# POPULATION DYNAMICS AND FEEDING ECOLOGY OF THE BLACK RHINO (*Diceros bicornis*) IN NGORONGORO CONSERVATION AREA, TANZANIA

**DONATUS E. GADIYE**

**A Thesis Submitted to Graduate School in Partial Fulfillment for the Requirements of the Award of Master of Science in Natural Resources Management of Egerton University**

**EGERTON UNIVERSITY**

**NOVEMBER 2016**

# DECLARATION

I declare that this thesis is my original work and has not been presented for any award of a degree at this university or any other university.

**Signature** ————————————————— **Date** —————————————————

**Donatus E. Gadiye   (NM11/3708/13)**


**APPROVAL**

This thesis has been presented for examination with our approval as university supervisors.


**Signature** ————————————— **Date** —————————————

Dr. Wilfred O. Odadi

Department of Natural Resources

EGERTON UNIVERSITY


**Signature** ————————————— **Date** —————————————

Dr. George Eshiamwata

Department of Natural Resources

EGERTON UNIVERSITY

## DEDICATION

To my most supportive and loving wife Anna and children Irene, Emanuel, Doreen and Leticia for their compassionate and endless support

# ACKNOWLEDGEMENT

# ABSTRACT

Africa was once known for abundant populations of the now Critically Endangered Black rhino (*Diceros bicornis*). However, large-scale poaching in many parts of this continent during 1970-1980 led to a 95% decline in the rhino numbers. Like in other countries that host remnant populations of the Black rhino, Tanzania's Black rhinos are now largely restricted to protected areas such as the Ngorongoro Conservation Area (NCA). This study sought to map the spatial distribution of the Black rhino population in the Ngorongoro Crater (NC), assess the temporal trends in selected population attributes (size, growth rate, sex ratio and age-structure) over the past 15 years and evaluate food selection by the Black rhino. Black rhino population trends and spatial distribution were assessed using records obtained from NCA and ranger posts. Ecological surveys were conducted at Black rhino foraging sites to assess food availability and diet selection during wet and dry seasons. There was a steady growth in population of Black rhino from the initial 14 in 2000 to 44 in 2014. The highest growth rate (1.3 individuals /year) occurred in 2005, while the lowest growth rates (0 individuals) occurred in year 2006, 2011 and 2013. The sex ratios were skewed in favor of females (2:1) and approximately constant for the entire 15-year period. Spatial distribution patterns varied across seasons, with rhinos occupying the crater floor during the wet season and crater walls and rims during the dry season. In addition, the spatial distribution patterns were influenced by anthropogenic activities; rhinos avoided areas proximate to busy roads, lodges and livestock. Grasses and forbs occurred in nearly equal proportions at the Black rhino feeding sites, constituting 50.4% and 49.6%, respectively. During the wet season, rhinos mostly selected *Commelina banagalensis, Amaranthus hybridus, Gutenbergia cordifolia, Justicia betonica* and *Lippia ukambensis* while in dry season*; Hibiscus aponeurus, Justicia betonica* and *A. xanthophloea*. There were significant differences in forage items utilized in each season. *A. hybridus* ($p=0.001$) were more utilized in wet than dry season as well as *C. bengalensis* ($p=0.008$), *E. arabicum* ($p=0.001$), *A. longiscupsis* ($p=0.019$) and *G. cordifolia* ($p=0.010$). These results recommend that human activities such as livestock grazing, tourism infrastructure etc. should be minimized in crater to avoid disruption of rhino movement and habitat selection patterns. As well, it is vital to maintain the monitoring regime, and possibly improve the ratio of ranger to rhinos or area of patrol to enhance effective monitoring and management.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AWF** | African Wildlife Foundation |
| **BLM** | Bureau of Land Management of Tanzania |
| **CITES** | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| **FZS** | Frankfurt Zoological Society |
| **GAWPT** | George Adamson Wildlife Preservation Trust |
| **GFRR** | Great Fish River Reserve |
| **GIS** | Geographical Information System |
| **ICI** | Inter-Calving Intervals |
| **IUCN** | International Union for Conservation of Nature |
| **MNP** | Mkomazi National Park |
| **MNRT** | Ministry of Natural Resources and Tourism |
| **NBSAPs** | National Biodiversity and Strategic Action Plans |
| **NC** | Ngorongoro Crater |
| **NCA** | Ngorongoro Conservation Area |
| **NCAA** | Ngorongoro Conservation Area Authority |
| **NGOs** | Non-Governmental Organizations |
| **NHFR** | Ngorongoro Highland Forest Reserve |
| **SADC** | South African Development Community |
| **SSC** | Species Survival Commission of IUCN |
| **TAWIRI** | Tanzania Wildlife Research Institute |
| **UNESCO** | United Nations Education, Scientific and Cultural Organization |
| **WWF** | World Wide Fund for Nature |

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background Information

Black rhinos (*Diceros bicornis*) were once abundant in many parts of Africa, especially in eastern and southern Africa (Dobson *et al.*, 1992). However, since 1970s most of the Black rhino populations have effectively been eliminated from a large part of their historical range. It is estimated that the Black rhino numbers has reduced by 95% from 65,000 to 3,500 individuals in 1990 (Hearne and Swart, 1991). The massive declines in Black rhino numbers have been attributed to rampant poaching within its ranges. Currently, native Black rhino populations are only found in Tanzania, Kenya, South Africa and Botswana. Most of the extant Black rhino populations in these countries are found within government protected areas and well managed private wildlife conservancies (Blake *et al.,* 2007). In Tanzania, the remnant Black rhino populations primarily occur in Ngorongoro Conservation Area, Selous Game Reserve, Serengeti National Park and Mkomazi National Park (Emslie *et al.* (2007).

Ngorongoro Conservation Area (NCA) is vital especially for Black rhino conservation because it is one of the only two ecosystems in Tanzania that host native Black rhino populations. The Black rhino population in the NCA is almost exclusively concentrated in the Ngorongoro Crater, which forms just 4 percent of the NCA area. The population of Black rhinos in NCA has dramatically declined since the mid-20th century, and especially since 1960s as a result of illegal poaching to supply the growing demand for rhino's horn (Emslie *et al.* 2007; Blake *et al.,* 2007) The NCA Black rhino population decline continued throughout 1980s and it is estimated that over 95% of the population that existed in 1960s (approximately 108 individuals) was eliminated (Bret, 2010).

Due to concerted efforts by the government and conservation agencies to curb poaching and enhance conservation, it is believed that the NCA Black rhino population is on the path to recovery although there have been no supporting scientific data. These conservation measures include stringent law enforcement and enhanced security measures within the NCA, including regular car patrols, regular monitoring of rhinos through radio transmitters and regular censuses. However, these measures have not been accompanied by requisite analyses of population

dynamics, food availability and foraging ecology of the Black rhino in the NCA. The role of food availability and feeding ecology is critical in understanding how different habitat parameters can affect the spatial distribution, habitat use and population growth and numbers within a given site. Such analyses could vitally augment the existing conservation measures and contribute to enhanced conservation and management of this threatened species.

## 1.2 Statement of the problem

In order to curb poaching and enhance the recovery of the Black rhino population in the Ngorongoro Conservation Area, several conservation and security measures have been put in place, including 24-hour surveillance of the crater through car and foot patrols. In addition, population censuses are carried out regularly. However, little is known about Black rhino population trends in this ecosystem over the past years since the inception of these conservation efforts. Understanding the demographics of the species is important in assessing the resilience, long-term persistence or vulnerability of this population to vagaries of extinction or extirpation. In addition, relative availabilities of different food resources and selection of these resources by the Black rhino have not yet been documented. In order to enhance conservation of the Black rhino in the NCA, there is a need to carry out an assessment of the past rhino population trends, and current food resources availability and selection by this globally threatened rhino species. This study therefore sought to fill these knowledge gaps.

**1.3 Study objectives**

**1.3.1 Broad objective**

To fill biological knowledge for effective management and conservation for saving globally threaten species from extinction.

**1.3.2 Specific objectives**

i) To map the spatial distribution of the Black rhino population in the Ngorongoro Crater (NC),

ii) To assess selection of different forage species by Black rhino in the NC,

iii) To assess temporal trends in selected population attributes (size, growth rate, sex ratio and age-structure) in the NC during 2000-2014.

**1.4 Research questions**

i) How are the Black rhino individuals distributed within the Ngorongoro Crater?

ii) What plant species are preferred by the Black rhino?

iii) How has the Black rhino population changed over the past 15 years?

**1.5 Justification of the study**

By assessing the population dynamics, feeding ecology of the Black rhino and forage availability, this study provides information that could contribute towards enhanced conservation and management of this critically endangered rhino species and its habitat. Specifically, this information could be used by the Ngorongoro Conservation Area Authority (NCAA) to formulate policies, management strategies and interventions that enhance conservation of the Black rhino in the Ngorongoro Crater. In addition, the information generated could vitally inform strategies and policies aimed at bolstering conservation of Black rhino populations in Tanzania and beyond. Such information could be of value to government agencies, NGOs and the local communities and international community concerned with Black rhino conservation and management.

## 1.6 Scope of the study

This study was geographically limited to Ngorongoro Conservation Area (NCA) in Tanzania. NCA was purposely selected because it is one of the two places in Tanzania where the last populations of rhinos are found in their native habitats. Data was collected over a period of four months starting from mid-May to mid-June (wet season) and from mid-August to mid-September (dry season). The trends in population attributes were analyzed for a period of fifteen years from year 2000 to year 2014. The study focused only on the Black rhino sub-species *Diceros bicornis michaeli*, a sub-species categorized as Critically Endangered under IUCN, 2015 classification. Observations on foraging ecology were done early in the morning between 0630hrs to 09hrs and late in the afternoon between 1600hrs to 1800hrs when the rhino was expected to be actively feeding.

## 1.7 Limitations of the study

The study focused only on the relative frequencies of food availability and selection rather than the actual biomass. It was difficult to observe the rhino once they disappeared into the forest and thickets, making it difficult to document their activities in such places. In addition, observations could not be carried out at night, making it difficult to document their night-time feeding locations. Assessing the number of bites was also difficult when the plant is wholly consumed. It was not possible to detect plants that could have been wholly consumed or uprooted using the feeding site survey method employed in this study.

## 1.8 Assumptions of the study

The study assumed that the population under study was a closed population, with no immigration or emigration.

**1.9 Definition of Terms**

| | |
|---|---|
| **Conservation Area** | The area set aside for multiple uses, (conservation of natural resources) |
| **Critically Endangered** | A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria for Critically Endangered and it is therefore considered to be facing an extremely high risk of extinction in the wild. |
| **Game Reserves** | These are areas protected for the conservation of wildlife, however, commercial hunting for permitted species of wildlife is allowed. |
| **Herbaceous material** | In this study it refers to seed bearing plants that do not have woody stems and withers off after flowering usually after one year and it includes grasses. |
| **National Park** | These are areas protected purposefully for conservation of natural resources, no anthropogenic activities allowed in this category except photographic tourism e.g. Serengeti National Park |
| *Operesheni Uhai* | A Swahili phrase meaning 'operation save life' |
| **Population attributes** | Refers to qualities and characterization of various types of population within a social group or geographic group, with emphasis on demography (age class, sex ratio) and health status (numbers/growth rate, natality rate or mortality rate) |
| **Population dynamics** | Concerned with changes in population characteristics (numbers/growth, age class distribution, sex ratio) through time and space, as well as the factors that influence those changes (wildlife, tourism and pastoralism) |

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 Distribution of Black rhino in Africa

There are two species of African rhino, the Black rhino (*Diceros bicornis*) and the white rhino (*Ceratotherium simum*). Both species have been driven to near extinction in recent years and the distributions as well as their populations have declined dramatically and been fragmented consigning them to highest categories of IUCN threat categories. Black rhinos were once very wide spread and numerous as well as very successful among herbivores (Estes *et al.,* 2006). They were found throughout sub-Saharan Africa with the exception of the Congo Basin and were estimated to be several hundred thousand in 1960s (Dobson *et al.*, 1992) and in spite of their solitary nature, it was usual to encounter dozens in a single day (WWF, 2004). There are four recognized subspecies of the Black rhino the southern-central Black rhino (*Diceros bicornis minor*), the most numerous sub-species, inhabited a historic range from central Tanzania down through Zambia, Zimbabwe and Mozambique to northern and eastern South Africa (Figure 1).

The South-western Black rhino (*Diceros bicornis bicornis*) is more adapted to the arid and semi-arid savannahs of Namibia, southern Angola, western Botswana and western South Africa. The East African Black rhino (*Diceros bicornis michaeli*) which had a historic distribution from South Sudan, Ethiopia, Somalia down through Kenya into north-central Tanzania, maintains its current stronghold in Kenya (Nevo *et al.,* 1984). The West African Black rhino (*Diceros bicornis longipes*) is the rarest and most endangered subspecies, whereas it once occurred across most of the savannas of West Africa (Rookmaaker, 2004). In Tanzania the population of Black rhinos ranged from Mkomazi National Park in the north-east to Serengeti ecosystem in the north and north-west, and from central Tanzania (Ruaha National Park) to Selous Game Reserve (SGR) in the south. Serengeti alone had about 700 individuals in 1974. Since then there had been drastic decline due to rampant poaching. By 1990s isolated small populations remained in Serengeti (Dobson *et al.*, 1992).
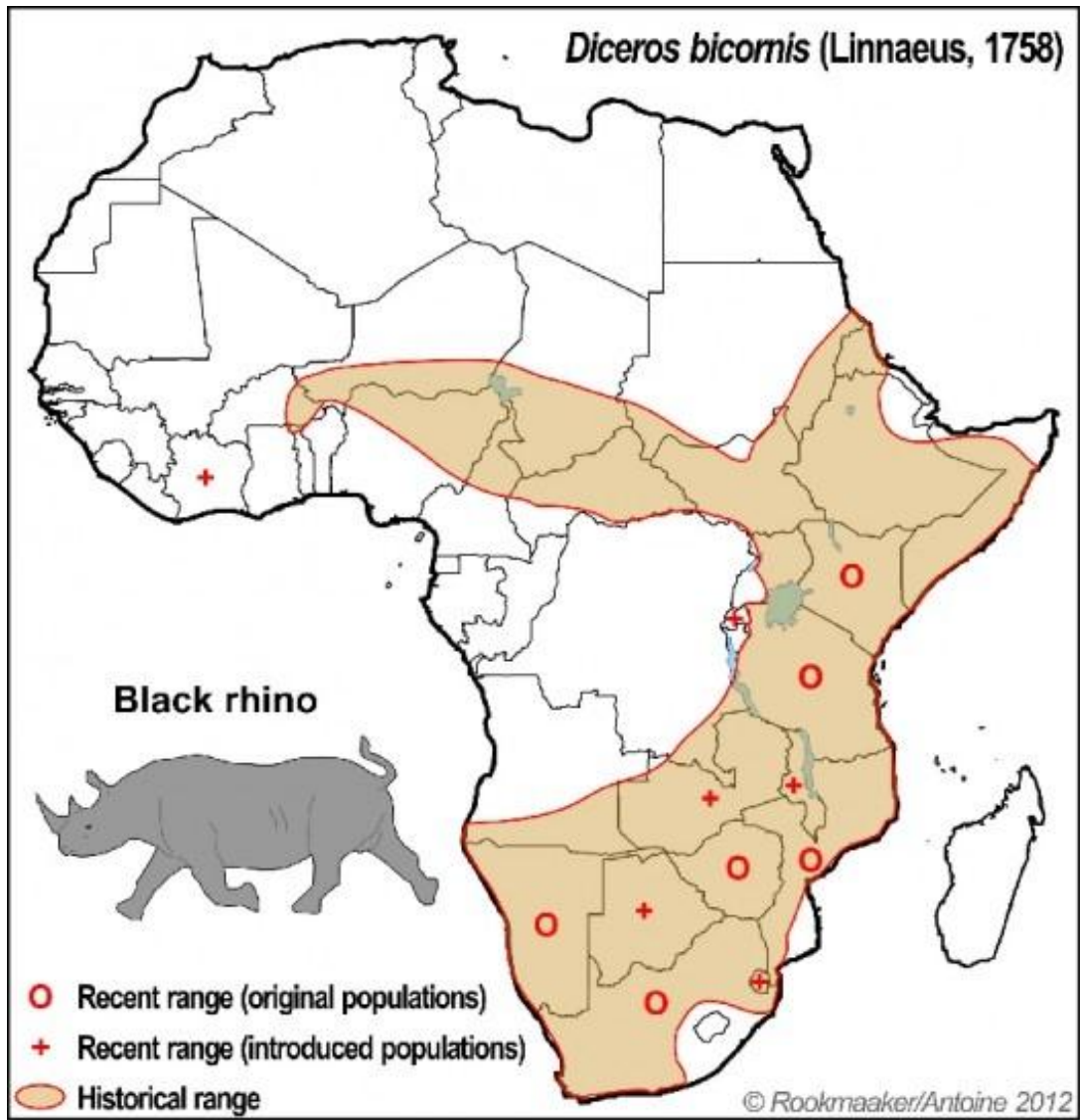
**Figure 1: Historical and current distribution range of Black rhino in Africa**

