APPLYING FORAGING THEORY TO DIET CHOICE AND HABITAT SELECTION IN BLACK RHINOCEROS

BY

ALINA J. KIPCHUMBA
B.S., University of Nairobi, Kenya. 1991

THESIS

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CERTIFICATE OF APPROVAL

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I hereby recommend that the thesis prepared under my supervision by

ALINA J. KIPCHUMBA

entitled APPLYING FORAGING THEORY TO DIET CHOICE AND HABITAT SELECTION IN BLACK RHINOCEROS

be accepted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Adviser (Chairperson of Defense Committee)

I concur with this recommendation

Department Head/Chair

Recommendation concurred in:

Members of Thesis or Dissertation Defense Committee

UIC University of Illinois at Chicago

I dedicate this thesis to my sweet great grandma, Maria Kobilo Kopchumba, who has been a great source of love, joy and encouragement. She has always inspired me to shoot for the stars.

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SUMMARY

Understanding the mechanisms behind diet choice and habitat selection of large herbivores is key to designing appropriate management and conservation strategies. I applied patch use theory to study three aspects of the foraging ecology of black rhinoceros (*Diceros bicornis*, L.) in Aberdares, Nairobi and Ngulia Rhino Sanctuary; habitat selection in time (wet and dry season), habitat selection in space (open and bush micro-habitats), and diet choice (foodplants). The role played by food availability, predation risk and grade in shaping dietary choices was examined. Individual foodplants (trees and shrubs) were considered as food patches (Astrom et al. 1990). I assumed that foragers should forage in each patch until the food density decreases to the average return from all available patches. The number of bites per individual foodplant and the mean bite diameter measured browse intensity in each food patch.

Feeding surveys were conducted in the wet season (Aberdares: October-November 1998, Nairobi: July-August 1998, Ngulia: December 1999), and dry season (Aberdares: August-September 1999, Nairobi: October-November 1999, Ngulia: September 1998). Of all the plants I sampled, 57% are browsed by black rhinos in Aberdares, 65% in Nairobi and 70% in Ngulia. In Aberdares, 82 food plants were identified as black rhino food plants in the wet season and 54 in the dry season. In Nairobi, 43 food plants were identified in the wet season and 68 in the dry season. I recorded 37 food plants from Ngulia Rhino Sanctuary in the wet season and 51 in the dry season.

SUMMARY (Continued)

In Aberdares, the mean number of bites per plant was 9.22 in the wet season and 7.65 in the dry season (Wet season: Range = 1 to 136, s.d = 10.94, dry season: Range = 1 to 100. s.d = 9.9).The mean bite diameter was 5.87mm (Range = 1.7mm to 21.5mm, s.d = 2.19mm) in the wet season and 5.89mm in the dry season (Range =2mm to 17mm, s.d = 2.02mm). The mean number of bites in Nairobi was 15.75 (Range =1-300, s.d = 23.03) in the wet season and 7.98 (Range = 1-171, s.d = 10.38) in the dry season. The mean bite diameter was 6.7 mm (Range = 1-20, s.d = 2.7mm) in the wet season and 6.7mm (Range = 2-23, s.d = 8.12mm) in the dry season. In Ngulia sanctuary, the mean number of bites was 11.25 (Range = 6-160, s.d = 14.79) in the dry season and 12.18 in the wet season (Range = 1-192, s.d = 15.54). The mean bite diameter was 5.67 mm (Range = I-18. s.d = 1.85) in the dry season and 5.39mm (Range = 1-20. s.d = 2.07) in the wet season.

Black rhinos approached each food plant differently. Mean bites and bite diameters differed significantly between food plants and between study sites. I observed some seasonal variation in the number of bites and bite sizes selected by rhinos. In Aberdares. season had a significant effect on mean number of bites and percent browse, and no effect on mean bite diameter. Mean number of bites were higher in the wet season and percent utilization was higher in the dry season. Only mean bite diameter showed a strong plant-season interaction. In Nairobi NP, season had a strong effect on mean number of bites and mean bite diameter. There was a strong plant-season interaction on all variables. I recorded more and bigger bites in the wet season than in the dry season. Percent utilization was higher in the dry season. In Ngulia, there was a strong effect of season on mean bite diameter. Black rhinos selected bigger bite diameters during the dry season. There was no significant difference in mean number of bites and percent utilization between seasons. Strong plant-season interaction was observed in all variables except percent utilization. Preliminary nutritional analyses of selected black rhino food plants suggest that black rhinos prefer food plants that contain low levels of nitrogen and condensed tannins.

CHAPTER 1

INTRODUCTION

In this study, I applied foraging theory to examine factors affecting diet choice and habitat selection in free-ranging populations of black rhinoceros (*Diceros bicornis*). Foraging theory was first introduced by MacArthur and Pianka (1966) to study how animals select their prey items and food patches. This was followed by studies on ways animals optimize their diet choice and use of depletable food patches (Pulliam 1974; 1975; Belovsky1978). These studies and others that followed (Schoener 1971; Krebs and Davies 1978; Stevens and Krebs 1986) derived a number of theories that attempt to explain how animals arrive at their foraging decisions. Charnov's (1976) Marginal Value Theorem and the concept of diminishing returns in a food patch became the focus of subsequent research on patch use (Kotler 1984; Lima and Valone 1986; Brown 1988; 1992; Kotler et al. 1991; 1994).

