicket	0.06	0.08	0.75
Isolated thicket	0.09	0.09	0.96
Grassland	0.11	0.12	0.93

Note: KHR= Kernel home range; habitat selection index scale 1.00-1.04 indicates neutral selection, >1.04 positive habitat selection and 0-0.90 indicates negative habitat selection

Carrying capacity in Ruma National Park was determined to be 80 black rhinoceros when habitat selection is not taken into consideration. This number decreases by 23 % when habitat selection index is included in the calculation totaling 65 black rhinoceros. Therefore a more accurate estimate of carrying capacity is 65 which involved the use of habitat selection is taken into consideration with *Acacia* grassland associations being able to support most black rhinoceros (Table 4.8).

Table 4.8 Carrying capacity index of each habitat type

Habitat type	Area (Ha)	K* index
Acacia grassland associations	3400	8
Acacia woodland	2500	9
Balanites grassland associations	1240	9
Combretum grassland associations	870	8
Dense continuous thicket	1790	13
Grassland	1490	8
Isolated thicket clumps	1300	11
Total	12590	65

Note: Area Ha= Area of each habitat type in hectares; K* index= the maximum number of black rhinoceros that can be sustained in each habitat type

The estimated carrying capacity in Ruma National Park was above the number of black rhinoceros that was reintroduced in 2012. This shows that RNP still has the capacity to accommodate the translocated black rhinoceros and allow for future population growth. In fact, the room for growth is even larger given that only 19 of the 21 translocated individuals could be accounted for during the present study.

The habitat selection approach in estimating ecological carrying capacity takes into consideration environmental and anthropogenic factors such as availability of water, shade, and food in a habitat selected for by species. One assumption is that individuals select habitats with key resources such as shade, salt-licks, availability of water and food (Schwabe, Gottert, Starik, Levick, & Zeller, 2015). However previous prediction of carrying capacity have been based on available browse and browse growth (Amin *et al*., 2006). How species use available space (Braithwaite *et al*., 2012) and the use of population models (Okita-Ouma *et al*., 2009) which do not take into consideration the habitat preferred by the species.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Three key findings arose from the study. First, none of the environmental and anthropogenic factors predicted habitat use by black rhinoceros in Ruma National Park. Second, although there was no significant difference in habitat preference between female and male rhinoceros, there was a 60 % difference in diet selection between the sexes. Third, the ecological carrying capacity of black rhinoceros in Ruma National Park is 65 individuals.

5.2 Conclusions

1. Results showing that environmental and anthropogenic factors do not predict habitat use by black rhinoceros imply that none of these factors is pulling or pushing the species from occupying certain habitats therefore much of the park is available for use by black rhinoceros.

2. Difference in diet between the female and male black rhinoceros even in the absence of a difference in habitat preference implies that there is minimal competition for browse between the sexes.

3. The maximum number of black rhinoceros that can be sustained in Ruma National Park is 65 individuals. Therefore, the current population of black rhinoceros in Ruma National Park is still within the carrying capacity of the park.

5.3 Recommendations

1. The absence of influence of environmental and anthropogenic factors on habitat use by black rhinoceros suggests that there is room for additional individuals to be brought in particularly in light of the male biased sex ratio.

2. Similarly difference in habitat use at the diet level suggests minimal competition for food between the sexes. Therefore, Ruma Park Management can consider reintroducing more individuals particularly females given the skewed sex ratio in favor of males.

3. It is important to note that the estimated carrying capacity of 65 individuals do not take into account future translocation of other megahebivore. Consequently, Ruma Park Management should reconsider such future translocations.

5.4 Suggestions for future studies

1. Since habitat use was measured qualitatively as presence or absence of rhinoceros in a sampling plot, future studies should consider assessing habitat use quantitatively.

2. The finding on potential niche partitioning suggests the absence of competition for ecological resources between the sexes. However, future studies should investigate other forms of competition such as intrasexual and interspecies.

3. The ecological carrying capacity of 65 black rhinoceros does not take into consideration the ecological needs of other species in the park. As a result, future research should incorporate the ecological needs of other species in the park.