**(Source: Antoine & Rookmaaker, 2013)**

**2.2 Foraging Ecology**

**2.2.1 Ecology and behavior of Black rhino**

The Black rhino is a browser that eats leafy plants, branches, shoots, thorny wood bushes, and fruit (Oloo *et al.*, 1994; Matipano, 2003; Estes *et al.,* 2006). The optimum habitat is the one consisting of thick scrub and bushland, often with some woodland, which supports the highest densities of rhinos. Their diet can reduce the amount of woody plants, which may benefit grazers (which focus on leaves and stems of grasses), but not competing browsers (which focus on leaves, stems of trees, shrubs or herbs) (Buk *et al.*, 2012; Atkinson, 1995; Hall-Martin *et al*., 1982). Most browsing takes place within a 2m height zone from the ground (Owen-Smith, 1988). Habitat types are also identified based on the composition of dominant plant types in each area. Different sub-species live in different bushlands including, Acacia bushlands, Euclea bushlands, and mixed bushlands (Buk *et al*., 2012). The Black rhino has been known to eat up to 220 species of plants with significantly restricted diet; a preference for a few key plant species and a tendency to select leafy species in the dry season (Steuer *et al.,* 2010).

When seasonal resources are reduced (e.g. forbs during the dry season), the coexistence of these herbivores on woody browse is presumably facilitated by their enhanced tolerance of lower quality food, provided that the quantity is not limiting. In these cases, competition is projected to be asymmetric in favor of elephant, due to their larger size (elephant: rhino body mass ratio: R 3:1 for male and 5:1 for female), which confers an advantage in terms of the costs of agonistic interactions (Landman *et al.*, 2013; Muya, 2000; Buk *et al*., 2012). The reduced intake of preferred foods and change in diet along the grass-browse continuum has been shown to reduce diet quality in ungulates, with consequences for life-history traits (e.g. body mass and reproduction) as noted by Landman *et al.* (2013). Importantly, rhinos switched their preferences for grasses such that these are avoided foods where there are no other ungulates (Buk *et al*., 2012)

Regarding reproductive behavior, Black rhino calves begin to wean at about 2 months of age. Although females reach sexual maturity at 4-5 years, they do not have their first calf until they are 6.5-7 years old. Males claim a territory and mate at the age of 10-12 years old. Black rhinos may reach 40-50 years of age. Breeding is reported to occur throughout the year. The gestation

period is between 419 and 478 days, with an average interval of 2.5-3.5 years between calves (Estes, 2006).

## 2.2.2 Forage selection Indices

Most models currently used to describe the preference of animals for various plants under given conditions; all have serious shortcomings for purposes of accurately explaining the data, in the regression sense. According to Chutter (1972) when five equations, based in various ways on preference and availability, were used to estimate diets of cattle and sheep, no clear advantage of one expression over another could be found. Two commonly used indices as measures of food ecology selection are; Ivlev's electivity index and the forage ratio.

### i) Ivlev's electivity index

The purpose of the index is to characterize the electivity, or degree of selection, of a particular prey species by the predator being studied.

Ivlev's (1961) electivity index as follows:

$$Ei = \frac{ri - pi}{ri + pi}$$

Where E$i$ is the measure of electivity, r$i$ the relative abundance of prey item $i$ in the gut (as a proportion or percentage of the total gut contents) and P$i$ the relative abundance of the same prey item in the environment. The index has a possible range of -1 to + 1, with negative values indicating avoidance or inaccessibility of the prey item, zero indicating random selection from the environment, and positive values indicating active selection.

Although some problems of applying the index to field data have been identified in the literature, the index has generally been assumed to be unbiased and relatively independent of sample size (Ivlev's, 1961). On this basis it has been used and evaluated indiscriminately by many investigators. However, these assumptions have not been empirically or theoretically confirmed and, on the basis of the known behavior of similar indices, are probably invalid. Ivlev's index is a ratio of essentially continuous variables which have been converted to percentages or proportions. As such, an expression for its expected sampling variance cannot be derived exactly. An asymptotic estimate of the variance may be obtained if r$i$ and P$i$ are assumed to be normally

or binomially distributed, in which case the sampling distribution of the ratio E is skewed (Cochran 1977).

Atchley *et al.* (1976) have shown stochastically that ratios of this type have frequency distributions that are leptokurtotic and skewed to the right. In practical terms, this means that (1) the expected value of E under conditions of random feeding by the predator may not always be zero, and (2) a value for the variance calculated from several replicate field samples is not a good measure of the deviation of the calculated electivity index from its expected value. As a consequence, values of Ivlev's index should not be compared by use of t-statistics, which are sensitive to significant deviations from normality. This same criticism can be applied to the socalled forage ratio, which was used in early feeding studies but has now been largely supplanted by Ivlev's index. It is treated here because it is similar in form to many other biological indices (such as sex ratios, predator)

The first of these problems is a particular difficulty in aquatic systems, for which Ivlev's index has most often been used. It has repeatedly been demonstrated that routine sampling by traditional methods to determine relative abundances and biomass of benthic invertebrates is unreliable (Chutter 1972). The variability of numbers and proportions of species in benthic samples is generally much greater than that of total weights.

The second problem with this method is the fact that the diets predicted by Ivlev's Index do not sum to 1 in all cases. Ratios derived for one pasture and applied to a similar one give diets that are reasonable but do not sum to 1. Ivlev's (1961) index of electivity has been widely used as a means of comparing the feeding habits of fishes and other aquatic organisms with the availability of potential food resources in natural habitats.

## ii) Forage ratio

The stochastic model used is one which assumes random sampling by a predator species from a mixed pool of prey with a fixed proportion $\pi_i$ of prey species $i$ (in terms of either numbers of individuals or biomass). No specific distribution of prey items in space or in relative importance is assumed. However, it is assumed that the capture of any given prey item is independent of the capture of any other (that is, the trials are independent).

The main principal problem encountered in food selection studies involves obtaining an unbiased sample which accurately represents the relative abundances of the prey as they are consumed. A gut sample is unbiased in this respect only if all prey items are digested at equal rates. Under this index, a digestion rate higher than average for a particular prey type will tend to underrepresent that species in the gut sample, while rates lower than average will have the opposite effect. Chutter (1972), for example, demonstrated that brook trout (*Salvelinus fontinalis*) digest soft-bodied organisms such as dipteran larvae much more rapidly than heavily chitinized forms such as stonefly nymphs and caddisfly larvae.

In summary, the particular index chosen for a quantitative food selection study should be one which is easily interpreted and compared and which has a known statistical reliability. The linear index described in this study is suggested as one which fulfills these criteria. However, it must also be recognized that inadequate habitat sampling, differential availability of prey to the predator, and differential digestion of prey may be significant sources of error in the interpretation of food selection data.

### 2.2.3 Laws of population Ecology

It has been claimed that ecology is not law governed (O'Hara, 2005) the reasons for denying the existence of laws in ecology is not always clear. Ecology is too complex to submit to general laws. Often appeals are made to lack of generality and lack of predictive success, but the complicated nature of ecology seems to feature especially prominently in this debate. While it is true that populations are affected by a great deal around them—the weather, predators, parasites, resources, fertility, and so on—considerations elsewhere in science show that complexity alone does not disqualify a discipline from being law governed. The complexity might "wash out", (Strevens, 2003), or much of the complexity might be properly ignored in many situations.

There is a very natural way to think of a highly simplistic and idealized equation like Malthus's equation, $N(t)= N_0e^{rt}$ (where, N is the population abundance, t is time, N0 is the initial abundance, and r is the population growth rate), as a fundamental law of ecology. After all, this equation can be thought of as analogous to Newton's first law. Each describes what the respective system does in the absence of disturbing influences (O'Hara, 2005)

In the ecological case, Malthus' law tells us that populations tend to grow exponentially unless interfered with other forces (Strevens, 2003). Interference can come in the form of density dependence, predators, and so on. Of course there always are influences, so no population grows exponentially for any significant period of time. Malthus' equation can be thought of as a fundamental law of population growth—it describes the default case from which departures are to be explained. Moreover, like Newton's first law, Malthus' equation has considerable empirical support (e.g., the approximate exponential growth of microbial populations in laboratory situations). If we do treat Malthus' equation as a law, analogous to Newton's first law, we are then faced with the project of identifying the "ecological forces" that result in such departures from exponential growth (Ginzburg and Colyvan, 2004).

Malthus' law has only initial abundance and the growth rate as parameters, and these both concern properties of the population, not the individual (O'Hara, 2005). The real explanation for why a population has the abundance it does will be about births, deaths, immigrations, and emigrations of individual members. The law seems to ignore the individual events and the latter are what are causally relevant. How can such a law be genuinely explanatory? This argument against ecological laws being explanatory fails.

**2.3 Rhino population and causes of decline**

The numbers of Black rhinos dramatically declined in the 20th Century as a result of hunting by European settlers. Towards the end of the 20th Century their numbers declined from 65,000 in the late 1960s to an estimated 3,500 in the 1990s (Hearne and Swart, 1991). The Black rhinos are now limited to a patchy distribution from Cameroon in the west, to Kenya in the east and south to South Africa, continentally there are now 5,055 Black rhinos (Emslie and Brooks, 1999; Save the Rhino, 2013).

Earlier in the 20th Century hunting to clear land for agriculture and human settlement was the main cause for the decline of African rhinos. According to Martin and Martin (1987) the major cause for the catastrophic decline of rhinos in the last quarter of the 20th Century was illegal hunting to meet insatiable demand for their horn in the Middle East and Eastern Asian markets. Historically, in medieval Europe, rhino horn was fashioned into chalices believed to have the power of detecting poisons. In the Far East, and in the many East Asian communities, the horn is

still used as a fever-reducing ingredient and an aphrodisiac in traditional Chinese medicine. In the Middle East, it is carved and polished to make prestigious dagger handles (WWF, 2004). As a result one subspecies, *Diceros birconis longipes* which once dominated sub-Saharan Africa has gone extinct (Emslie, 2011). Additionally, land encroachment, illegal logging and pollution are destroying their habitat and political conflicts adversely affect conservation programmes (Sinclair *et al.*, 2008).

According to Emslie *et al.* (2007), population characteristics such as annual population growth rates and inter-calving intervals for populations performing well (7% per annum, ICI<2.5 yrs), averagely (5-6%, 2.8 yrs) or very poorly (<3%, >3.5 yrs) is relevant in conservation initiatives. As a result of no or insufficient information on rhinos, non-experts generally grossly overestimate Black rhino ecological carrying capacities, and this could lead to overstocking, poor performance and even death of animals. Therefore the study of population characteristic is important as it helps in an elaborate study of any population and consequently makes comparisons of different attributes possible. When reliable information on births and deaths rates of animals is not available, population characteristics such as age-sex distribution, it may be utilized to obtain these data. Additionally, the data on population characteristics are useful in the preparation of inventories of resources necessary for effective developmental planning (Emslie, 2011).

In Tanzania, the rhino population declined drastically due to high poaching pressure in 1970s and by the end of 1990 only three isolated small populations remained at Ngorongoro Crater, Serengeti National Park and Selous Game Reserve (Makacha *et al.*, 1982; Sinclair, 1995) respectively. In the Serengeti ecosystem alone, two major factors that contributed to the high poaching activities that affected the rhino population in the 1980s were identified as increasing anthropogenic activities close to the boundaries of the protected areas and increasing human population which resulted in the blockage of wildlife corridors (Emslie, 1999). Moreover, lack of connectivity among protected areas is probably suppressing the genetic diversity of the endangered species (Nevo *et al.*, 1984; Makacha *et al.,* 1982; Emslie, 1999).

## 2.4 Important rhino conservation areas in Tanzania and Conservation interventions

In Tanzania, before the 1960s, the Black rhino population ranged from Mkomazi Game Reserve (now upgraded to a national park) in the north-east, to Lake Victoria in the north-west and from Selous Game Reserve in the south to Ruaha National Park in central Tanzania (Frame, 1980). The Black rhino population in Serengeti National Park alone was about 700 individuals in 1974 (Frame, 1980). Wildlife and habitat deteriorated significantly through invasion by livestock and heavy poaching in Mkomazi occurred in the 1970s and 80s due to inadequate funding and levels of protection. This included the loss of all resident Black rhino and virtually all the elephant. Currently, the important rhino conservation areas in Tanzania include; Serengeti, Mkomazi, Selous and Ngorongoro Conservation Area (Fyumagwa and Nyahongo, 2010).

In 1989, the Government of Tanzania invited the George Adamson Wildlife Preservation Trust (GAWPT) to work with them to undertake a rehabilitation programme for Mkomazi, including restoration of habitat and re-introduction and breeding programmes for the highly endangered wild dog and Black rhino. GAWPT introduced four Black rhinos into Mkomazi Game Reserve in 1997. In 2001, the GAWPT added four more rhinos into the same game reserve making a total of eight rhinos, four females and four males (Fyumagwa and Nyahongo, 2010). The recovery of the Mkomazi Game Reserve was enabled by the Tanzanian Wildlife Division and the GAWPT through extensive rehabilitation of the infrastructure of the reserve, with work activities bolstered by local community involvement and projects linked to wildlife protection and maintaining the integrity of the MNP. The Government gazetted Mkomazi, formerly a Game Reserve to National Park status in 2008 (Fyumagwa and Nyahongo, 2010).

The number of Black rhino in the Ngorongoro Crater decreased from about 200 in the early 1960's to 20 by mid-1970's (Sinclair *et al.,* 2008). The rhino population has fluctuated around 20 individuals for the last thirty years and the last poaching incident was in 1995. The security in the Crater has greatly improved over the last decade and the risk of poaching is now much reduced (Sinclair *et al.,* 2008). Frankfurt Zoological Society (FZS) brought two female rhinos into Ngorongoro Crater from South Africa in 1997 aimed at mixing the genes of rhinos in the Crater so as to avoid possible inbreeding (Norton-Griffiths, 2007).

Despite the improved security, the rhino population in the crater has not increased to its original numbers. From 1996 to 2000 a study of Ngorongoro Crater ungulate ecology was carried out at the request of the Ngorongoro Conservation Area Authority and sponsored by the World Conservation Union of Nature (IUCN). The project focused on the effects of environmental changes and impacts of human activities on wildlife habitats, corridors, distribution and behavior, identified by the General Management Plan of 1996. The wildlife monitoring programme continued in the Crater since 1963 (Estes *et al.,* 2006).