Within foraging theory, a forager must decide what to eat (diet choice) and where to find it (habitat selection or patch use). Foraging decisions have to be made at various spatial and temporal scales (Bailey 1995). Herbivores are confronted with a wide variety of possible food plants and must decide what food items to eat or reject depending on the prevailing conditions. These include food availability both in space and time (Rosenzweig 1981; 1987; Brown 1988; Holbrook and Schmitt 1988; Bailey et al. 1996), forage quality and quantity (Robbins 1983; Senft et al. 1985; Brown and Morgan 1995), nutritional requirements (Tilman 1980; 1992; Crawley 1983; Robbins 1983), Toxins (Feeny 1968; 1970; Rhoades 1979; Provenza et al. 1984; Provenza and Malechek 1984;

Robbins et al. 1987; 1991; Bernays 1981; Cooper and Owen-Smith 1985; Smallwood and Peters 1986; Bernays et al 1989; Dearing 1997) and predation risk (Lima and Valone 1986; Brown 1988; 1992; Kotler 1984; Kotler et al. 1991; 1994). In nature there exists a variety of habitats each containing a mosaic of food patches within which food items vary in density, size and profitability. An essential premise of patch use is that the forager experiences diminishing returns within a patch, and that moving to a new patch is costly in terms of time and energy (Laca et al. 1994).

Once a forager locates a patch, it must decide to accept the opportunity to harvest the patch (Rosenzweig 1981), and how much time or energy to devote to those patches it accepts for harvesting (Charnov 1976). There are other factors that affect the fitness of a forager in a patch apart from the energy obtained from food. Foraging behavior of an animal in a patch may be influenced by the cost of predation (Kotler 1984; Brown 1988; Holbrook and Schmitt 1988; Lima and Dill 1990; Kotler et al 1991; Brown 1992; Moody et al 1996), the metabolic cost expended during foraging, and the missed opportunity cost, that is, the missed opportunity of not performing other fitness enhancing activities such as mating (Brown 1988). A forager that is behaving optimally should exploit a resource patch so long as its energy gain (H) from the patch exceeds its metabolic (M), predation (P), and missed opportunity (MOC) costs of foraging. Consequently, it should leave the patch when harvest rates equal the sum of metabolic, predation and missed opportunity costs. These costs can be presented in equation form: Harvest rate $H = M + P + MOC$. It also follows that when a forager is confronted with a variety of foraging opportunities, it should allocate effort to each such that the marginal value of each activity is equal. Patches that present equal costs of foraging should be foraged to the same quitting harvest rate (Valone and Brown 1989).

I applied these concepts in my experimental design and used the framework of optimal foraging theory to describe patch use behavior in black rhino and to analyze their foraging decisions. I used intensity of browse (number of bites and mean bite diameter) as an index of food patch utilization. I considered individual trees and shrubs as food patches (Astrom et al. 1990) and used the patch use model to examine foraging decisions in black rhino. This model is of greater relevance when analyzing the exploitation of discrete depletable food patches (e.g trees) by browsers. In this study I applied patch use theory to examine three aspects of the foraging ecology of black rhino: habitat selection in time (seasonal variations), habitat selection in space (habitat variations), and diet choice (forage plants). Under diet choice, I determined the nutritional quality of food plants selected by black rhino, and the role played by (1) plant secondary compounds, specifically condensed tannins, (2) predation risk and (3) environmental factors in shaping dietary choices.

While examining the mechanisms affecting diet choice and habitat selection in wild populations of black rhino, I used the patch use model to interpret my results. In my study, I assumed that foragers will follow the decision rule outlined in the patch use model (Brown 1988). Each patch (represented here by individual food plants) should be foraged until the food density has decreased to the average rate of return from all available patches. The patch is assessed by measuring what was left in the patch after the forager has left. The density or amount of food remaining in a depletable patch after a foraging activity, described as the giving-up density (GUD, sensu Brown 1988), indicates the forager's assessment of that patch with respect to patch quality and associated costs of foraging. An efficient forager leaves a low GUD. I used browse intensity, measured by the number of bites per individual foodplant and bite diameter, to assess the GUD. High browse intensity (number of bites and bigger bite diameters) as large bite diameter indicates a low GUD. I carried out my study in three Parks (Aberdares, Nairobi and Ngulia Rhino Sanctuary). These are priority black rhino conservation areas, support important black rhino populations and differ in their overall abundance of food. They also represent all potential black rhino conservation areas in Kenya.

Some studies on the black rhinoceros ecology, behavior and conservation status have been conducted in several localities in East and Southern Africa. The ecology and behavior of black rhino has been described by Goddard (1966, 1967b), Schenkel and Schenkel - Hullinger 1969; Ritchie (1963), Roth and Child (1968), Joubert (1971), Mukinya (1973) and Kiwia (1989). These studies describe black rhinos as sedentary animals within distinct home-ranges. They observed that the size of home-ranges was determined by density of rhinos in the area, and the availability of food, water and shelter. Black rhino habitats include wet upland forested areas, woody/grassland savanna to arid dessert conditions.

Pioneering studies on the food preferences of black rhinoceros were carried out by Goddard (1968, 1970) who described the food preferences of two rhino populations, the first one in Northern Tanzania (1964-1966) and the second one in Tsavo National Park, Kenya, (1967-1969). He observed rhinos in six habitats that ranged from grasslands, bush-grasslands to bush-woodlands and forested areas; in both areas, rhinos preferred green succulent herbs throughout the year and legumes contributed a high percentage of their diets. This observation suggests that the protein content in the diets of wild black rhinos is probably high. Goddard also noted that some plant species were more available in one season than in others, and that diet selection in black rhinos was influenced by seasonal variation.

The data available on the foraging ecology of black rhino also describes the plant species consumed (Goddard 1969, 1970; Joubert 1971; Mukinya 1977; Loutit et al. 1987 and Oloo et al. 1994) and the plant parts consumed. According to these studies, the black rhino is described as a browser, feeding on a large number of species of plants with a diverse array of physical characteristics and nutrients (e.g spiny *Acacia spp* and plants with high levels of tannins). They also have an ability to feed on coarser material of low nutritional value than other herbivores. Black rhinos are somewhat selective in their feeding strategy consuming the stem, leaves, buds, twigs, seeds or any combination of these plant parts. They showed seasonal shifts in plant species and plant parts browsed. Rhinos fed less on each plant species in the dry season than in the wet season (Oloo et al. 1994). The physical characteristics of the plant parts browsed ranged from very soft stems of *Ferula communis* in Kenya (Oloo et al. 1994) to very spiny *Euphorbia virosa* in Namibia (Loutit et al. 1987). Mukinya (1977) noted that rhinos fed mostly in areas close to watering points especially in the dry season.