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APPENDICES

Appendix 3.1

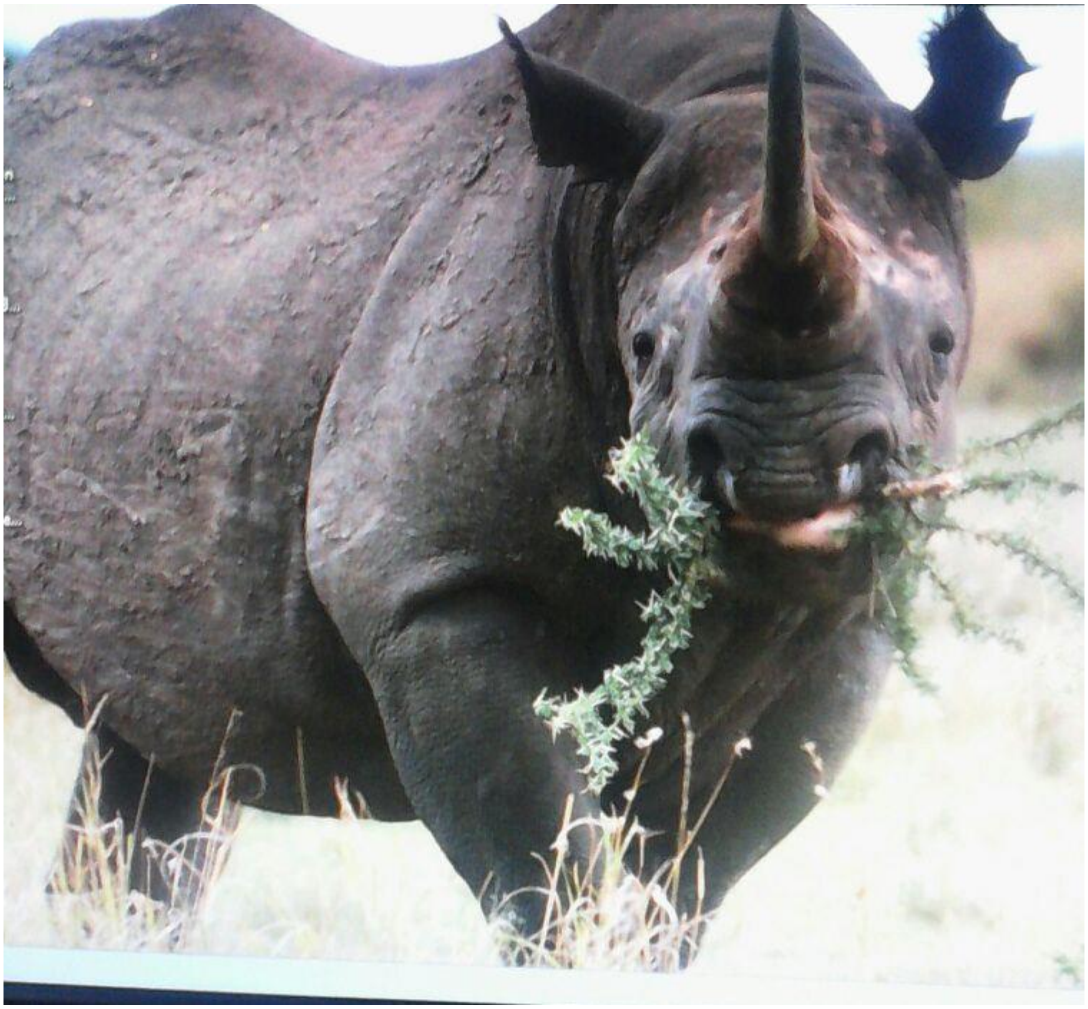

Figure A1 a picture of black rhinoceros

Appendix 3.2 Research permit

KENYA WILDLIFE SERVICE

ISO 9001:2008 Certified

KWS/BRM/5001

31 July 2014

Dr. Patrick Ogola Onyango
Department of Zoology
Maseno University
P.O.Box 333
MASENO

Dear Dr. Onyango,

PERMISSION TO CONDUCT RESEARCH IN RUMA NATIONAL PARK

We acknowledge receipt of your letter dated 23 July 2014 requesting permission to conduct research on a project titled: *'Demographic status update , habitat preference and availability and genetic viability of a recently translocated population of critically endangered Black rhinoceros (Diceros bicornis micheli) in Kenya'*. The study will generate data and information to enhance conservation of the species.

You have been granted permission to conduct the study from **August 2014 to August 2015** upon payment to KWS of academic research fees of **Ksh. 12,000**. However, you will abide by the set KWS regulations and guidelines regarding the conduct of research in and outside protected areas. You will also be required to work closely with our Senior Scientist in-charge of Western Conservation Area (WCA), whom you will give a copy of the research proposal and progress report on the study.

You will submit a copy of your findings to the KWS Deputy Director, Biodiversity Research and Monitoring on completion of the study.

Yours sincerely,

SAMUEL M. KASIKI, PhD, OGW
DEPUTY DIRECTOR
BIODIVERSITY RESEARCH AND MONITORING

Copy to:
- Senior Scientist, WCA
- Senior Warden, Ruma N. Park
- Senior Warden, Rhino Conservation Program

P.O Box 40241-00100, Nairobi, Kenya. Tel: +254-20-6000800, 6002345. ISDN: +254-020-3992000/1000
Wireless: +254-020-2379407/8/9. Mobile: +254-735 663 421, +254-726 610 508. Fax: +254-020-6003792
Email: kws@kws.go.ke Website:www.kws.go.ke