In order to address rampant poaching several conservation and security measures were put in place worldwide in the year 2000 (Walpole *et al*., 2001). This included the formulation and enforcement of policy interventions (e.g. CITES), which ban trade in species in various categories. Other policy initiatives include the Convention on Biological Diversity (CBD), which focuses on saving global flora and fauna. This has been customized at national and regional level. At national level, through the preparation of the National Biodiversity and Strategic Action Plans (NBSAPs) and at a regional level there exists the Lusaka Agreement Task Force responsible for monitoring and enforcing regulations on regional trafficking and trade in wild species or parts of endangered species (Walpole *et al*., 2001). TRAFFIC International investigates and analyzes wildlife trade trends, patterns, impacts and drivers to provide the leading knowledge base on trade in wild animals and plants; and informing, supporting and encouraging action by governments, individually and through inter-governmental cooperation to adopt, implement and enforce effective policies and laws.

At a national level efforts have included the formulation of legislation (e.g. Wildlife Management and Conservation Act of 2013 in Kenya and Wildlife Policy of 1974 in Tanzania). Designation of protected areas and enhanced anti-poaching efforts, law enforcement, sensitization of the communities living adjacent to the protected areas and monitoring rhinos through regular population censuses have also been significant efforts in conserving habitats, species and creating stewards for conservation of rhinos (Walpole *et al.,* 2001). These interventions have been effective in certain areas but have not worked in other areas. An example is the conservation efforts by Tanzanian government on the remaining local population of rhinos in Ngorongoro Crater, Serengeti National Park and Selous Game Reserve were given special monitoring systems and law enforcement was strengthened (Sibalatini, 2004). During the

operation many illegal immigrants from Somalia who were at the forefront in the ruthless and illegal killing of rhinos and elephants were repatriated and many illegal arms were confiscated (Sinclair *et al*., 2003).

A range of options for establishing rhino protection areas is described in the IUCN African rhino plan; these are helpful in developing solutions appropriate to the local situations, habitats and threats and the limitations of funding and expertise. However, the efforts in some areas failed. For instance in Serengeti ecosystem, introduction of protection fences failed initially. The failure of fences-and-fines strategies, combined with increasing international focus on the welfare of local people, led to a new strategy for conservation, a paradigm shift towards community-based conservation (Western *et al.*, 1994; Sinclair, 1995). Tanzanian government took a bold action to reduce the rampant poaching when the rhino population approached extinction level. In order to create public awareness on the poaching of rhinos, the government launched a special operation in 1989 called *Operesheni Uhai*, a Swahili phrase meaning 'operation save life', which coincided with the world ban on ivory trade (Sinclair *et al*., 2003). As a result of these conservation measures, Black rhino population has increased to 88 in Tanzania while Ngorongoro Crater has estimated population of about 40 individuals despite the existing waves of poaching worldwide (Sinclair *et al*., 2003).

## 2.5 Literature summary and research gaps

The reviewed literature attribute the drastic decline in population of the rhino to rampant poaching that was pervasive in early 1970 to late 1990s (Frame, 1980). As a result of poaching pressure, several conservation efforts worldwide have set up measures to reduce the menace which includes putting the rhino horn and rhino parts beyond economic use by CITES, enhancement of anti-poaching activities, law enforcement, education of the communities surrounding the protected areas and regular population censuses. However, in reality poaching is not the sole reason for decline in population of rhino in their habitats. Other factors include food unavailability, competition among related families for space and other resources, habitat degradation among others. Moreover, there has been limited research on spatial and-temporal dynamics of Black rhino distribution. There are no studies done on the Black rhino population trends, distribution and foraging ecology simultaneously. This study was therefore vital in assessing these parameters so as to establish whether for instance the distribution of Black rhino

was influenced by forage availability and seasonal trends and whether the population trends was related to forage availability.

With respect to foraging ecology studies from the reviewed literature indicate that the rhino habitat optimally comprises of thick scrub and bushland, often with some woodland, and that these habitats support the highest rhino densities. Also habitat types are identified based on the composition of dominant plant types in each area. Additionally, the studies indicate that rhinos have a significantly restricted diet with a preference for a few key plant species and a tendency to select leafy species in the dry season (Steuer *et al.,* 2010). However, no studies have been carried out on Black rhino diet selection and forage availability in a crater ecosystem. Broadly, the literature reviewed points out that there are four recognized sub-species of rhino; the southern-central Black rhino (*Diceros bicornis minor*), South-western Black rhino (*Diceros bicornis bicornis*), the East African Black rhino (*Diceros bicornis michaeli*) and West African Black rhino (*Diceros bicornis longipes*). However it does not illustrate the trends in population size, growth, and age-structure of specific rhino species. This study aimed to elucidate on population attributes of East African Black rhino that include population size, growth, age-structure and their spatial distribution as well as the feeding ecology.

## 2.6 Conceptual framework

The conceptual framework below puts the spatial-temporal and population attributes of Black rhino in Centre of their focus (Figure 2). These dependent variables are influence by independent variables that range from anthropogenic to ecological dynamics. Independent variables include; weather conditions (Seasons), vegetation classes and growth forms as well as human activities such as grazing and infrastructural development (i.e. roads, lodges etc.). Other independent variables that influence distribution of rhinos were availability of water and presence of intra-specific and inter-specific competitions within their ecological niches. Human activities and presence of competitors influence forage availability indirectly as well as distribution and population attributes.

**Independent variables**

- Seasonal variations
- Vegetation types
- Relative cover
- Relative availability

**Human activities**
- Livestock grazing
- Infrastructure
- Tourism

**Competition**
- Intra-specific
- Inter-specific

Hydrology

**Dependent variables**

Forage availability,

Preference and Selection

**Distribution**
- *Spatial*
- *Temporal*

**Population attributes;**
- *Population size*
- *Sex ratio*
- *Age structure*
- *Growth rate*

**Figure 2: Conceptual framework**

⟶  Direct relationship

- - - ⟶  Indirect relationship

18
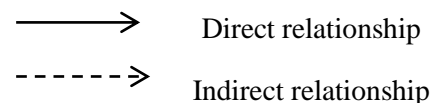
# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Study area

## 3.1.1 Location and size

Ngorongoro Conservation Area (NCA) is located at 3°12′S, 35°27′E. The NCA covers a total area of 8,292km$^2$. It borders Loliondo to the North, Serengeti National Park and Maswa Game Reserve to the west, the Great Rift Valley to the east, and Karatu farmlands and Lake Eyasi to the south. In the heart of NCA lies a collapsed volcano, the Ngorongoro Crater, which hosts 99% of the Black rhinos in the Ngorongoro Conservation Area (Figure 3). This is the world's largest intact caldera with floor area measuring about 250-260km$^2$ (Roodt, 2012). The NCA was established in 1959 as a multiple land use area where wildlife and human activities coexisted. The conservation area is managed by the Ngorongoro Conservation Area Authority (NCAA), an arm of the Tanzanian Government. Administratively, the NCA falls under the Ngorongoro Division of the Ngorongoro District, Arusha Region.
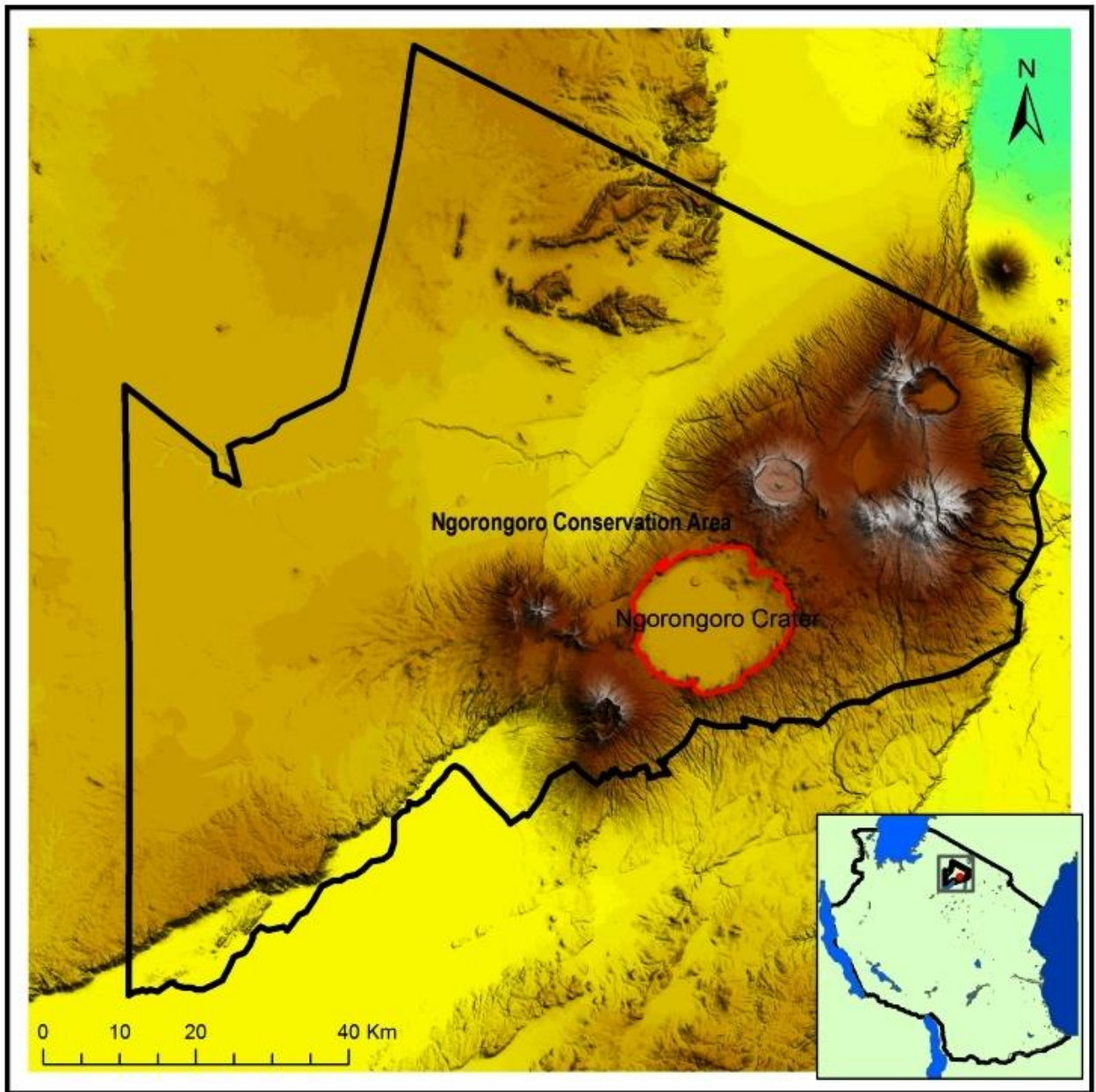
**Map datum and Projection: ARC 1960**

**Data source: NCAA and Field survey, 2015**

**Figure 3: Map of Ngorongoro Conservation Area**

### 3.1.2 Climate and topography

The main feature of the Ngorongoro Conservation Area is the Ngorongoro Crater, the world's largest inactive, intact, and unfilled volcanic caldera. It is 610m (2,000 feet) deep and its floor covers 260km$^2$. Estimates of the height of the original volcano range from 4,500 to 5,800m (14,800 to 19,000 feet) high. The NCA has an altitudinal range of 960m to 5800m. The elevation of the crater floor is 1,800m (5,900 feet) above sea level and 2235m at crater rim. Its climatic zones range from semi-arid to montane forest, all of it accounts to widely ranging levels of precipitation (from under 500mm to 1700mm) and annual average temperature oscillate between 2°C to 35°C. The crater floor is much hotter than the rim, which is often swathed in morning fog, and depending on the time of the year, can range from warm to chilly to freezing at night. The crater highlands on the forested eastern slopes facing the easterly trade winds receives 800 to 1500mm of rain a year and the less-steep west wall receives only 400 to 600mm of rainfall and covered by thickets, shrubs and other grassland vegetation. The crater is generally dry in months of January and February, May to July and wet during moths of April and August. However the western plains are particularly dry during February and between June and September. It therefore consists of micro-habitat that includes a saline lake, swamp, plain and forest.

### 3.1.3 Hydrology

The Munge stream drains Olmoti Crater to the north, and is the main water source draining into the seasonal salt lake in the center of the crater, Lake Magadi. The crater floor has several fresh water springs including Lerai and Ngoitoktok. There are three large swamps namely Ngoitoktok, Gorigor and Mandusi (Estes, 2002). There is no outlet for water in the crater and therefore water percolates down through the crater floor and in other sites accumulates forming swamps and lake. The Lerai forest and Lake Magadi filled by the Munge river, along with the famous hippo pool, are surrounded by vast plains that cover a crater floor which is up to 20km wide (260 km$^2$).

### 3.1.4 Vegetation

To the highlands' montane forest and grassland, the NCA includes the semi-arid short-grass plains lying between the highlands and Serengeti National Park which are an integral part of the 30,000km$^2$ Serengeti ecosystem (Tukahirwa, 1997). The crater floor is mostly open grassland with two small wooded areas dominated by *Acacia xanthophloea* and *Euphorbia bussei* trees.

Weed infestations recurred in the crater grasslands in year 2002 where an estimated three-quarter of the floor was overgrown, mainly by *Bidens schimperi* and *Gutenbergia cordifolia* (Henderson, 2002). Both are indigenous species that frequently cover sizeable areas, forming tall, dense stands that can shade out the underlying grass and persist after drying until burned or trampled. As most of the crater's grazers and browsers avoid weed infested areas, the extent of good pasture can be significantly reduced (Roodt, 2012). On the rim of the crater towards the eastern and southern part, the dominant vegetation type is dense forest with *Croton macrostachyus* and *Nuxia congesta* as dominant tree species while on the western part of crater which lies on the leeward section is covered by sparse woody vegetation mainly acacias and dominated by grasses such as *Themeda triandra* and *Chloris gayana.*

### 3.1.5 Conservation importance of the Ngorongoro Crater

The Ngorongoro Crater has global importance for biodiversity conservation due to the presence of globally threatened species, the density of wildlife inhabiting the area, and the annual migration of wildebeest, zebra, gazelles and other animals into the northern plains. Approximately 25,000 large animals, mostly ungulates, live in the crater (Roodt, 2012). Large animals in the crater include the Black rhino (*Diceros bicornis*), the local population of which declined from about 108 in year 1964-66 to between 11-14 in year 1995, the African buffalo (*Syncerus caffer*), and the Hippopotamus (*Hippopotamus amphibius)*. There are also many other ungulates: the wildebeest (*Connochaetes taurinus*) (7,000 estimated in year 1994), Burchell's zebra (*Equus burchelli*) (4,000), the common eland (*Taurotragus oryx*), and Grant's (*Gazella granti*) and Thomson's gazelles (*Gazella thomsoni*) (3,000). Waterbuck (*Kobus ellipsiprymnus*) occur mainly near Lerai Forest. Impala (*Aepyceros melampus*) and giraffes (*Giraffa camelopardalis*) are absent because the open woodland they prefer does not exist in the crater floor. Cheetah (*Acinonyx jubatus*), African wild dog (*Lycaon pictus*), and Leopard (*Panthera pardus*) are rarely seen. Some of the species are of global conservation concern including Lion (Vulnerable), African wild dog (Endangered) and Leopard (Near Threatened) (Estes *et al*., 2006). Besides mammals, the site is of global conservation importance with respect to avifaunal diversity. It hosts bird species of global conservation concern such as Livingstone turaco, Rufous-tailed weaver, Hartlaubs' turaco and Jackson's widow bird (Birdlife International, 2016)

### 3.1.6 Socioeconomic activities

Land in the conservation area is multi-use and unique because it is the only conservation area in Tanzania that protects wildlife while allowing human habitation (Emslie, 2011). Land use is controlled to prevent negative effects on the wildlife population. For example, cultivation is prohibited in NCA. The Ngorongoro Conservation Area (NCA) is unique because it is one of the few places on earth where humans and wildlife coexist (Melita and Mendlinger, 2013). The NCA became a Man and Biosphere Reserve in 1971 and was declared a World Heritage Site by UNESCO in 1979. Originally part of the Serengeti National Park when the later was established by the British in 1951; in 1959 the Ngorongoro Conservation Area Authority (NCAA) was formed, separating NCA from Serengeti. Semi-nomadic Maasai and Datoga pastoralists practice traditional livestock grazing within the area, an activity which easily coexists with conservation of wildlife. As well, the area attracts about 300,000 tourists a year for both wildlife and cultural tourism. Extensive archaeological research has also yielded a long sequence of evidence of human evolution and human-environment dynamics, including early hominid footprints dating back 3.6 million years. No human settlements are allowed in the crater floor and livestock are only allowed to drink fresh water and lick salts near or at Seneto springs during the day time. Tourists are allowed to see the animals between 0600hrs and 1800hrs in the crater floor (Melita and Mendlinger, 2013).