This dissertation has been organized into five chapters. In chapter one, I present a full analysis of the Aberdares National Park data and examine all the factors that influence diet choice and habitat selection except food quality which will be discussed in chapter four. This is the only chapter that explores predation risk in detail. Chapter two focuses on food availability and preferences in all the three Parks in the wet and dry season. This chapter provides a comparative analysis of seasonal changes in food abundance and preferences as well as comparisons across Parks. In chapter three, I explore the significance of black rhino bites and bite sizes in determining giving up density (GUD), food availability using bite sizes and how foraging decisions made at the bite level have important consequences to browsing herbivores and the plants they eat. This chapter also compares bites and bite diameters between seasons and across Parks. Chapter four examines the role played by food quality in diet choice and food preference. This chapter provides the preliminary results of the nutritional study that we conducted in the three study areas.

I explore the conservation status and management practices of the black rhino in chapter five. This chapter summarizes the significance of the entire study for using foraging theory to study diet choice and habitat selection in black rhino. In this chapter, I discuss ways in which the findings from this study can be integrated into the management and conservation of this endangered species. I also explore the use of bite diameter and patch use behavior as indicators of environmental change.

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CHAPTER II

APPLYING FORAGING THEORY TO DIET CHOICE AND HABITAT SELECTION OF BLACK RHINOCEROS *(Diceros bicornis michaeli L.)*

INTRODUCTION

The efficient exploitation of available food resources is vital for all animals. The ability to harvest food at low resource abundance influences the amount of food available to a forager and its competitive ability against other foragers that share the same resources. Many scientists have investigated how animals select their prey items and food patches (MacArthur and Pianka 1966; Schoener 1971; Charnov 1976; Pulliam 1974; Stevens and Krebs 1986), and as such have come up with theories that attempt to explain how animals arrive at their foraging decisions. The marginal value theorem (Charnov 1976) and the concept of diminishing returns from a patch (Brown 1988; 1992) have been used to address the question of when a forager should leave a depletable patch. We were interested in how optimal foraging theory applies to the foraging ecology of free ranging black rhinoceros, *Diceros bicornis*

Within foraging theory, a forager must decide what to eat (diet choice), and where to find it (habitat selection and patch use). Diet choice and habitat selection are influenced by (1) the safety of the patch (predation risk), (2) patch richness (food abundance), (3) encounter probability of the food item (or detectability), and (4) the nutritional quality of the food (Brown and Morgan 1995). There are a variety of habitats in nature that generally offer a mosaic of food patches within which food items vary in density, size and profitability. An essential premise of the patch use model is that the forager experiences diminishing returns within the patch, and that moving to a new patch is costly in terms of time and energy (Laca et al. 1994)

Herbivores are confronted with a wide variety of possible food plants and must make foraging decisions at a variety of spatial and temporal scales (Bailey 1995). Their major task is to decide what food items to eat and reject depending on the prevailing conditions. These include food availability in time and space (Rosenzweig 1981; 1987; Brown 1988; Holbrook and Schmitt 1988; Bailey et al. 1996), forage quality and quantity (Robbins 1983; Senft et al. 1985; Pinchak et al. 1991), nutritional requirements (Tilman 1980; 1982; Crawley 1983; Robbins 1983), toxins (Feeny 1968; 1970; Rhoades 1979; Provenza et al. 1984; Robbins et al 1987; 1991; Bernays 1981; Smallwood and Peters 1986; and Dearing 1997) and predation risk (Lima and Valone 1986; Brown 1988; 1992; Kotler 1984; Kotler et al. 1991; 1994). Once a forager locates a patch, it must decide whether to accept the opportunity to harvest it (Rosenzweig 1981), and how much time or energy to devote to those patches it accepts for harvesting (Charnov 1976). Bailey et al. (1996) found a positive relationship between the time an herbivore spends in a plant community and the available quantity and quality of forage.

Apart from energy gained from a patch, the fitness of a forager in a patch is influenced by the cost of predation, the metabolic cost expended during foraging, and the missed opportunity cost, that is, the cost of not performing other fitness enhancing activities such as mating (Brown 1988). A forager that is behaving optimally should exploit a resource patch so long as its energy gain (H) from the patch exceeds its metabolic (M), predation (P), and missed opportunity (MOC) costs of foraging. Consequently, it should leave the patch when harvest rates equal the sum of metabolic, predation and missed opportunity costs. It also follows that when a forager is confronted with a variety of foraging opportunities, it should allocate effort to each such that the marginal value of each activity is equal. Patches that present equal costs of foraging should be foraged to the same quitting harvest rate (Valone and Brown 1989)

Most studies on large herbivores in tropical savanna ecosystems have been directed at their feeding strategies and diet selection, and the implication of these behaviors on their conservation and management (Napier and Sheldrick 1963; Pellew 1984; Owen-Smith 1988; Young et al. 1991). Diet selection has been analyzed by direct observation in the field, and indirect observation through fecal analysis and feeding site observation. The black rhinoceros is a browser, feeding on a large number of plant species with a diverse array of physical characteristics and nutrients (Ritchie 1963; Goddard 1968; 1970; Joubert and Ellof 1971; Mukinya 1977; Loutit et al. 1987; and Oloo et al. 1994). They are somewhat selective in their feeding strategy consuming the stem, leaves, buds, twigs, seeds or any combination of these plant parts. Other studies (Schenkel and Schenkel 1969; Kiwia 1989) describe black rhinos as sedentary animals that exhibit distinct home-ranges. They observed that the size of home-ranges was determined by density of rhinos in the area, and the availability of food, water and shelter.