Appendix 4.1

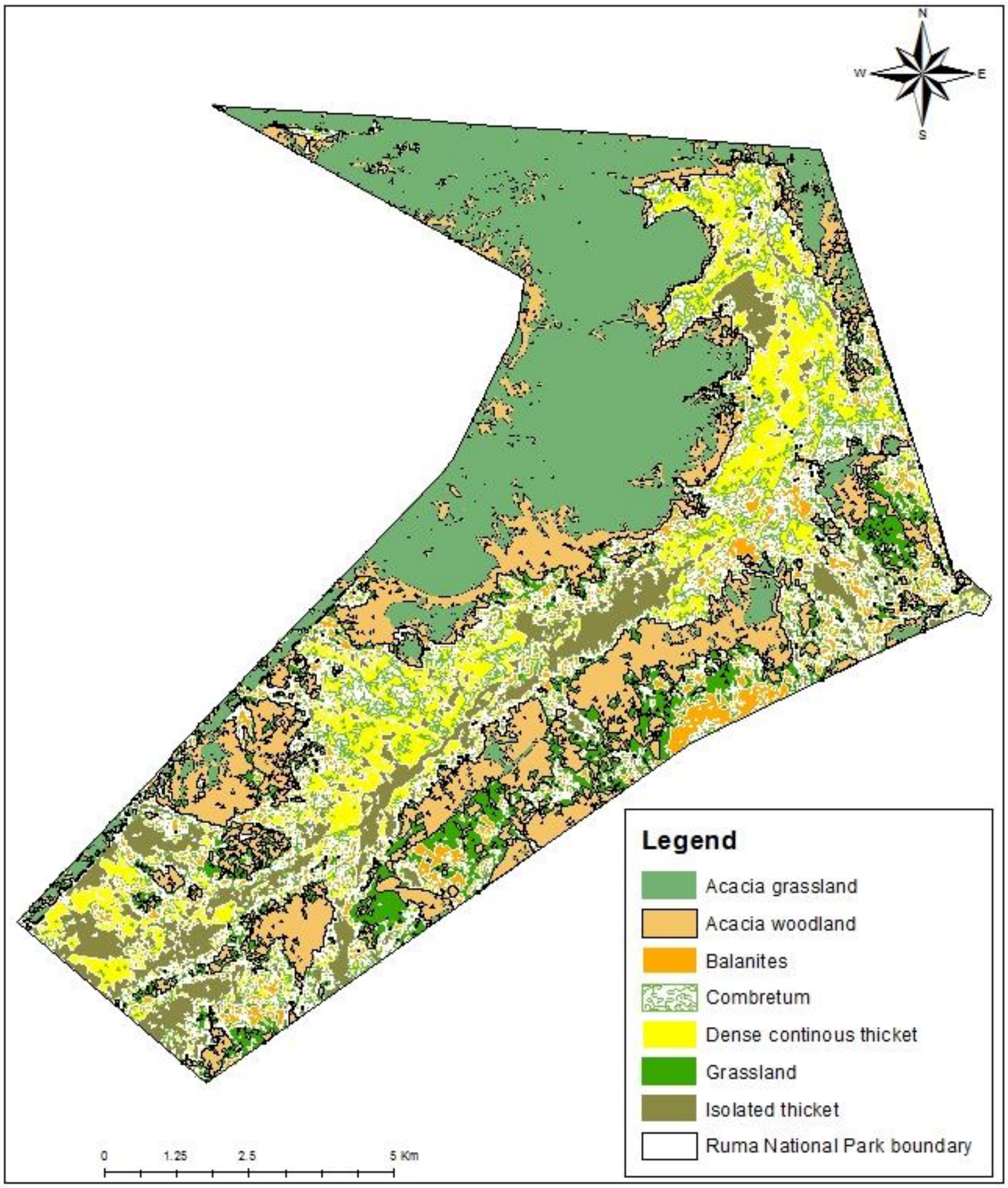

Figure A2 Vegetation types of Ruma National Park 2017

Appendix 4.2

Table A2 Error Matrix table

	Reference							
Classification	1	2	3	4	5	6	7	Total reference points
1	504	0	0	0	0	0	0	504
2	0	5	1	0	15	0	0	21
3	0	0	8	1	2	0	0	11
4	0	0	0	1169	3	0	0	1172
5	0	1	2	7	236	0	1	247
6	0	0	0	33	0	16	0	49
7	0	0	2	47	8	0	17	74
Total	504	6	13	1257	264	16	18	2078

KEY

1 *Acacia* grassland associations

2 *Balanites* grassland associations

3 *Combretum* grassland associations

4 Dense continuous thicket

5 Grassland

6 *Acacia* woodland

7 Isolated thicket clumps

Appendix 4.3

Table A3 Accuracy assessment table

Vegetation class	Producer accuracy %	User accuracy %	Kappa hat
1	100	100	1.0
2	83.3	23.8	0.2
3	61.5	72.7	0.7
4	93.0	99.7	1.0
5	89.4	95.5	0.9
6	100	32.7	0.3
7	94	23	0.2
Overall accuracy	94		
Kappa hat classification	0.9		

Appendix 4.4 Jaccard`s coefficient calculation

Isj= (18 ⁄ 7+20+18)*100

=18/45*100

=40

However Jaccard`s dissimilarity

(1-0.4)*100

= 60 %