### 3.2 Data collection

### 3.2.1 Rhino distribution mapping

Road drives were conducted daily for a period of one month during each season to map the spatial distribution of the Black rhino, and assess the relative abundance of its forage resources and diet selection. During each drive, the roadsides were inspected for the presence of rhinos, with stops being made each time an individual or group of rhinos is located. In addition, rhinos were located from 13 established ranger observation points distributed strategically within the crater. The approximate position of any sighted individual or group was marked using any conspicuous landmarks. Subsequently, the rhinos were observed from a safe distance using a pair of binoculars and their sex, age (calves, sub-adults and adults) and group sizes was recorded. Efforts were made to ensure minimal interference with the normal behavior of rhinos during location and observation. Once the individual or group of rhinos under observation moved to a

safe distance, its original location was accessed (either by car or by foot) and the geographical position recorded using a hand-held GPS.

### 3.2.2 Forage availability surveys at rhino foraging sites

During each season 50m by 50m plots were established at sites where rhinos were encountered foraging and surveyed for forage availability and rhino bite marks. Vegetation was sampled along four 50-m long line transects placed systematically at 10-m intervals across each plot. For woody vegetation plant canopy cover was measured along each transect using the line intercept method. This involved measuring the lengths of woody plant canopies intercepting each transect by species. Relative canopy cover was then estimated for each species by totaling the canopy intercepts of the species divided by the total number of intercepts by all species and multiplying the result by 100. Herbaceous plants (grasses and forbs) were sampled using the point-step method. This involved placing a 1m long pin 25 times at 2m intervals along each transect, and recording the first hits on herbaceous vegetation by species. Pins not touching vegetation were recorded as bare hits. Relative cover of each herbaceous species was calculated as the total number of pin hits on that species divided by the total number of pin hits on all species, multiplied by 100. Plants were categorized based on whether or not their canopies are within 2m from the ground level, the typical upper limit of the foraging height of an adult rhino (Bonham, 1989; Oloo *et al*., 1994; Bureau of Land Management, 1996; Muya and Oguge, 2000). Plants were also categorized into different vegetation classes (trees, shrubs, forbs).

### 3.2.3 Forage consumption and selection surveys

To assess the relative use of different plants by the Black rhino, each vegetation sampling transect was inspected for Black rhino bite marks. This method involved counting and recording the number of rhino bite marks by plant species within 2m of either side of each transect. The bites of rhino was discerned from other browsers' bites from its sharp-cut edges (Plate 1)

**Plate 1: Black rhino fresh bites on *Amaranthus hybridus***



**Plate 2: Rhino bite on *Acacia xanthophloea***

The relative bites on each species were calculated for each plot by dividing the total number of bites on that species by the total number of bites on all species. Diet selection was assessed using Ivlev's (1961) electivity index as follows:

$$Ei = \frac{ri - pi}{ri + pi}$$

Where $E_i$ is the measure of electivity, $r_i$ *is* the relative bites on plant species *i*, and $p_i$ is the relative cover of species *i*. The index ranges between 1 and -1, where -1 indicates total avoidance, 0 indicates no selection or avoidance, and 1 indicates total selection.

### 3.2.4 Assessment of population trends

The study relied on the population records collected by NCA over the past 15 years to analyze trends in population attributes of interest (size, age-structure, sex ratio and growth rate). Records were available from daily Black rhino surveillance patrols in the Ngorongoro Crater dating back to year 2000 at the NCA's department of conservation services. These records included rhino identities, numbers, ages and sexes. Growth rate was estimated by calculating change in population size and dividing it by the period of time corresponding to that change. Sex ratio (female: male) was obtained by dividing the number of females by number of males. To assess the age structure, the population was sub-divided into three age groups; 0-4 years old (calves), 5-7 years old (sub-adults) and above 7 years (adults), in accordance with several authors (Owen-Smith, 1988; Walpole *et al*., 2001; Hrabar and du Toit, 2005).

### 3.4 Data analysis

All statistical analyses were carried out using Microsoft excel 2010 and Minitab 14.0. Data exploration was done using box-plots. In all cases, normality and homogeneity test showed data followed normal distribution pattern and the assumptions made were valid.

Table 1 shows the summary of variables under study and statistical tests.

**Table 1: Summary of data analysis**

| Research Questions | Variables | Statistical Test |
|---|---|---|
| How are the Black rhino individuals distributed within the Ngorongoro Crater? | Geographical locations | Descriptive statistics |
| How has the Black rhino population changed over the past 15 years? | Population size, Sex ratio Growth rate, Age structure | Descriptive statistics (frequencies and percentages) |
| What are the preferred plant species by Black rhino? | Relative cover, relative availability Number of bites | Two sample t-tests, ANOVA and Ivlev's Index, |

## RESULTS

### 4.1 Spatial distribution of the Black rhino in Ngorongoro Crater

The distribution patterns of the Black rhino differed markedly between wet (May-June, 2015) and dry (August-September, 2015) sampling periods (Figure 4 and Figure 5). During the dry period, rhinos were mainly concentrated in the crater slopes dominated by shrubby vegetation, swamps and along riverine areas of the crater. In the crater walls the Black rhinos were largely sighted on the southern inner walls of the Ngorongoro Crater, Ngoitoktok shrubland (63%), in Leyanai area (22%), and in crater floor Mandusi swamps (12%). Moreover, some individuals were seen in the small perched forest of Lerai in the western side of the crater floor (2%). In the wet period, however, rhinos were found mainly in crater floor mostly in areas around Lake Magadi and near Lerai forest (39%) and in grasslands (37%). Notably, the rhinos avoided areas west and east of crater in both sampling periods.
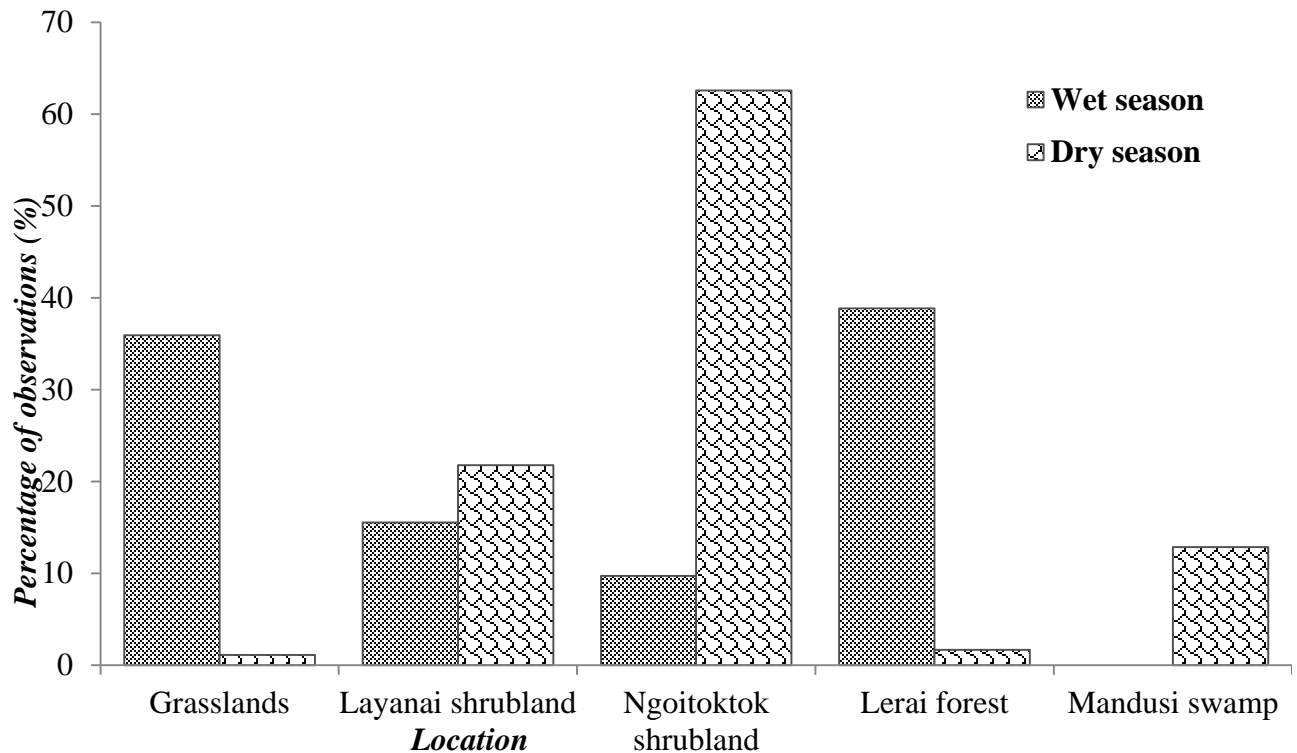


**Figure 4: Percentage sightings of Black rhinos across different vegetation types in Ngorongoro Crater during May-June 2015 (wet season) and August-September 2015 (dry)**
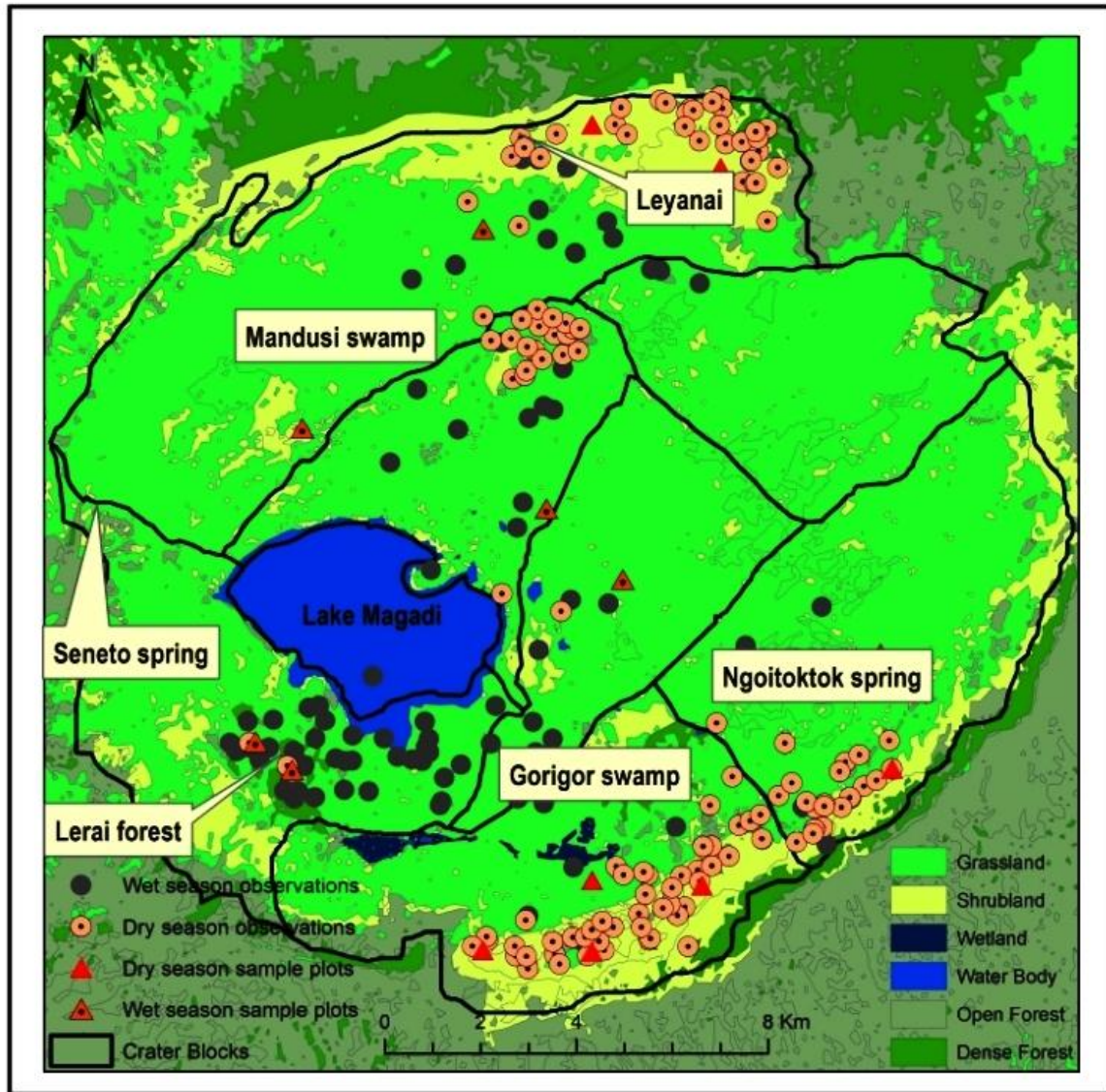
**Figure 5: Rhino distribution across Ngorongoro Crater during May-June 2015 (wet season) and August-September 2015 (dry season).**

**4.2 Vegetation attributes at Black rhino feeding sites**

**4.2.1 Herbaceous vegetation cover**

Overall, during the wet season (May-June) grasses and forbs occurred in nearly equal proportions at rhino foraging sites (relative cover = 50.4% and 49% for grasses and forbs, respectively). Grasses were more common in the dry (August-September) than the wet (May-June) sampling period, while the converse was the case for forbs. Overall, the most common grasses were *Chloris gayana*, *Cynodon dactylon*, *Themeda triandra*, *Setaria spp.* and *Pennisetum clandestinum* (Table 2). Of these dominant grasses, *Chloris gayana, Setaria spp* and *Themeda triandra* were more common in the dry than the wet sampling period, while the others exhibited a converse pattern. *Amaranthus hybridus*, *Gutenbergia cordifolia*, *Eracastrum arabicum* and *Commelina bengalensis* were the dominant species of forbs. Of these forbs, *Oxalis latifolia, Gutenbegia codirdifolia*, and *Amaranthus hybridus* were significantly more common in the wet than dry sampling period. A similar pattern was exhibited by *Bidens schimperi*, a rarer forb species.