I applied patch use theory to examine three aspects of the foraging ecology of black rhino; habitat selection in time (seasonal variations, wet and dry season), habitat selection in space (habitat variations, open and bush micro-habitats), and diet choice (foodplants). Under diet choice, we examined the role played by food availability, predation risk and slope (percent grade) in shaping dietary choices. I considered individual trees or shrubs as food patches (Astrom et al. 1990). I assumed that foragers follow the decision rule outlined in the patch use model. Each patch (represented here by individual foodplants) should be foraged until the food density decreases to the average return from all available patches. The patch was assessed by what was left after a foraging activity. The density or the amount of food remaining in a depletable patch after foraging, described as the giving-up density (GUD, Brown 1988), indicates the forager's assessment of that patch with respect to patch quality and associated costs of foraging. An efficient forager leaves a low GUD. The GUD was assessed by measuring the browse intensity, measured by the number of bites per individual foodplant and mean bite diameter. High browse intensity (number of bites) and a bigger bite diameter indicates a low GUD. Our specific goals were to determine the plant species utilized by black rhinoceros in Aberdares National Park, their diet preferences and habitat selection, and how these factors change with changing seasons, background food abundance and predation risk.

METHODS

A. Study site: Aberdares National Park

Aberdares National Park, located on the eastern side of the Great Rift Valley, 200Km North of Nairobi, Kenya, lies between the equator (00^0 00^1 latitude) and 00^0 45^1S. and between 36^0 30^1 and 30^0 51^1E. The study was conducted in the wet season (October-November 1998) and the dry season (August-September of 1999) in the eastern part of the Park, the Salient. The Salient covers an area of $70km^2$ and presently supports an estimated population of 45 black rhinos (KRCP, 1996). Aberdares was known to hold the highest densities (1 rhino/km^2) of black rhinos in the 1940's (Brett 1993). Estimated rhino numbers in the park fell from 450 in the early 1970's to 30 in 1987. The Salient area of Aberdares NP was identified as a priority black rhino conservation area in 1988.

The soils in this area are of volcanic origin with deep clay soils dominating the lower elevations of the Park and granulated sandy soils at higher elevations. The Salient is characterized by steep ravines dissected by deeply incised valleys with rivers flowing in an Easterly direction. The grade varies from 0 to 45^0. Several rivers (Kinaini, Muringato, Thara, Maguchi and their tributaries) drain the area. The mean annual rainfall is 1000mm with two marked peaks in March-June and October-December depicting a bimodal distribution. The study area lies between 2100 to 2500m above sea level and a mean diurnal temperature of 17^0C. Temperature varies with altitude.

There are three major vegetation types in the Salient: bamboo zone, forest and scrubland with glades of open grassland. The dominant tree species are *Podocarpus spp, Croton macrostachyus,* and *Cassipourea malossana.* Shrubs include *Crotalaria agatiflora, Solanum aculeastrum, Abutilon longicuspe, Toddalia asiatica* and *Vernonia auricufera.* The Salient holds the highest density of herbivores in the Park. Large herbivores include cape buffalo *Syncerus caffer*, elephant *Loxodonta africana*, black rhinoceros *Diceros bicornis*, water-buck *Kobus ellipsiprymnus*, bush-buck *Tragelaphus scriptus*, bongo *Tragelaphus euryceros,* giant forest-hog *Hylochoerus meinertzhageni,* and warthog *Phacochoerus aethiopicus.* Major predators include lion *Panthera leo*, spotted hyena *Crocuta crocuta* and leopard *Panthera pardus T.*

B. Plant survey

I surveyed the woody and herbaceous plants in October and November 1998. Three vegetation types were identified, forest composed of tall tress (>5m tall), bushy scrubland composed of shrubs (<5m tall) and open wooded grassland. The first plot in each vegetation type was selected and subsequent plots were mapped in relation to the first plot. The distance between plots was determined by driving 1km from the first plot. The plots were established 10m away from the roadside. A total of 26 (10x10m) plots were selected throughout the study area. I identified and counted all woody and herbaceous plants (excluding grasses) present in the 26 plots. These data estimate the plant densities and availability to black rhinos in the area.

C. Feeding Surveys

Previous studies on the ranging patterns of black rhinoceros show that they reside in home ranges that vary in size depending on water, food availability and densities of conspecifics in the area (Kiwia 1989). With the help of rhino surveillance personnel in the Park, I mapped current black rhino home ranges in the Salient. I used these areas for identifying black rhino feeding activity in the Salient.

Transects were established in the rhino home ranges, the length of which was determined by the size of the home range. I grouped feeding sites into stations along a transect. Stations were selected by the appearance of plants browsed by rhinos. Unlike the plant survey these feeding stations do not represent a random sampling of plants. Rather, they represent a stratification of plants by the rhino's presence and decision to feed. Once in the home range, I looked for footprints along game tracks and watering points, and for rhino feeding activity. Sometimes this meant walking along actual rhino tracks. The first feeding site we located was recorded as the first station. Feeding stations were set up such that they were at least 10m apart. It was easy to distinguish black rhino feeding activity because of their characteristic way of cutting browse. They use the upper prehensile lip to pull twigs into the mouth where they are cut off cleanly at the proximal end of the molars. Plants browsed by black rhino have a pruned look.

Feeding surveys were conducted in the wet (October-November 1998) and dry (August-September 1999) seasons. I sampled a total of 11 transects in the wet season and 10 transects during the dry season. In total, 469 stations were recorded in the wet season and 255 in the dry season. Feeding stations ranged from 7 to 36 per transect in the wet season and 4 to 43 in the dry season.