**Table 2: Relative cover (%; mean ± SE) of different herbaceous species at rhino feeding sites in Ngorongoro Crater at different sampling periods**

| Herbaceous | May-June, 2015 | Aug-Sep, 2015 | | | |
|---|---|---|---|---|---|
| Species | Mean ± SE | Mean ± SE | Mean ± SE | t-value | p-value |
| **Grasses** | | | | | |
| *C. gayana* | 6.3±3.7 | 42.9±11.3 | 24.1±3.2 | -3.17 | **0.013** |
| *P. clandestinum* | 7.3±2.1 | 1.4±1.1 | 4.3±0.6 | 2.49 | **0.032** |
| *C. dactylon* | 15.7±3.2 | 1.7±1.7 | 8.7±1.1 | 3.83 | **0.003** |
| *Cyperus spp* | 7.8±3.1 | 1.5±0.7 | 4.7±0.5 | 1.98 | 0.088 |
| *D. aegyptium* | 5.5±3.0 | 0.1±0.0 | 2.8±0.2 | 1.78 | 0.118 |
| *T. triandra* | 2.7±0.9 | 32.2±7.7 | 17.4±2.3 | -3.78 | **0.007** |
| *Setaria spp* | 0.1±0.3 | 16.3±3.9 | 8.2±1.2 | -4.14 | **0.004** |
| *D. macroblephara* | 5.0±1.3 | 0.2±0.1 | 2.6±0.1 | 3.78 | **0.007** |
| **Total grasses** | **50.4**±1.6 | **96.3**±6.0 | **72.8**±8.7 | **2.77** | **0.272** |
| **Forbs** | | | | | |
| *E. arabicum* | 8.2±3.7 | 0.1±0.1 | 4.1±0.2 | 2.17 | 0.067 |
| *G. codirdifolia* | 6.6±1.2 | 0.1±0.1 | 3.4±0.1 | 5.31 | **0.001** |
| *O. latifolia* | 6.5±2.1 | 0.0±0.0 | 2.7±0.9 | 2.52 | **0.04** |
| *T. burchellianum* | 4.3±2.3 | 0.1±0.0 | 2.2±0.6 | 1.84 | 0.109 |
| *A. hybridus* | 9.5±2.1 | 0.1±0.1 | 5.7±0.5 | 4.24 | **0.000** |
| *T. minuta* | 4.9±2.0 | 0.0±0.0 | 2.7±0.1 | 2.38 | 0.060 |
| *B. schimperi* | 1.3±0.3 | 0.0±0.0 | 0.7±0.0 | 3.24 | **0.012** |
| *C. bengalensis* | 5.4±3.0 | 0.1±0.2 | 2.9±0.1 | 1.77 | 0.121 |
| *U. panicoides* | 2.3±0.2 | 2.7±1.6 | 2.5±0.3 | -1.55 | 0.165 |
| **Total forbs** | **49.6**±0.9 | **3.37**±0.3 | **27.2**±4.5 | **22.24** | **0.575** |

### 4.3.2 Canopy cover of shrubs

The shrub layer at Black rhino feeding sites was dominated by *Sphaeratus bullatus, Lippia javanica, Hypericum revolutum, Caparis tomentosa, Clausena anisata* and *Abutilon longicupsis* (Table 3).

**Table 3: Relative canopy cover (%; mean ± SE) of shrubs at Black rhino feeding sites in Ngorongoro Crater at different sampling periods**

| Species | (May-June 2015) | (Aug-Sept 2015) | Mean | t-value | p-value |
|---|---|---|---|---|---|
| *Abutilon logiscupsis* | 10.2±2.2 | 3.5±1.0 | 7.0±1.4 | -2.8 | **0.019** |
| *Asclepias fruticosus* | 0.3±0.3 | 0.6±0.4 | 0.4±0.2 | 0.75 | 0.464 |
| *Aspilia mosambicensis* | 0.0±0.0 | 1.2±0.7 | 0.6±0.4 | 1.58 | 0.132 |
| *Basella alba* | 0.0±0.0 | 4.6±1.6 | 2.3±1.0 | 2.86 | 0.012 |
| *Buddleiya polystachya* | 0.0±0.0 | 5.7±2.4 | 2.8±1.4 | 1.28 | 0.035 |
| *Calpunia aureta* | 0.0±0.0 | 3.7±1.5 | 1.8±0.9 | 1.26 | **0.027** |
| *Caparis tomentosa* | 0.3±0.0 | 13.1±9.5 | 6.6±4.9 | 1.36 | 0.199 |
| *Clausena anisata* | 0.0±0.0 | 4.9±2.4 | 2.5±1.3 | 0.01 | 0.058 |
| *Hibiscus aponeurus* | 0.0±0.0 | 3.8±3.1 | 1.9±1.7 | 0.04 | 0.267 |
| *Hibiscus fuscus* | 0.0±0.0 | 11.1±4.5 | 5.5±2.8 | 2.22 | 0.041 |
| *Hypericum revolutum* | 20.7±5.4 | 0.2±0.2 | 10.4±3.8 | -3.77 | **0.007** |
| *Hypoestes forskahlii* | 4.4±1.4 | 0.0±0.0 | 2.2±0.9 | 0.12 | **0.000** |
| *Justicia betonica* | 23.7±7.0 | 1.00±0.8 | 11.9±4.6 | -2.90 | **0.001** |
| *Lantana trifolia* | 0.0±0.0 | 2.08±1.2 | 1.0±0.7 | 0.10 | 0.116 |
| *Lippia javanica* | 0.0±0.0 | 25.6±11.7 | 12.7±6.6 | 1.80 | 0.046 |
| *Lippia ukambensis* | 1.5±1.3 | 5.1±2.3 | 3.3±1.4 | -0.54 | 0.189 |
| *Solanum aculeastrum* | 0.1±0.0 | 1.7±0.7 | 0.9±0.4 | 2.40 | 0.047 |
| *Sphaeratus bullatus* | 22.9±4.8 | 4.7±3.0 | 11.4±3.8 | -3.20 | **0.008** |
| *Vernonia auriculifera* | 0.7±0.7 | 1.0±0.6 | 0.8±0.4 | -0.10 | 0.687 |
| Other species | 16.0±0.1 | 7.6±2.4 | 11.8±4.2 | 0.12 | 0.256 |

Among the shrubs that differed significantly between sampling periods, *Sphaeratus bullatus*, *Hypericum revolutum*, *Justicia betonica* and *Abutilon longicupsis* were more common in the wet (May-June) than dry (August-September) sampling period, while the converse pattern was the case for the others. The combined relative cover of all other species that were relatively less common (*A. fruticosus, A. mosambicensis, Caparis tomentosa, Hibiscus aponeurus, Lantana trifolia* and *Lippia ukambensis*) did not differ significantly between sampling periods

### 4.3.3 Canopy cover of trees

The tree layer at the sampled Black rhino feeding locations was dominated by *Acacia xanthophloea*, *Croton megalocarpus* and *Osyris lanceolata,* each of which comprised more than 10% of the tree canopy cover (Table 4)*.*

**Table 4: Relative canopy covers of trees (% mean +SE) at Black rhino feeding sites in Ngorongoro Crater at different sampling periods**

| Trees species | May-Jul 2015 | Aug-Sep 2015 | Mean | p-value |
|---|---|---|---|---|
| *Acacia xanthophloea* | 36.4±15.0 | 0.2±0.2 | 18.3±8.6 | 0.030 |
| *Bersama abyssinica* | 0.0±0.0 | 3.0±2.1 | 1.6±1.1 | 0.182 |
| *Clutia abyssinica* | 11.5±11.5 | 1.8±1.0 | 6.6±5.7 | 0.416 |
| *Combretum molle* | 0.0±0.0 | 4.8±3.0 | 2.4±1.6 | 0.125 |
| *Croton macrostachyus* | 0.0±0.0 | 8.8±2.7 | 4.4±1.7 | 0.000 |
| *Croton megalocarpus* | 0.0±0.0 | 29.1±9.8 | 14.5±6.0 | 0.000 |
| *Ekebergia capensis* | 0.0±0.0 | 8.3±3.1 | 4.1±1.9 | 0.020 |
| *Euclea divinorum* | 1.1±1.1 | 2.8±2.0 | 1.9±1.1 | 0.436 |
| *Nuxia congesta* | 0.0±0.0 | 8.1±3.2 | 4.0±1.9 | 0.024 |
| *Osyris lanceolata* | 0.0±0.0 | 25.0±13.7 | 12.6+7.4 | 0.088 |
| *Rauvolfia cafra* | 17.6±12.8 | 0.0±0.0 | 8.8±6.6 | 0.192 |
| *Vangueria spp* | 0.0±0.0 | 0.7±0.5 | 0.3±0.2 | 0.156 |
| Other species | 32.7±9.2 | 1.9±0.2 | 17.3±3.6 | 0.025 |

Other common tree species were *Rauvolfia spp., Clutia abyssinica*, *Croton macrostachyus*, *Ekebergia capensis*, and *Nuxia congesta*. Of the tree species that differed significantly between

sampling periods, *Acacia xanthophloea* was more common in the wet than dry sampling period, while all the rest showed a converse pattern (Table 4)

## 4.4 Diet composition

Rhino bites comprised forbs, shrubs and trees but not grasses. On average, shrubs (62.7% bites) were the most utilized vegetation class in both sampling periods followed by forbs (26.4% bites). Forbs were mostly utilized in the wet sampling period, while shrubs were mostly used during the dry sampling period. Of the consumed forage classes, trees were the least utilized vegetation class, comprising an average of 10.4% of bites in both sampling periods (Table 5). Relative consumption of several plant species differed significantly between sampling periods (Table 5). Specifically, *S. bullatus, A. hybridus, C. bangalensis, E. arabicum, A. longiscupsis, G. cordifolia* and *H. revolutum* were consumed more frequently during wet than dry sampling period. Conversely, *C. anisata, S. incanum, H. forskahlii, J. betonica* and *Ocimum spp*. were utilized more frequently in the dry than wet sampling period. However, relative consumption of *P. olaraceae, L. javanica, L. ukambensis, A. xanthophloea and G. bicolor* did not differ significantly between sampling periods.

**Table 5: Relative bites (mean ± SE %) on different plant species and classes by the Black rhino in Ngorongoro Crater at different sampling periods**

| Species | May-June (2015) | Aug-Sep 2015 | Mean | t-value | p-value |
|---|---|---|---|---|---|
| **Forbs** | | | | | |
| *A. hybridus* | 15.5±2.3 | 0±0 | 7.8±1.2 | 1.88 | **0.001** |
| *C. anisata* | 0.0±0.0 | 18.6±1.4 | 9.3±1.1 | -4.19 | **0.004** |
| *C. bengalensis* | 3.6±0.5 | 0.0±0.0 | 1.8±0.3 | 1.91 | **0.008** |
| *E. arabicum* | 9.6±0.7 | 0.0±0.0 | 4.8±0.5 | 3.82 | **0.001** |
| *P. oleraceae* | 2.7±0.5 | 0.4±0.1 | 1.6±0.3 | 1.45 | 0.191 |
| Total Forbs | 31.4±2.5 | 21.3±3.0 | 26.4±1.4 | 4.71 | 0.205 |
| **Shrubs** | | | | | |
| *A. longiscupsis* | 3.2±0.4 | 0.0±0.0 | 1.6±0.2 | -2.84 | **0.019** |
| *S. incanum* | 0.0±0.0 | 3.5±0.4 | 1.8±0.2 | -2.98 | **0.020** |
| *S. bullatus* | 24.1±1.5 | 1.1±0.2 | 12.8±1.1 | 4.65 | **0.002** |
| *G. cordifolia* | 7.7±0.7 | 0.0±0.0 | 3.9±0.4 | 3.50 | **0.010** |
| *H. revolutum* | 12.3±0.8 | 0.0±0.0 | 6.2±0.8 | 2.88 | **0.024** |
| *H. forskahlii* | 0.5±0.1 | 35.9±7.1 | 18.2±3.6 | -2.92 | **0.019** |
| *J. betonica* | 4.5±0.6 | 20.4±2.0 | 12.5±1.3 | -2.64 | **0.030** |
| *L. javanica* | 2.7±0.4 | 0.7±0.3 | 1.7±0.2 | -0.97 | 0.348 |
| *L. ukambensis* | 0.5±0.1 | 0.4±0.1 | 0.5±0.1 | 1.54 | 0.162 |
| *G. bicolor* | 3.2±0.5 | 0.0±0.0 | 1.6±0.3 | 1.34 | 0.112 |
| *Ocimum spp* | 0.0±0.0 | 10.9±0.8 | 5.5±0.6 | -3.97 | **0.001** |
| Total Shrubs | 62.8±2.2 | 76.7±3.5 | 67.8±1.9 | -0.44 | 0.745 |
| **Trees** | | | | | |
| *A. xanthophloea* | 4.5±0.9 | 2.1±0.5 | 3.3±0.5 | -2.42 | 0.634 |
| Trees total | 4.5±0.9 | 2.1±0.5 | 3.3±0.5 | -2.42 | 0.634 |

## 4.5 Diet selection

The most selected (Ivlev's index >0) forage species during wet sampling period include; *C. bengalensis*, *E. arabicum*, *G. cordifolia*, *A. hybridus*, *H. revolutum*, *S. bullatus*, *J. betonica*, *L. ukambensis*, *P. oleraceae* and *A. xanthophloea.* Species that were often avoided (Ivlev's index < 0) during the same period include; most grasses such as *C. dactylon*, *C. alternatifolia*, *C. rotundifolia*, *P. clandestinum*, *D. aegyptiacum*, herbs such as *B. schimperi*, *O. latifolia,* shrubs such as*; T. burchellianum*, *L. javanica*, *A. longiscupsis* and *Vernonia spp* and most trees except *A. Xanthophloea* (Table 6).

**Table 6: Ivlev's electivity indices (mean ± SD %) for different herbaceous items consumed by the Black rhino in Ngorongoro Crater at different sampling periods.**

| Species | May-June 2015 | | | Aug-Sept 2015 | | |
|---|---|---|---|---|---|---|
| | | | Ivlev's | | | Ivlev's |
| Herbaceous | P*i* | R*i* | Index | P*i* | R*i* | Index |
| *T. minuta* | 2.7±1.3 | 4.9± | -0.3 | 0.9±0.1 | 2.4±0.2 | -0.5 |
| *C. bengalensis* | 7.7±2.0 | 5.4±1.6 | 0.2 | 0.0±0.0 | 0.0±0.0 | 0 |
| *C. dactylon* | 4.5±1.7 | 15.7±3.1 | -0.6 | 0.0±0.0 | 8.7±2.1 | -1 |
| *C. alternatifolia* | 5.2±0.6 | 7.8±1.2 | -0.2 | 0.0±0.0 | 1.6±0.7 | -1 |
| *E. arabicum* | 12.5±2.1 | 8.2±1.6 | 0.2 | 0.0±0.0 | 0.1±0.1 | -1 |
| *G. cordifolia* | 4.5±1.3 | 6.6±2.1 | 0.2 | 0.0±0.0 | 0.1±0.1 | -1 |
| *A. hybridus* | 13.8±0.1 | 9.1±2.7 | 0.2 | 0.0±0.0 | 0.0±0.0 | 0 |
| *C. rotundifolia* | 0.37±0.1 | 7.8±0.2 | -0.9 | 0.0±0.0 | 1.6±0.6 | -1 |
| *P. clandestinum* | 0.7±0.2 | 7.3±1.5 | -0.8 | 0.0±0.0 | 1.4±0.4 | -1 |
| *C. hirta* | 2.2±1.0 | 1.8±1.0 | 0.1 | 0.0±0.0 | 0.0±0.0 | 0 |
| *D. aegyptiacum* | 0.9±0.2 | 5.5±1.6 | -0.7 | 0.0±0.0 | 0.0±0.0 | 0 |
| *B. schimperii* | 0.23±0.1 | 1.3±0.9 | -0.7 | 0.0±0.0 | 0.0±0.0 | 0 |
| *O. latifolia* | 2.8±0.9 | 5.5±0.7 | -0.3 | 0.0±0.0 | 2.8±1.9 | -1 |

During dry sampling period the species that were often preferred were mostly shrubs and trees such as; *H. aponeurus, J. betonica, L. javanica, O. lanceolata* and *G. bicolor* (Table 7). Species that were often avoided or randomly selected were mostly grasses and herbs such as *T. burchellianum, L. trifolia, H. revolutum, S. bullatus* and *A. fruticosus, L. ukambensis, A. longiscupsis* and *Vernonia spp*

**Table 7: Ivlev's electivity indices (mean ± SD %) for different shrubs and trees consumed by the Black rhino in Ngorongoro Crater at different sampling periods.**

| Species | May-Jun 2015 | | | Aug-Sep 2015 | | |
|---|---|---|---|---|---|---|
| Shrubs | P$i$ | R$i$ | Ivlev's I. | P$i$ | R$i$ | Ivlev's I. |
| *H. revolutum* | 10.6±2.5 | 2.7±1.5 | 0.6 | 0.0±0.0 | 0.0±0.0 | 0 |
| *T. burchellianum* | 0.0±0.0 | 4.3±3.6 | -0.6 | 0.0±0.0 | 2.2±1.3 | -1 |
| *L. trifolia* | 0.0±0.0 | 0.0±0.0 | 0 | 0.5±0.1 | 2.1±0.6 | -0.6 |
| *H. fuscus* | 0.0±0.0 | 0.0±0.0 | 0 | 0.8±0.2 | 11.8±3.2 | -0.9 |
| *H. aponeurus* | 0.0±0.0 | 0.0±0.0 | 0 | 17.3±1.8 | 4.4±1.2 | 0.6 |
| *S. bullatus* | 16.8±4.8 | 22.9±6.2 | 0.2 | 0.0±0.0 | 0.0±0.0 | 0 |
| *A. fruticosus* | 0.3±0.1 | 0.3±0.2 | 0.0 | 0.4±0.3 | 0.6±0.2 | -0.2 |
| *J. betonica* | 4.0±1.2 | 23.7±5.3 | 0.7 | 23.3±2.9 | 16±1.9 | 0.2 |
| *L. ukambensis* | 0.3±0.1 | 0.2±0.1 | 0.2 | 0.4±0.1 | 5.8±0.6 | -0.9 |
| *L. javanica* | 0.5±0.3 | 1.0±0.1 | -0.3 | 2.6±0.3 | 22.8±4.3 | 0.8 |
| *P. oleraceae* | 3.5±0.5 | 1.9±0.8 | 0.3 | 0.0±0.0 | 0.0±0.0 | 0 |
| *A. longiscupsis* | 1.4±0.2 | 10.2±2.1 | -0.8 | 0.0±0.0 | 3.5±1.2 | -1 |
| *G. bicolor* | 0.0±0.0 | 4.5±1.2 | -1 | 2.2±1.5 | 0.1±0.1 | 1 |
| *Vernonia spp* | 0.4±0.1 | 1.3±0.1 | -0.5 | 0.5±0.1 | 1.0±0.1 | -0.4 |
| **Trees** | | | | | | |
| *A. xanthophloea* | 1.5±1.2 | 0.2±0.2 | 0.7 | 2.4±1.1 | 36.4±8.7 | -0.9 |
| *O. lanceolata* | 0.0±0.0 | 25.1±6.2 | -1 | 0.4±0.1 | 0.1±0.1 | 1 |
| *V. madagascariensis* | 0.0±0.0 | 1.3±1.1 | -1 | 0.4±0.1 | 1.0±0.1 | -0.5 |
| *C. anisata* | 0.0±0.0 | 0.0±0.0 | 0 | 23.5±2.9 | 5.6±1.3 | 0.6 |

P$i$ represents the measure of species i utilized by rhino whereas R$i$ represents the relative availability of species *i* in the environment

**4.2 Trends in Black rhino population attributes in Ngorongoro Crater**

**4.2.1 Population size**

The Black rhino population records showed that there was an overall increase in population size from 14 individuals in 2000 to 44 individuals in 2014. The population growth form exhibited a logistic pattern, with relatively slow growth during 2000-2004, a rapid increase during 2004-2010, and a slow growth and eventual leveling off during 2010-2014 (Figure 6).
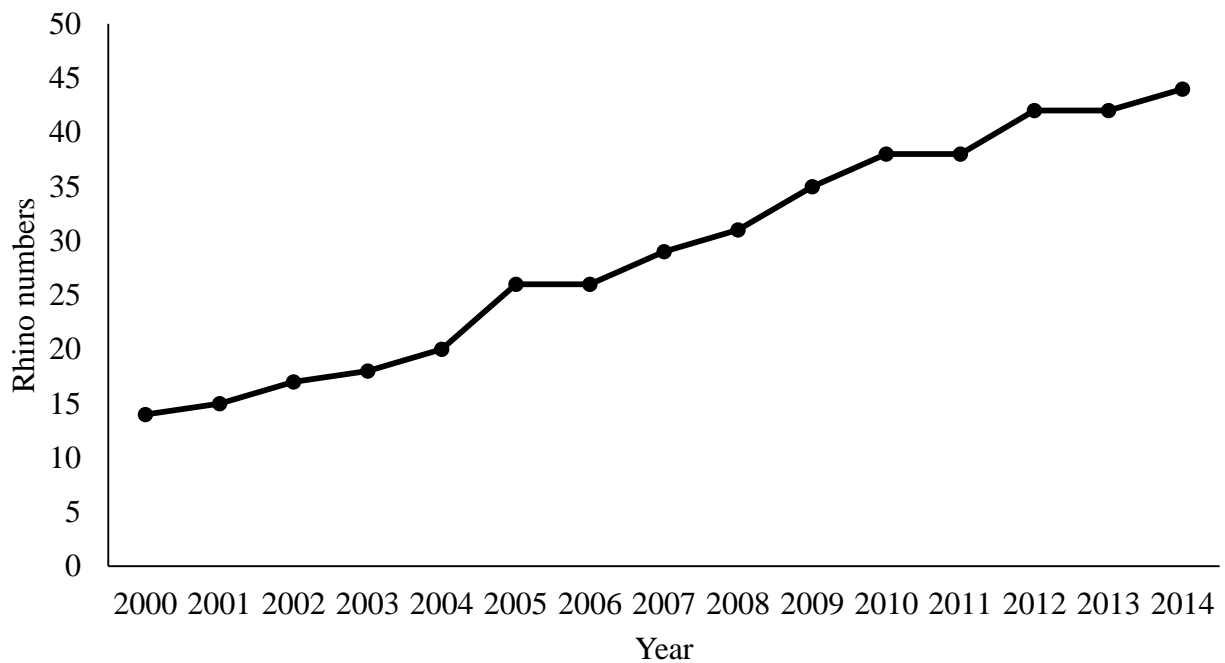


**Figure 6: The Ngorongoro Crater Black rhino population size during 2000-2014.**

### 4.2.2 Population birth, death and growth rates

The absolute and per capita growth rates of the rhino population during 2000-2014 were in the range 0-6 individuals/year and 0.00-0.30 individual(s)/year, respectively (Table 8). The highest absolute and per capita growth rates occurred in 2004, while the lowest growth rates were in 2005, 2010 and 2012. Notably, there was no population decline recorded in any of the 15 years.

**Table 8: Absolute and per capita growth rates of the Black rhino population in Ngorongoro crater during 2000-2014**

| Year | N | Absolute increase rate (Individual rhinos) | Per capita increase rate |
|------|----|------|------|
| 2000 | 14 | 1 | 0.07 |
| 2001 | 15 | 2 | 0.13 |
| 2002 | 17 | 1 | 0.06 |
| 2003 | 18 | 2 | 0.11 |
| 2004 | 20 | 6 | 0.3 |
| 2005 | 26 | 0 | 0 |
| 2006 | 26 | 3 | 0.12 |
| 2007 | 29 | 2 | 0.07 |
| 2008 | 31 | 4 | 0.13 |
| 2009 | 35 | 3 | 0.09 |
| 2010 | 38 | 0 | 0 |
| 2011 | 38 | 4 | 0.11 |
| 2012 | 42 | 0 | 0 |
| 2013 | 42 | 2 | 0.05 |
| 2014 | 44 | - | - |

Absolute birth rate ranged 0-30 individuals in 100 individuals while per capita birth rate ranged 0 and 0.3 (Table 9). Both measures of birth rate were highest in 2004 and lowest in 2005, 2010 and 2012. There were no deaths, immigrations or emigrations during the study period.

**Table 9: Absolute and per capita Birth rates of Black rhino between year 2000-2014**

| Year | N | Absolute Birth rate in 00' | Per capita birth rate |
|------|-----|------|------|
| 2000 | 14 | 7 | 0.07 |
| 2001 | 15 | 13 | 0.13 |
| 2002 | 17 | 6 | 0.06 |
| 2003 | 18 | 11 | 0.11 |
| 2004 | 20 | 30 | 0.3 |
| 2005 | 26 | 0 | 0 |
| 2006 | 26 | 12 | 0.12 |
| 2007 | 29 | 7 | 0.07 |
| 2008 | 31 | 13 | 0.13 |
| 2009 | 35 | 9 | 0.09 |
| 2010 | 38 | 0 | 0 |
| 2011 | 38 | 11 | 0.11 |
| 2012 | 42 | 0 | 0 |
| 2013 | 42 | 5 | 0.05 |
| 2014 | 44 | 0 | - |

**4.2.3 Population sex ratio**

The overall sex ratio of the Black rhino population for the entire 15-year period was 2:1 (females: males) (Table 10). The ratio of females to males in 2014 was 2:1 (29 females and 15 males). This was similar to the sex ratio in 2000 (2:1; 9 females and 5 males). This ratio was maintained in all other years except 2003, 2005, 2006 and 2007 when it was approximately 3:1.

**Table 10: The sex ratio of Black rhinos in NC across years during 2000-2014**

| Year | Female | Males | Sex ratio(s) |
|------|--------|-------|--------------|
| 2000 | 9 | 5 | 2:1 |
| 2001 | 10 | 5 | 2:1 |
| 2002 | 12 | 5 | 2:1 |
| 2003 | 13 | 5 | 3:1 |
| 2004 | 14 | 6 | 2:1 |
| 2005 | 19 | 7 | 3:1 |
| 2006 | 19 | 7 | 3:1 |
| 2007 | 21 | 8 | 3:1 |
| 2008 | 22 | 9 | 2:1 |
| 2009 | 24 | 11 | 2:1 |
| 2010 | 26 | 12 | 2:1 |
| 2011 | 26 | 12 | 2:1 |
| 2012 | 28 | 14 | 2:1 |
| 2013 | 28 | 14 | 2:1 |
| 2014 | 29 | 15 | 2:1 |

## 4.2.4 The population age structure

The Black rhino age classes were calves (0-4 years) sub-adults (5-7 years) and adults (>7 years). In overall, adults were the dominant age class in all years except 2000 when calves were more dominant than the other age classes (Table 11). Calves were the second most dominant age class while sub-adults were the least dominant. The percentage of adults in the population increased from 36% in 2000 to 62% in 2014, while the percentages of calves and sub-adults in the population declined from 42% and 21%, respectively, in 2000 to 20% and 14% in 2014.

**Table 11: Age-structure of the Black rhino population in NC during 2000-2014**

| Year | 0 to 4 (Calves) | % | 5 -7 (sub-adults) | % | >7 years (Adults) | % | Total |
|------|-----------------|----|-------------------|----|-------------------|----|-------|
| 2000 | 6 | 43 | 3 | 21 | 5 | 36 | 14 |
| 2001 | 5 | 33 | 4 | 27 | 6 | 40 | 15 |
| 2002 | 7 | 41 | 3 | 18 | 7 | 41 | 17 |
| 2003 | 4 | 22 | 4 | 22 | 10 | 56 | 18 |
| 2004 | 6 | 30 | 4 | 20 | 10 | 50 | 20 |
| 2005 | 11 | 42 | 1 | 4 | 14 | 54 | 26 |
| 2006 | 11 | 42 | 1 | 4 | 14 | 54 | 26 |
| 2007 | 12 | 41 | 3 | 10 | 14 | 48 | 29 |
| 2008 | 13 | 42 | 4 | 13 | 14 | 45 | 31 |
| 2009 | 15 | 43 | 3 | 9 | 17 | 49 | 35 |
| 2010 | 12 | 32 | 8 | 21 | 18 | 47 | 38 |
| 2011 | 12 | 32 | 8 | 21 | 18 | 47 | 38 |
| 2012 | 13 | 31 | 3 | 7 | 26 | 62 | 42 |
| 2013 | 13 | 31 | 3 | 7 | 26 | 62 | 42 |
| 2014 | 9 | 20 | 6 | 14 | 29 | 66 | 44 |

# CHAPTER FIVE

## DISCUSSIONS

### 5.1 Spatial distribution patterns of the Black rhino

The disparity in the spatial distribution patterns of the Black rhino between sampling periods was likely driven by seasonal differences in forage availability and quality which in turn influenced selection of foraging sites. In the wet period when forbs were abundant and of high nutritional quality, the rhinos were mostly sighted on the crater floor. However, in the dry sampling period when forbs were apparently less abundant and apparently of poor nutritional quality, the rhinos were most frequently observed on the crater slopes dominated by shrubs. The Black rhino distribution patterns observed in this study demonstrates that this species uses a variety of habitat types, including shrubland, open grasslands, closed canopy forests and swampy areas.

The observed rhino distribution patterns across different habitat types are consistent with the findings of past studies elsewhere (Oloo *et al.,* 1994, Tatman *et al.,* 2000, Buk and Knight, 2012). These studies generally indicate that Black rhinos utilize a variety of habitat types including shrubland, woodlands and marshlands. The observed rhino distribution pattern is also related to human activity. Specifically, rhinos avoided the eastern and western parts of the crater during both seasons possibly due to anthropogenic disturbances in these areas. The western part of the crater is frequented by local community herders and their livestock for purposes of accessing water and salt licks. This area is also used as descent road into the crater floor by tourists. In addition, the western slopes contain an ascent road, tourist lodges and campsites. Likewise, the eastern part of the crater has a road used to both descend and ascend. Total avoidance of these areas by rhinos indicates that rhinos have zero tolerance to all sorts of disturbances from human.

According to Brett (2001) human-related impacts on rhinos have clearly been evident in the 'crowding' by tourist vehicles of rhinos during daily movements between forest and plains. The spatial distribution of the present rhino population now covers a small proportion of the total area of the crater formerly used by the Black rhinos. Although the 61 rhinos recorded by Sinclair and Arcese (1995) were mostly found in the central area of the crater, all intervening reports up to the mid-1980 record the rhinos using most of the crater floor, including northern and western sectors

where rhinos were not sighted in the present study. The rhino density noted by Sinclair and Arcese in the early 1980s (Sinclair and Arcese, 1995) was approximately 20% of that observed by Goddard (1968), but the 25 rhinos resident in 1980-82 were widespread, used most of the crater floor and had larger home ranges on average. According to another earlier study, rhinos frequented the Seneto/Mandusi area (Brett, 2001), which was not the case in the present study.

The distribution patterns of rhinos within the crater was explored by Landman *et al.* (2013) who discussed the possible changes in grass species composition accompanying these changes, the lack of burning of grasslands in the crater since the early 1970s and in particular, the effects of isolation of the crater's large mammal fauna through increased settlement and recent increase in human population in the NCAA and numbers of their stock.

In this study it was evident that habitat usage by rhinos is influenced by seasonal variations. This finding is consistent with studies elsewhere. Ganqa *et al.* (2005) found out that wild rhinos fed most on herbs in thickets and in riverine habitats in the wet and early dry seasons, respectively. Van Lieverloo *et al.* (2009) concluded that rhino groups adjusted habitat usage for browsing according to season. Wild rhinos used most *Colophospermum-Terminalia-Combretum* woodland and plains with abundant herbs in the wet season and thickets in the early dry season.

 Additionally, they (Van Lieverloo *et al.*, 2009) found out that wild rhinos increased feeding in thickets and riverine areas in the early dry season compared to the wet season. Seasonal requirement for succulence (high-moisture food) could have been a major factor governing diet selection; choice of riverine habitats in the dry season would have exposed wild rhinos to a 'new' range of plant species from which to select. Riverine vegetation has a higher moisture content providing more 'green bite' during the dry season. Secondly, rhinos changed browse selection in response to browse phenological changes. Reduced palatability of browse in the dry season will induce a shift to more palatable species, as well as to other plant parts of the same species (Atkinson, 1995).