The following data were recorded at a station: (1) all plants browsed, (2) number of bites per individual food plant, (3) the diameter of 5 freshly clipped branches, (4) the height of the tallest branch browsed, (5) percentage of branches browsed per plant (0 – 100%, estimated at increments of 10%), (6) the parts eaten (leaves, fruit, flower, stem) and, (7) the condition of the plant (green, dry, broken branches, uprooted plants). The slope (percent grade ranked between 0 – 45% at increments of 5%) and microhabitat (bush or open depending on where the rhino stood to reach the branches) was recorded at each station. This gave a relative measure of safety of the forager at the feeding station. The amount of food harvested from each patch depends on the relative safety of the patch to rhinos. More food should be harvested from a patch in a safe (comfortable) micro-habitat than one in a risky (more prone to harassment by lions and hyenas) micro-habitat. All plants that were not eaten within a 5m radius from the station were identified. These are plants that the rhino actually encountered but rejected as feeding opportunities.

RATIONALE FOR THE TECHNIQUE

A. Rationale behind plant surveys

The 10x10m plots were used to estimate the plant densities and forage availability to black rhinos across each habitat. This data is important in evaluating the marginal value of food across habitats. The marginal value of food is expected to vary inversely with background abundance. These data will also be used to compare utilization versus availability of food in the area, and to evaluate the overall quality of the habitat for black rhinos.

B. Rationale behind feeding surveys

In this experimental design, there are two microhabitats, open and bush. I predict that the open habitat is safe or presents less risk of being harassed by predators whereas the bushy habitat is riskier than the open (rhinos have a high chance of being harassed by predators). I also predict that steeper microhabitats (high grade) present higher risk of falling or injury than less steep slopes. As discussed earlier, predation risk is a cost to a forager and influences a forager's net energy gain from a food patch. Predation here implies lethal and non-lethal effects. The black rhino is larger than its potential predator. The lion and hyena have been reported to prey on young (less than 2 years old) rhinos and sometimes harass adult rhinos. The interactions between rhinos and their predators may be lethal if rhinos do not respond appropriately. I predict that the open habitat is less risky than bush because rhinos can detect and respond to predators faster than in the bush. It is difficult for an animal weighing over a 1000kg to escape from predators in the bush because its mobility is limited. Similarly, we predict that steep areas present a risk to rhino browsing because they can easily fall or fall prey to predators.

The feeding stations were stratified according to plant species eaten and not eaten, micro-habitat (bush and open) and percent grade. The safety of the patch or predation risk was quantified using the number of bites and mean diameter in the safe or risky area, and compared across different grades. The number of bites per food plant, percent branches browsed (percent utilization) and mean bite diameters was an indication of browse intensity and a measure of GUD. A high mean bite diameter and high number of bites or percent utilization indicates a low GUD. Similarly, patches that had fewer bites or percent utilization and low mean bite diameter were an indication of a high GUD. The following predictions can be made from this approach: (1) if two patches exist in different nearby microhabitats within the same environment, safe and risky, the safe patch will have a lower GUD. I expect a higher abundance of food in riskier habitats (high GUD) than safer ones, and competition from other browsers will be high in these safe areas. (2) a food patch in a high quality environment will have a higher GUD than one in a lower quality environment. Similarly, patches should have higher GUDs in the wet season due to higher quality and abundance of food than in the dry season when food quality and abundance is low and water is scarce.

The mean bite diameter was also used as an indication of off take and as a measure of diminishing returns from a given patch (Shipley et al. 1999). The bigger the bite diameter, the larger the quantity of browse and the lower its nutritional value because of higher fiber content with diameter. Plants were grouped into three categories depending on their potential or available twig diameters and the actual mean bite diameters. I chose a mean bite diameter of 5.5mm (the median value for mean bite diameter) to be the dividing line between small and large bite diameter. The first category were food plants with small (<5.5mm) actual mean bite diameter due to their small twig size. These plants, high quality but of low quantity, may be valuable to rhinos but do not offer much offtake due to their small stature. The second category were food plants with large (>5.5mm) potential twig diameter and small actual mean bite diameter. These plants, high quantity but of low quality, may not be particularly valuable to black rhinos and may be fed on less in the presence of preferred plants. The third category were food plants that have a large (>5.5mm) potential twig diameter and large actual mean bite diameter. These are high quality-high quantity plants and are liked by black rhinos as they offer large amounts of profitable browse material.

The height of the browse was important because some profitable browse may be inaccessible to rhinos. Height indicates how thoroughly a tall plant can be fed on by rhinos. Plants that exceed the reach of rhinos therefore are less browsed while the short plants are easily browsed. This provided data to estimate the height with the most number of bites. This could be the height mostly selected by black rhinos.

The description of data analyses will be presented as they are used.

RESULTS

A. General

Table Ia and Ib summarize descriptive statistics from the wet and dry season. All the plants surveyed are listed along with family names. The columns that follow the family name represent the data recorded from black rhino food plants only. The last 2 columns in table Ia (percent plant representation in plots and density) show data from the 10x10m plots.

B. Plant surveys

A total of 26 (10x10m) plots were sampled throughout the Salient area of Aberdares National Park during the wet season. At least 144 plant species from 51 families were sampled (Table Ia). All but 18 plants were identified to the species level. Of the plants sampled, 47% were woody and 53% herbaceous.

I categorized the plants into high (>100 plants/ha), medium (10-100 plants/ha) and low (<10 plants/ha) density (Table II). I recorded 23 plant species in the high density category, 86 into the medium and 368 in the low density category (Table Ia for plant densities). Of the black rhino foodplants, 17 plant species fell into the high density category, 44 into the medium density category and 19 into the low density category. Ten abundant foodplants plants, *Abutilon longicuspe, Ocimum gratissimum, Sida rhombifolia, Toddalia asiatica. Vernonia auricufera, Achyranthes aspera, Hypoestes verticillaris, Hypoestes forskahlii, Pentas lanceolata, and Erythrococca bongensis* occurred in at least 50% of the plots (Table1a, % representation column).