## 5.2 Forage availability and selection by Black rhino

Black rhinos are selective feeders (Duffy, 2007; Oloo *et al.,* 1994; Muya and Oguge, 2000); that primarily browse on forbs and low-growing shrubs within the 2m height zone (Owen-Smith 1988). A preferred plant species is defined by the extent to which the species is consumed in relation to its availability in the environment (Shrader *et al.,* 2006). A highly preferred plant is one which is consumed in greatest quantities relative to its occurrence. In their study (Shrader *et al.*, 2006) in South Africa, the highly preferred plants by Black rhino in winter were *Azima tetracantha* and *Senna auriculata* and in summer were *Baphia massaiensis* and *Azima tetracantha.*

In the present study, there were three vegetation classes used by rhino; shrubs, forbs (herbaceous) and trees. It was evident that shrubs (62.7% bites) were the most utilized vegetation class in both sampling periods followed by forbs (26.4%). Forbs were mostly utilized in the wet sampling period, while shrubs were mostly used during the dry sampling period. Of the three vegetation classes consumed by the rhinos, trees were the least utilized vegetation class, comprising an average of 10.4% of bites in both sampling periods. Grasses were totally avoided by Black rhino.

According to Makhabu (2005) and Atkinson (1995) Black rhino eat woody plants, forbs, creepers and succulents. However, grass and forbs constitute only a very small proportion of the overall diet, relative to woody matter. Buk and Knight (2010) noted the complete absence of grass in the recorded diet and grass bitten off with browse was discarded The findings of this study are in line with studies conducted elsewhere (Atkinson, 1995; Oloo *et al.,* 1994; Makhabu, 2005), which also reported that there were temporal variations in diet selection by the Black rhino. These studies also reported that Black rhinos select a wide range of plant species, as was found in the present study.

In this study the total number of browse material was 32; herbaceous 13, forbs 14 and trees 5. In study by Buk and Knight (2010) the number of food species eaten decreases with increasing aridity. For example, woody browse species increased in number from 74 in the desert of Namibia to 113 species in semi-arid regions like Sinamatella, Hwange National Park in Zimbabwe and to 191 in the moist Ngorongoro Crater of Tanzania.

The present findings show that relative consumption of several plant species differed significantly between sampling periods. Specifically, *S. bullatus, A. hybridus, C. bangalensis, E. arabicum, A. longiscupsis, G. cordifolia* and *H. revolutum* were consumed more frequently during wet than dry sampling period. Conversely, *C. anisata, S. incanum, H. forskahlii, J. betonica* and *Ocimum spp*. were utilized more frequently in the dry than wet sampling period. The results are similar to the findings of Matipano (2003) who found out that the total numbers of bites on woody species in different vegetation types were significantly different among rhino groups for both the wet and in the early dry seasons. In the present study, rhinos included slightly more plant species in their diet during the wet than dry sampling period.

These findings are also consistent with the findings of Matipano (2003) who also reported a higher Black rhino diet breadth during wet than dry season. In this study, the browsing height of herbaceous vegetation was less than 0.5m above in both seasons (mean 44cm for dry and 42cm for wet). This was not statistically different (P>0.05). A similar range of browsing height was reported for Black rhinos elsewhere (Kerley *et al.*, 2010). Black rhinos in this study were found to be selective browsers, feeding more frequently on selected forbs and herbaceous as well as avoiding some AWF (2003). Although the rhino can be highly selective for a few food species and plant sizes (Emslie and Adcock, 1994), the species has the ability to feed on a variety of plants, at least in small quantities (Oloo *et al.,* 1994).

In other studies elsewhere, Buk and Knight, (2010) confirms that rhinos have a significantly restricted diet with a preference for a few key plant species and a tendency to select leafy species in the dry season. Though this study was limited to Ngorongoro Crater, Hearn (2000) concluded that rhino diet selection varies regionally. In this study the most important diet was *G. bicolor* and *O. lanceolata* .Studies in other parks show similar trends, with *Acacia* species being important in Itala, Masai Mara and Nairobi National Park, *Indigofera* species in Tsavo National Park, *Grewia* in Great Fish River Reserve (GFRR) and *Euphorbia* in Olduvai Gorge, Liwonde National Park, GFRR and in Kunene (Kotze and Zacharias, 1993; Hearn, 2000; Ganqa *et al*., 2005). These studies also show that not all species in these plant families are preferred and/or principal food plants.

In other studies elsewhere (e.g. Emslie and Adcock, 1994) although 40 species of plants are listed as being eaten by the rhinos, the number will probably increase substantially, particularly

when herbaceous species are recorded and when observations intensify. Smithers (1983) stated that over 200 plant species are eaten by the Black rhino, while Goddard (1970) recorded 102 species eaten in Tsavo National Park, Kenya. However, Emslie and Adcock (1994) found that only a few woody species (about ten) account for the bulk of the Black rhino's diet. In Liwonde, six "key" species were utilised throughout the year, namely *C. mopane, A. nigrescens, E. ingens C. fragrans* and Z*. mucronata.*

The seasonal differences diet selection by rhinos reported in the present study could be related to differences in forage availability rather than quality. According to Muya and Oguge (2000), plant quality is one factor that drives diet selection patterns of Black rhino. However, previous work on Black rhino in the Great Fish River Reserve indicated no relationship between quality and preference during autumn (Ausland *et al.,* 2001). The observed seasonal variation in rhino diet selection compares favorably with the findings of Matipano (2003) who conclude that rhinos selected more herb matter in the wet season than in the early dry season.

These findings are further supported by the study of Makhabu, (2005) and Landman *et al.* (2013) who reported that Black rhino is mostly attracted to woody plants during dry seasons. Though the overall variation in food availability was not measured in this study, species variations were detected. There were significant seasonal variations in species availability in some species (e.g *G. codirdifolia*, *O. latifolia, A. hybridus, B. schimperi, B. alba* and *C. aureta* $P<0.05$). Although food availability is expected to decline to a minimum during the dry season (particularly, grasses, forbs and some geophytes), Landman *et al.* (2013) detected no difference in the relative abundance of growth forms between seasons for rhino.

Most species selected by rhino in both seasons were succulent herbaceous varieties; *C. banagalensis*, *P. olaraceae, A. hybridus*, *H. aponeurus*, *O. lanceolata* and C*. anisata*. This was in consistent with other studies for example Emslie and Adcock (1994) noted that plants with high moisture content, such as leguminous plants and species in the *Euphorbiaceae* family, are important dietary items for Black rhinos. Loutit *et al*. (1987) specified that the *Euphorbia* was an important food item and that *Euphorbia* species, along with other succulent plant species, provide rhinos with water in the absence of free water.

Black rhinos have high dietary selection for a few species and high dietary diversity by taking other species at lower preferences. In this study, the most selected (Ivlev's index > 0) forage species during wet sampling period were *C. banagalensis, E. arabicum, A. hybridus, G. cordifolia, C. hirta, H. revolutum, S. bullatus, J. betonica, L. ukambensis, P. olaraceae* and *A. xanthophloea.* During dry period the species that were consumed in proportion to their availability included; *H. aponeurus, J. betonica, L. javanica*, *G. bicolor, O. lanceolata* and *C. anisata*. This feeding strategy can be explained by the need to obtain the full complement of food quality requirements (Emslie and Adcock, 1994).

In East Africa Muya and Oguge (2000) found that when browse species are widely available to Black rhino they tend to be highly utilized. Additionally, he concluded that there are more browse materials available during wet than dry season. However, in the present study, this was not apparent; during the wet season (May-June) herbaceous vegetation was dominant at rhino feeding sites. As drier conditions prevail, evergreen species contribute more to the diet than deciduous species (Atkinson, 1995). Species like *J. betonica* were eaten by rhinos, in the early dry season. In the results of study done by Makhabu (2005) it is evident that rhino diet varied across seasons in different ways, depending on the presence and absence of elephant. This suggests at least tentatively that the trend of increased diet separation may be evidence of current displacement caused by elephant.

## 5.3 Trends in Black rhino population attributes

The rhino population growth form followed a logistic pattern, suggesting that the population is influenced by density-dependent factors. Since year 2000 the Black rhino population status has grown from 14 rhinos to 44 rhinos as at year 2014. This trend can be attributed to several conservation and security measures that were put in place worldwide and nationally, including formulation and enforcement of policy interventions (e.g. CITES, which ban trade in any rhino's body parts) to address rampant poaching (Bret, 2010).

A pragmatic intervention at national level to address rampant poaching that reduced the number of rhinos to only 14 individuals in Ngorongoro crater in 1993 from 108 individuals in 1966 was the conservation efforts by Tanzanian government on the remaining local population of rhinos in Ngorongoro Crater, Serengeti National Park and Selous Game Reserve (Adcock, 2001). Considerable efforts include regular surveillance and monitoring systems and strengthened law

enforcement. During the operation, many illegal immigrants from Somalia who were at the forefront in poaching of rhinos and elephants were repatriated and many illegal arms were confiscated (Adcock, 2001).

Rhino population status has been fluctuating from year to year but a serious trend was decline from 108 individuals in 1966 to 14 individuals in 1993. According to Roodt (2012), there were 108 rhinos in the Ngorongoro Crater a density of approximately 1 rhino per 3.1km$^2$. After 1975, rhino poaching became a serious problem in Northern parts of Tanzania as a result of increased demand in rhino products in world markets such as Far East where horns were used as medicine, aphrodisiac and dagger handles (Bret, 2010).

From the findings of this study, rhinos numbered 14 individuals in year 2000, 5 males and 9 females. This result compares favorably with the findings by Roodt (2012) who reported that in May 2000, the rhino population of NC had had reached 17 individuals but three were lost to natural causes. The large scale decline of Black rhino numbers and fragmentation of its habitat have created a number of discrete small populations (Leader -Williams *et al.,*1988; Hanski *et al.* 1996; Hanski and Simberloff, 1997), making these populations vulnerable to random fluctuations in size and eventual extinction unless actively managed as a meta-populations. Today, there are various threats posed to the Black rhino including habitat changes, illegal poaching, and competing and rapidly rising human populations.

The current sex ratio of female to male rhinos in the crater is 2:1 (29 females and 15 males). In the year 2000, the ratio was correspondingly 2:1 (9 females and 5 males). Sex ratio alteration influences the population dynamics of a species and thus has important implications for large herbivore welfare and management (Verme and Ozoga, 1981; Adcock, 2001; Milner-Gulland *et al.,* 2001; Saltz, 2001). This sex ratio is skewed towards female and skewed sex ratios (<1:1 or >1:1) may be indicative of chance demographics and/or differential survival between females and males. However, the sex ratio skewed in favor of female is demographically healthy as compared to the skewed ratio towards male proportion. The reproductive success of a population is influenced mostly by female proportion (Taylor, 1984).

Effective protection and surveillance of rhino populations depend on concentration of manpower and resources to sufficient levels (1 scout/ranger per 10-30 km$^2$) to ensure adequate patrol effort,

detection of illegal activity and rhino mortalities. Adequate levels of surveillance are essential for monitoring rhinos, including confirming the presence and health of rhinos through individual identification, detection of mating, calves, and estimating population sizes. Provision of good information gathered in rhino surveillance enhances confidence in the capacity of the organization or conservation authority involved. Consolidation of vulnerable rhinos (e.g. away from international boundaries), exchange and removal of surplus rhinos, and establishing new rhino populations through translocation have all been key ingredients of successful rhino conservation programs (Sibalatini, 2004).

# CHAPTER SIX

## CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

- This study demonstrates that the spatial distribution pattern of the Black rhino is driven by seasonal differences in forage availability and quality. Specifically, rhinos appear to prefer foraging in the crater floor dominated by forbs during the wet season, but shift to thickets and shrublands on the crater slopes during the dry season.

- The observed rhino distribution patterns are also related to human activity. Specifically, rhinos tend to avoid areas proximate to intense human activity such as lodges, roads, tourist camps and areas accessed by livestock. Human activities therefore limit the area that is useable by the rhinos and may therefore limit their population growth.

- Black rhinos feed selectively on different species of forbs, shrubs and trees. Forage selection is strongly season-dependent. Shrubs and trees are mostly utilized in dry seasons while forbs are mostly utilized during the wet season. The most selected forage species during wet sampling period were: *C. bangalensis, E. arabicum, A. hybridus, G. cordifolia, C. hirta, H. revolutum, S. bullatus, J. betonica, L. ukambensis, P. olaraceae* and *A. xanthophloea* while during dry period the most selected species include: *H. aponeurus, J. betonica, L. javanica*, *G. bicolor, O. lanceolata* and *C. anisata*

- The rhino population growth form followed a logistic pattern, suggesting that the population is influenced by density-dependent factors. The rampant poaching led to decline of rhinos in 1980s but with a pragmatic conservation intervention at national level, the number of Black rhinos in crater has increased from 14 individuals to 44

## 6.2 Recommendations for conservation and management

- Human activities such as livestock grazing, tourism infrastructure (lodges, campsites and roads) should be kept minimal to minimize disruption to rhino movement and habitat selection patterns especially in east and west of crater rim which currently shows no distribution in both dry and wet seasons.

- Although the current surveillance and monitoring system operating at the crater is of a high standard, and all animals are regularly accounted for, mostly within small inter-sighting intervals, it will be vital to maintain this monitoring regime, and possibly improve the ratio of ranger to rhinos or area of patrol to enhance effective monitoring of their distribution and management.

- More sophisticated monitoring system is also necessary in ranger observation posts; that can be effective in poor weather and in long distances as well as recording the rhino activity as opposed to current binocular systems which cannot store the information.

- The key rhino foraging areas and the distribution and abundance of the major rhino forage species such as *A. hybridus, G. cordifolia, L. ukambensis*, *H. aponeurus, J. betonica, L. javanica* and *C. anisata* should be monitored regularly for enhanced management and conservation of the Black rhino and its habitat.

## 6.3 Recommendations for further research

- There is need for further investigations to evaluate the strengths of density-dependent factors influencing the Black rhino population, especially intra-specific and inter-specific competition for forage resources.
.

# REFERENCES

Adcock, K. (2001). Black rhino carrying capacity and performance. In Emslie, R. (Ed.) Proceedings of a SADC Rhino Management Group (RMG) workshop on biological management to meet continental and national Black rhino conservation goals

Antoine, P. and Rookmaaker, K. (2013). The first historical record of a rhinos in Togo. *Mammalia*, *77* (1). http://dx.doi.org/10.1515/mammalia-2012-0049

Atchley, W. R., Gaskins, C.T., and Anderson. D. (1976). Statistical properties of ratios. I. Empirical results. *Systematic Zoology* 25: 137-148.

Atkinson, S.J. (1995). Maintenance of captive Black rhinos (*Diceros bicornis*) on indigenous browse in Zimbabwe: Energetics, nutrition and implications for conservation. MSc. Thesis. University of Zimbabwe

Ausland, C., Sveipe, A., Ganqa, N.M., Raats, J.G. and Palmer, T. (2001). Feeding behavior of Black rhino (Diceros bicornis minor) in the Great Fish River Reserve, South Africa. Proceedings of the 5th International Wildlife Ranching Symposium, 20–23 March 2001. Pretoria, South Africa.

AWF (2003). Management of the Black rhinos in the Ngorongoro Crater A report on the workshop held at Serena Lodge, Ngorongoro. September 2003.