C. Feeding surveys

At least 82 plant species from 33 families were eaten by black rhinos in the Salient area of Aberdares National Park during the wet season (Table Ia) and 56 plants from 25 families in the dry season (Table Ib). 61.7% of the plants selected were woody

TABLE IA: WET SEASON BLACK RHINO FOOD PLANTS FROM SALIENT (ABERDARES NP)

Plant name	Family name	N	Mbites	Mdiam	Mheight	%browsed	%open	grade	freqE	freqNE	%Rplots	Density
Abutilon longicuspe	Malvaceae	89	8.8	6.26	1.37	70	73.03	10.5	50	2	57.69	310
Ocimum gratissimum	Labiatae	80	12	1.19	70	4.5	70	5.36	62	18	76.92	610
Solanum aculeastrum[2]	Solanaceae	79	8.1	5.55	1.22	66	79.75	3	35	8	11.54	60
Solanum aculeastrum[1]	Solanaceae	42	5.6	7.53	1.07	66	88.1	5.5	85	10	30.77	70
Sida rhombifolia	Malvaceae	41	5.9	4.74	0.55	84	95.12	6	20	1	57.69	430
Leucas deflexa	Labiatae	20	13.6	4.64	0.91	68	45	15.5	13	2	23.08	40
Senna septemtrionalis	Caesalpiniaceae	11	13.5	9.14	1.12	96	100	0	8	0	3.85	10
Senna didymobotrya	Caesalpiniaceae	10	9.2	7.79	1.39	67	70	5.5	10	14	26.92	100
Indigofera arrecta	Papilionaceae	9	9.6	3.66	0.62	85	100	0	3	0	19.23	50
Rhamnus prinoides	Rhamnaceae	8	4.5	7.92	1.51	76	87.5	4	8	2	26.92	70
Solanum incanum	Solanaceae	8	4.1	6.77	0.55	96	100	0	1	0	26.92	0
Erythrococca bongensis	Euphorbeaceae	7	27.3	3.65	1.76	57	85.7	0	6	13	57.69	180
Pentas lanceolata	Rubiaceae	6	10	4.35	0.65	88	33.33	16.5	5	0	65.38	350
Hibiscus vitifolius	Malvaceae	6	44.7	4.52	1.68	98	88.6	5	6	3	0	0
Vernonia galamensis	Compositae	5	5.6	7.15	1.19	54	100	4	3	0	7.69	90
Crotalaria incana	Papilionaceae	5	8	6.18	1	78	80	1	3	2	7.69	100
Sida tenuicarpa	Malvaceae	5	9	5.64	0.29	88	20	3	4	4	19.23	500
Urtica massaica	Urticaceae	5	6.6	5.64	0.84	92	100	3	4	7	23.08	420
Leucas grandis	Labiatae	5	8.6	5.47	1.03	92	40	0	5	0	0	0
Toddalia asiatica	Rutaceae	4	7.3	5.01	0.85	44	0	11	4	16	65.38	160
Achyranthes aspera	Amaranthaceae	4	7.3	5.01	0.85	44	0	11	2	2	61.54	550
Dovyalis abyssinica	Flacourtiaceae	4	16	5.64	1.74	63	5	7.5	4	1	30.77	40
Sida schimperana	Malvaceae	4	5.5	8.21	0.46	89	75	21	4	0	7.69	50
Solanum mauense	Solanaceae	3	6.3	5.07	0.34	67	100	5	3	0	0	0
Clausena anisata	Rutaceae	3	5.3	4.65	1.5	77	33.33	0	3	0	34.62	80
Hyppoestes forskahlii	Acanthaceae	2	3	4.25	0.84	30	50	10	2	0	76.92	1270
Croton macrostachyus	Euphorbeaceae	2	3	16.2	1.03	35	50	0	1	12	30.77	60
Nuxia congesta	Loganiaceae	2	8	4.85	1.23	65	100	0	2	2	23.08	20
Leonotis mollissima	Labiatae	2	2.5	7.06	1.01	65	50	0	2	0	11.54	20
Hypoestes aristata	Acanthaceae	2	14.5	2.75	1.1	68	100	7.5	2	0	7.69	70
Microglossa pyrifolia	Compositae	2	3.5	3.45	1.32	75	50	12.5	2	0	30.77	130