Birdlife International (2016). *BirdLife Partnership for nature and people*. *Birdlife.org*. Retrieved 18 July 2016, from http://www.birdlife.org

Blake, S., Strindberg, S., Boundjan, P. and Makombo, C. (2007). "Forest elephant crisis in the Congo Basin". *Public Library of Science* 5: 945 - 953

Bonham, C.D. (1989). Measurements for Terrestrial Vegetation, Wiley, New York

Bret, R. (2001). Investigation of Black rhino mortalities at Ngorongoro crater, Tanzania: Black rhino habitat and ecological requirements; Coordination with National and Continental Rhino Conservation Semester 4 Task 1.3-1.3

Bret, R. (2010). SADC Regional Programme for Rhino Conservation: Investigation of Black rhino mortalities in Ngorongoro Crater. Black rhino and ecological requirements

Buk, K. G., and Knight, M. H. (2010). Seasonal diet preferences of Black rhinos in three arid South African National Parks. *African Journal of Ecology*, *48*(4), 1064-1075.

Buk, K.G. and Knight, M.H. (2012). Habitat Suitability Model for Black rhinos in Augrabies Falls National Park, South Africa. *South African Journal of Wildlife Research* 42 (2):82**.**

Bureau of Land Management (1996). Sampling Vegetation Attributes: Interagency Technical Reference. BLM National Applied Resource Sciences Center. Supersedes BLM Technical Reference 4400-4, Trend Studies dated May 1995 p. 163 Cambridge University Press, Cambridge

Chutter, F.M. (1972). A reappraisal of Needham and Usinger's data on the variability of a stream fauna when sampled with a Surber sampler. *Limnology and Oceanography* 17: 139-141.

Cochran, W.G. (1977). Sampling techniques, 3rd edition. John Wiley and Sons, New York, New York, USA.

Dobson, A.P., Mace, G.M., Poole, J and Brett R.A (1992). Conservation Biology: The ecology and genetics of endangered species. Genes in Ecology: 33rd Symposium of the British Ecological Society, Cambridge University Press

Duffy, J.E, Carinale, B.J, France, K.E, McIntyre, P.B, and Thebault, E., (2007). The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Journal of Ecology 10*:522–538.

Emslie, R. (2011). "*Diceros bicornis* ssp*. michaeli*. In: IUCN 2013. IUCN Red List of
    Threatened Species Version 2013

Emslie, R.H. and Adcock, K. (1994) Feeding ecology of Black rhinos. In: Proceedings of a
    Symposium of Rhinos as Game Ranch Animals. Ed: B.L. Penzhorn & N.P.J. Kriek.
    Onderstepoort, South Africa. pp 65-81

Emslie, R.H., and Brooks, M. (1999). African Rhino: Status, Survey and Action Plan.
    IUCN/SSC African Rhino Specialist Group, Gland, Switzerland

Emslie, R.H., Milledge, S., Brooks, M., van Strien, N.J. and Dublin, H.T. (2007). African and
    Asian Rhinoses – Status, Conservation and Trade CoP14, Doc. 54 CITES Secretariat,
    Geneva, Switzerland

Estes, R.D. (1992). Behavior Guide to African Mammals: Including hoofed mammals,
    Carnivores, Primates. London, University of California Press

Estes, R.D. (2002). The Ngorongoro Crater Ungulate Study, 1996– 2000. Final Report, Part 1, p.
    43

Estes, R.D., Atwood J.L., and Estes A.B. (2006),"Downward trends in Ngorongoro Crater
    ungulate populations 1986–2005: Conservation concerns and the need for ecological
    research", *Biological Conservation*, 1(2) p.116-7

Frame, G.W. (1980). Black rhinos (*Diceros bicornis* L) Sub-population on the Serengeti plains,
    Tanzania. *African Journal of Ecology* 18: 155 - 166

Fyumagwa R.D. and Nyahongo J.W. (2010). Black rhino conservation in Tanzania:
    Translocation efforts and further challenges Tanzania Wildlife Research Institute
    (TAWIRI).

Gannon, J. E. (1976). The effects of differential digestion rates of zooplankton by alewife, *Alosa pseudoharengus*, on determinations of selective feeding. *Transactions of the American Fisheries Society* 105:89-95

Ganqa, N.M., Scogings, P.F and Raats, J.G. (2005). Diet selection and forage quality factors affecting woody plant selection by Black rhinos in the Great Fish River Reserve, South Africa. *South African Journal of Wildlife Research 35(1): 77–83 (April 2005)*

Ginzburg, L. and Colyvan. M (2004). Ecological Orbits: How Planets Move and Populations Grow. *New York*: Oxford University Press.

Hall-martin, A.J., Erasmus T., and Botha, B.P. (1982). Seasonal variation in the diet and faeces composition of Black rhino, *Diceros bicornis* in Addo Elephant National Park Koedoe 25: 63–82

Hanski, I. and Simberloff, D. (1997).The meta-population approach, its history, conceptual domain and application to conservation. In: Meta-population Biology (Ed. by Hanski, I. and Simberloff, D.), pp. 5- 26. San Diego, CA: Academic Press, Inc.

Hanski, I., Moilanen, A. and Gyllenberg, M. (1996). Minimum viable population size. *American Naturalist*, 147, 527-541.

Hearn, M. (2000). Factors limiting fecundity and movement patterns of the Black rhinos (Diceros bicornis) in Kunene Region, Namibia. M.Sc., University of Kent.

Hearne, J.W. and Swart, J. (1991). Optimal translocation strategies for saving the Black rhino. *Ecological Modelling* 59: 279

Henderson, L. (2002). Problem plants in Ngorongoro Conservation Area. *Final Report to NCAA*

Hrabar, H., and Du Toit, J. T. (2005). Dynamics of a protected Black rhino (Diceros bicornis) population: Pilanesberg National Park, South Africa. *Animal Conservation*, *8*(03), 259-267.

IUCN (2015). "IUCN Red List of Threatened Species (ver. 2011.2) Available at: http://www.iucnredlist.org." retrieved on 20th September, 2016

Ivlev, V.S. (1961). Experimental ecology of the feeding of fishes. Yale University Press, New Haven, p 302

Kerley, G.H, Landman, M, and DeBeer, S. (2010). How do small browsers respond to resource changes? Dietary response of the C ape grysbok to clearing alien Acacias. *Functional Ecology 24*: 670–675.

Kotze, D.C. and Zacharias, P.J.K. (1993) Utilization of woody browse and habitat by the Black rhino (*Diceros bicornis*) in western Itala Game Reserve. *African Journal of Range Forage Sciences*10 (1), 36–40.

Landman, M, Schoeman, D.S, and Kerley, G.H (2013). Shift in Black Rhinos Diet in the Presence of Elephant: Evidence for Competition? *Journal pone* 8(7) p 37-48

Leader-Williams, N. (1988). "Pattern of depletion of Black rhinos population in Luangwa Valley, Zambia" *African Journal of Ecology* 26: 181 -186

Loutit, B.D., Louw, G.N. and Seely, M.K. (1987) First approximation of food preferences and the chemical composition of the diet of the desert-dwelling Black rhinos,*Diceros bicornis* L. Mado qua15, 35-54.

Makacha, S., Msingwa, M.J. and Frame, W. (1982). Threats to the Serengeti herds. Oryx 16:437–444.

Makhabu, S.W (2005) Resource partitioning within a browsing guild in a key habitat, the Chobe Riverfront, Botswana. *Journal of Tropical Ecology* 21: 641–649

Martin, E B. and Martin C.B. (1992). Run Rhino Run. London, Chato and Windus.

Matipano, G. (2003). A comparison of woody browse selection by hand-raised, bomaadapted and wild Black rhinos, *Diceros bicornis*, L. in Matusadona National Park, Zimbabwe. Koedoe 46(2): 83–96. Pretoria. ISSN 0075-6458.

Melita, A. and Mendlinger, S. (2013). The Impact of the Tourism Revenue on the Local Communities' livelyhood. A case study of Ngorongoro Conservation Area. *Service Science and Management,* 2013: 6, 117-126.

Milner-Gulland, E.J., Kholodova, M.V., Bekenov, A., Bukreeva, O.M., Grachev, l. A., Amgalan, L. and Lushchekina, A.A. (2001). Drastic decline in saiga antelope populations. *Oryx*, 35, 340-345.

Muya, S.M., and Oguge, N.O. (2000). "Effects of browse availability and quality on Black rhino (*Diceros bicornis michaeli* Groves 1967) diet in Nairobi National Park, Kenya" *African Journal of Ecology* 38: 62-70

Nevo, E., Beiles, A. and Ben-Shlomo, R. (1984). The evolutionary significance of genetic diversity: Ecological, demographic and life history correlates. In: Evolutionary Dynamics of Genetic Diversity. (G. S. Mani Ed.). Springer, Berlin. pp 13-213.

Norton-Grifiths, N. (2007). "How many wildebeest do you need?." *World Economies.* 8(2): 41-64.

O'Hara, R. B. (2005): An anarchist's guide to ecological theory. Or, we don't need no stinkin' laws. Oikos 110:2 (August), 390–393.

Oloo, T.W., Brett, R. and Young, T.P. (1994). Seasonal variation in feeding ecology of Black rhinos (*Diceros bicornis L.*) in Laikipia, Kenya. *African Journal of Ecology* 32: 142–157.

Owen-Smith, N., (1988). Mega-herbivores the influence of very large body size on ecology. Cambridge University Press

Roodt, V. (2012). Tourist Travel and Field Guide of Ngorongoro Coservation Area. Struik Lifestyle.

Rookmaaker, L.C. (2004). "Historical distribution of the Black rhinos (*Diceros bicornis*) in West Africa". *African Zoology* 39 (1): 63–70.

Saltz, D. (2001). Progeny sex ratio variation in ungulates: maternal age meets environmental perturbation of demography. *Oikos*, 94, 377-384.

Save the Rhino (2013). The Black rhino status. Retrieved from *www.savetherhino.org* on 27th March, 2015

Shrader, A. M., Owen-Smith, N., and Ogutu, J. O. (2006). How a mega-grazer copes with the dry season: food and nutrient intake rates by white rhinos in the wild. *Functional ecology*, *20* (2), 376-384.

Sibalatini, M. (2004). The potential of safaris to track desert-dwelling Black rhino as a form of community-based tourism in north-west Namibia, MSc thesis to the Durrell Institute of Conservation and Ecology

Sinclair, A. R. and Arcese, P. (1995). *Serengeti II: dynamics, management, and conservation of an ecosystem* (Vol. 2). University of Chicago Press.

Sinclair, A. R., Hopcraft, G.C., Olff, H., Mduma, S.A.R., Galvin, K.A. and Sharam. G. J. (2008). Historical and future changes to the Serengeti ecosystem. Pages 7-46 in A. R. E. Sinclair,

C. Packer, S. A. R. Mduma and J. M. Fryxell, editors. Serengeti III human impacts on ecosystem dynamics. The University of Chicago Press, Chicago, IL.

Sinclair, A.R. (1995). Serengeti past and present, In: Serengeti II, Dynamics, management and conservation of an ecosystem. The University of Chicago Press, Chicago, USA. pp 3–30.

Sinclair, A.R., Mduma, S. and Brashares, J.S. (2003). "Patterns of predation in a diverse predatory-prey system" *Journal ofNature* 425(6955): 288-290.

Smithers, R.H.N. (1983). The Mammals of Southern Africa Sub-region. University of Pretoria, Pretoria

Steuer, P., Clauss, M., Südekum, K.H., Hatt, M., Silinski, S., Klomburg, S., Zimmermann, W., Fickel, J., Streich, W.J. and Hummel, J. (2010). Comparative investigations on digestion in grazing (Ceratotherium simum) and browsing (*Diceros bicornis*) rhinoses. *Comparative Biochemistry And Physiology Part A: Molecular & Integrative Physiology*, *156*(4), 380-388. http://dx.doi.org/10.1016/j.cbpa.2010.03.006

Strevens, M. (2003): Bigger than Chaos: Understanding Complexity through Probability. Cambridge, Ma: Harvard University Press.

Tatman, S.C., Stevens-Wood, B. and Smith, V.B.T. (2000). Ranging behaviour and habitat usage in Black rhinos, *Diceros bicornis*, in a Kenyan sanctuary. *African Journal of Ecology* 38, 163–172.

Taylor, R. J. (1984). The Predation, New York: Chapman Hall.

Tukahirwa, E. (1997). An Introduction. In: Thompson, D.M. (Ed.), Multiple Land-Use: the Experience of the Ngorongoro Conservation Area, Tanzania. IUCN Protected Areas Programme, IUCN, Gland, Switzerland and Cambridge, UK, pp. 3–6.

van Lieverloo, R. J., Schuiling, B. F., de Boer, W. F., Lent, P. C., de Jong, C. B., Brown, D., and

    Prins, H. H. (2009). A comparison of faecal analysis with back tracking to determine the

    diet composition and species preference of the Black rhinos (*Diceros bicornis minor*).

    *European Journal of Wildlife Research*, 55(5), 505-515.

Verme, L. J. and Ozoga, J. J. (1981). Sex ratio of white-tailed deer and the oestrus cycle. *Journal*

    *of Wildlife Management*, 45, 710-715.

Walpole, M.J., Morgan-Davies, M., Milledge, S., Bett, P. and Leader-Williams, N. (2001).

    Population dynamics and future conservation of a free-ranging Black rhinos (*Diceros*

    *bicornis*) population in Kenya. *Biological Conservation*.99, 237–243.

Western, D., Wright, M. and Strum, S. C. (1994). Natural connections. Island Press, Washington,

    D.C.

WWF (2004). Factsheet Black rhinos (*Diceros bicornis*) 13th Meeting of the Conference of the

    Parties to the CITES, Bangkok, October 2-14, 2014.

# APPENDICES

**Appendix 1: Herbaceous Material Availability Data Sheet**

| Date | Site | South | East | TRSCT | *Spp* | Category |
|------|------|-------|------|-------|-------|----------|
| **Herbaceous material** | | | | | | |
| **Season: (dry/wet)** | | | | | | |
| | | | | | | Herbs/grass |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Appendix 2: Woody plants availability data sheet**

| Date | site | South | East | TRSCT | *Spp* | Category | Canopy intercept (cm) |
|------|------|-------|------|-------|-------|----------|----------------------|
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |
|      |      |       |      |       |       |          |                      |

The header "Woody Plants Availability" spans across the top of the table.

**Appendix 3:  Vegetation type and use**

| Date | Obs. time | Weather | Site | So | East | Transect | Spp | Veg. Class | Height class | Max height | Rhino | | Elephants | | Others | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Fresh | Old | Fresh | Old | Fresh | Old | |
| | 1615 | Sunny | A | | | 1 | | | | | | | | | | | |
| | | | A | | | 1 | | | | | | | | | | | |
| | | | A | | | 1 | | | | | | | | | | | |
| | | | A | | | 1 | | | | | | | | | | | |
| | | | A | | | 1 | | | | | | | | | | | |
| | | | B | | | 1 | | | | | | | | | | | |
| | | | B | | | 1 | | | | | | | | | | | |
| | | | B | | | 1 | | | | | | | | | | | |
| | | | B | | | 1 | | | | | | | | | | | |

**Appendix 4: Distribution Data Sheet**

| | | | | | Rhino Sightings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Composition** | | | | | | | | |
| **Date** | **Site** | **Weather** | **Start obs** | **Number** | **Female calves** | **Male calves** | **Female SA** | **Male SA** | **Female AD** | **MALE AD** | **Names** | **End obs** | **Remarks** |
| | | | (Time) | | | | | | | | | (Time) | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

**Appendix 5: Black Rhino population attributes data sheet**

| Name of rhino (Cons. Naming) e.g John, | Date of Birth (Year) | Sex | Mother | Father | Calf (offspring) | Remarks |
|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

**Plate 3: Rhino feeding on *G. cordifolia* in crater floor during wet season**



**Plate 4: Shrub (*S. aculeastrum*) with fresh rhino bites in dry season**

**Plate 5: Forage habitats during dry season**

**Plate 6: Observation of foraging rhinos during wet season**