TABLE IA continued

Hibiscus fuscus	Malvaceae	2	10	6.6	0.64	75	100	25	1	2	0	0
Conyza bonariensis	Compositae	2	3	5.55	0.56	100	100	0	2	1	34.62	80
Phytolacca dodecandra	Phytolaccaceae	1	4	8.25	1.08	25	100	15	1	5	3.85	120
Hypoestes verticillaris	Acanthaceae	1	30	3	1.4	50	100	10	2	4	53.85	290
Solanum sp	Solanaceae	1	6	3.8	0.89	60	0	15	1	2	0	0
Lantana trifolia	Verbenaceae	1	3	3.17	1.4	60	100	0	1	7	42.31	100
Crassocephalum sp	Compositae	1	8	5.4	1.17	60	100	20	1	1	30.77	370
Triumfetta sp	Tiliaceae	1	6	4.5	0.37	80	100	25	1	0	15.38	190
Solanum nigrum	Solanaceae	1	18	5	0.52	90	100	0	1	0	0	0
Abutilon engeleranum	Malvaceae	1	14	7.5	1.66	90	0	0	1	0	11.54	30
Conyza newii	Compositae	1	8	3.7	0.92	95	100	5	1	0	23.08	170
Vernonia auriculifera	Compositae	1	3	8.5	1.67	100	100	0	1	21	50	130
Vangueria infausta	Rubiaceae	1	4	3.25	1	100	0	15	1	9	38.46	50
Tephrosia sp	Papilionaceae	1	16	6.1	1.39	100	100	0	1	0	0	0
Sp A	not identified	1	6	6.8	0.4	100	100	5	1	0	0	0
Sida cordifolia	Malvaceae	1	6	2.9	0.37	100	100	5	1	0	3.85	20
Pavonia urens	Malvaceae	1	22	4.1	0.98	100	0	10	1	1	15.39	40
Leucas urticifolia	Labiatae	1	16	3.7	0.63	100	100	0	1	0	15.38	30
Ehretia cymosa	Boraginaceae	1	6	4.8	0.68	100	100	0	1	0	23.08	30
Asparagus africanus	Asparagaceae	1	1	4.5	0.64	100	0	0	1	0	0	0
Vernonia lasiopus	Compositae					E					15.34	20
Thunbergia alata	Acanthaceae					E	———				26.92	40
Teclea simplicifolia	Rutaceae					E					11.54	20
Teclea nobilis	Rutaceae					E					15.38	50
Scutia myrtina	Rhamnaceae					E					7.69	10
Rhus natalensis	Anacardiaceae					E					7.69	20
Rhamnus staddo	Rhamnaceae					E					3.85	40
Pavonia patens	Malvaceae					E					23.08	60
Olea europaea	Oleaceae					E					19.23	50
Momordica foetida	Cucurbitaceae					E					30.77	20
Maytenus senegalensis	Celastraceae					E					7.69	20

TABLE IA continued

Maerua triphylla	Capparaceae	E	3.85	4
Lawsonia inermis	Lythraceae	E	11.54	30
Kalanchoe sp	Crassulaceae	E	1.33	70
Kalanchoe lugardii	Crassulaceae	E	3.85	10
Kalanchoe densiflora	Crassulaceae	E	11.54	50
Juniperus procera	Cypressaceae	E	11.54	40
Jasminium abyssinica	Oleaceae	E	34.62	10
Hyoestes sp	Acanthaceae	E	3.85	20
Hyoestes triflora	Acanthaceae	E	3.85	40
Heliotropium steudneri	Boraginaceae	E	3.85	1
Helinus integrifolius	Rhamnaceae	E	19.23	40
Grewia similis	Tiliaceae	E	3.85	4
Gomphocarpus semillunatus	Asclepiadaceae	E	3.85	4
Euclea divinorum	Ebenaceae	E	3.85	8
Convolvulus kilimandschari	Convolvulaceae	E	15.38	8
Commelina africana	Commelinaceae	E	7.69	2
Carissa edulis	Apocynaceae	E	3.85	2
Bidens pilosa	Compositae	E	3.85	3
Asparagus racemosus	Asparagaceae	E	3.85	4
Arudinaria alphina	Graminea	E	3.85	130
Zanthoxylum usambarence	Rutaceae	NE	3.85	4
Vigna sp	Papilionaceae	NE	3.85	4
Vigna parkeri	Papilionaceae	NE	3.85	4
Vernonia sp	Compositae	NE	7.69	20
Trifolium baccarinii	Papilionaceae	NE	7.69	10
Thalictrum rhynchocarpum	Ranunculaceae	NE	3.85	4
Sphaeranthus sp	Compositae	NE	30.77	280
Solanum sessillestellatum	Solanaceae	NE	15.34	30

TABLE IA continued

Solanecio mannii	Compositae	NE	7.69	30
Senecio syringifolius	Compositae	NE	26.92	90
Senecio petitianus	Compositae	NE	30.77	10
Rytigynia uhligii	Rubiaceae	NE	11.54	40
Ritchiea albersii	Capparaceae	NE	7.69	40
Pteris captotera	Pteridophytes	NE	7.69	30
Prunus africana	Rosaceae	NE	7.69	10
Podocarpus latifolius	Podocarpaceae	NE	7.69	10
Podocarpus falcatus	Podocarpaceae	NE	7.69	20
Plectranthus edulis	Labiatae	NE	3.85	10
Plectranrthus barbatus	Labiatae	NE	3.85	40
Plantago sp	Plantaginaceae	NE	3.85	3
Passiflora mollisima	Passifloraceae	NE	7.69	20
Olinia rochetiana	Oliniaceae	NE	3.85	40
Newtonia buchananii	Mimosaceae	NE	15.38	20
Impatiens tweediae	Balsaminaceae	NE	3.85	170
Geigeria sp	Compositae	NE	3.85	8
Galium simense	Rubiaceae	NE	3.85	20
Galium scioanum	Rubiaceae	NE	15.38	120
Ficus natalensis	Moraceae	NE	3.85	4
Falkia canescens	Convolvulaceae	NE	15.38	30
Fagaropsis angolensis	Rutaceae	NE	15.38	20
Euphorbia nepetita	Euphorbiaceae	NE	7.69	30
Euphorbia maderaspatensis	Euphorbiaceae	NE	3.85	30
Elaedendron buchananii	Celastraceae	NE	3.85	20
Drypetes gerrardi	Euphorbiaceae	NE	11.54	20
Diospyros abyssinica	Ebenaceae	NE	7.69	4
Digera muricata	Amaranthaceae	NE	7.69	20
Desmodium sp	Papilionaceae	NE	19.23	20
Cyphostema	Vitaceae	NE	3.85	4

TABLE IA continued

maranguense				
Cyathula polycephala	Amaranthaceae	NE	7.69	20
Cyathula peruviana	Amaranthaceae	NE	3.85	4
Cyathula cylindrica	Amaranthaceae	NE	7.69	30
Cucumis sp	Cucurbitaceae	NE	7.69	10
Crotalaria agatiflora	Papilionaceae	NE	19.23	20
Conyza sp	Compositae	NE	11.54	20
Clutia abyssinica	Euphorbiaceae	NE	15.38	120
Clerodendrum johnstonii	Verbenaceae	NE	23.08	60
Clematis simensis	Ranunculaceae	NE	7.69	100
Clematis hirsuta	Ranunculaceae	NE	15.38	40
Celtis africana	Ulmaceae	NE	3.85	4
Cassipourea malosana	Rhizophoraceae	NE	19.23	80
Calodendrum capense	Rutaceae	NE	7.69	10
Caesalpinia volkensii	Caesalpiniacae	NE	7.69	10
Caesalpinia sp	Caesalpiniacae	NE	3.85	10
Brachylaena sp	Compositae	NE	3.85	4
Bersama abyssinica	Melianthaceae	NE	23.08	40
Asplenium loxoscaphoides	Pteridophytes	NE	3.85	8
Aningeria adolfi	Sapotaceae	NE	3.85	4
Albizia gummifera	Mimosaceae	NE	3.85	4
Agrocharis melanantha	Umbelliferae	NE	7.65	20
Agrocharis incognita	Umbelliferae	NE	65.38	620
Achyrospermum sp	Labiatae	NE	3.85	3
Achyrospermum schimperi	Labiatae	NE	30.77	30

Solanum aculeastrum[1] = *Solanum aculeastrum ssp. Aculeastrum var. 1*
Solanum aculeastrum[2] = *Solanum aculeatrum ssp. Aculeastrum var. aculeastrum*

TABLE IA continued

NOTE

N = The number of individual plants sampled
Mbites = mean number of bites per plant
Mdiam = Mean bite diameter per plant
Mheight = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
Grade = percent grade
FreqE = Represents the number of times a plant was eaten at a station
FreqNE = Represents the number of times a plant was not eaten at a station
%Rplots = Percent occurrence of plant in the 10x10plots
Density = Denstity of the plant in the study area expressed as number of plants per hectare

TABLE IB: DRY SEASON BLACK RHINO FOOD PLANTS FROM SALIENT (ABERDARES NP)

Plant name	Family name	N	Mbites	Mdiam	Mheight	%browsed	%open	grade	freqE	freqNE
Ocimum gratissimum	Labiatae	108	7.8	5.35	1.13	74.35	26.9	3.29	53	34
Solanum aculeastrum[1]	Solanaceae	94	6.57	6.76	1.12	71.76	71.3	4.31	54	2
Abutilon longicuspe	Malvaceae	66	6.64	5.74	1.29	75.38	33	7.2	41	24
Sida tenuicarpa	Malvaceae	63	5.83	5.55	0.4	82.84	60.3	7.06	25	7
Sida rhombifolia	Malvaceae	44	4.73	7.53	0.56	89.55	59.1	5	20	3
Solanum aculeastrum[2]	Solanaceae	23	7.96	5.65	1.27	68.04	87	4.35	15	4
Senna septemtrionalis	Caesalpiniacea	23	9.57	10.26	1.08	91.52	17	4.13	11	0
Rhamnus prinoides	Rhamnaceae	22	6.05	6.98	1.44	80.46	68.2	0.91	12	9
Leucas urticifolia	Labiatae	22	8.32	4.4	0.91	92.04	18.2	6.14	13	4
Hyoestes forskahlii	Acanthaceae	22	32.82	4.16	0.76	88.64	0	4.55	11	35
Toddalia asiatica	Rutaceae	20	3.85	6.4	1	59.75	40	3.25	7	30
Rhamnus staddo	Rhamnaceae	13	5.46	6.03	1.73	91.15	69.2	0.77	13	0
Senecio syringifolius	Compositae	11	7.56	7.38	1.27	64.09	27	1.82	6	14
Olea europaea	Oleaceae	10	8.4	5.81	1.61	96.5	90	0	1	0
Hibiscus vitifolius	Malvaceae	8	14.88	4.43	1.31	72.5	0	6.25	7	3
Solanum incanum	Solanaceae	7	4.14	6.48	0.45	97.14	100	30	2	11
Lantana trifolia	Verbenaceae	6	3.5	4.81	1.36	93.33	0	3.33	4	10
Erythrococca bongensis	Euphorbeaceae	6	5.17	3.93	1.18	84.17	33.3	1.67	3	18
Dovyalis abyssinica	Flacourtiaceae	6	7.5	4.68	1.43	91.67	33.3	4.17	3	3
Clausena anisata	Rutaceae	6	2	4.82	1.21	100	0	6.68	6	1
Leonotis mollissima	Labiatae	5	3.6	6.53	1.27	76	40	7	2	1
Euclea divinorum	Ebenaceae	5	6.2	4.73	0.93	87	20	2	1	3
Senna didymobotrya	Caesalpiniacea	4	9.25	8.83	1.03	65	50	5	3	1
Rhus natalensis	Anacardiaceaae	4	1.75	6.44	0.81	100	75	0	4	0
Pentas lanceolata	Rubiaceae	4	4.25	4.76	0.48	97.5	0	6.25	4	2
Ehretia cymosa	Boraginaceae	4	5	5.78	1.17	100	0	3.75	3	0
Vernonia galamensis	Compositae	3	6	7.08	0.53	90	33.3	11.67	2	0
Vernonia auriculifera	Compositae	2	3.5	9.43	0.97	100	50	0	2	4

TABLE IB continued

Urtica massaica	Urticaceae	2	2	5.25	0.89	82.5	50	12.5	1	5
Teclea nobilis	Rutaceae	2	4.5	3.18	1.34	100	50	5	1	3
Pavonia patens	Malvaceae	2	35.5	3.75	0.98	100	50	2.5	3	0
Microglossa pyrifolia	Compositae	2	5	4.54	1.53	80	0	5	2	7
Junipera procera	Cypressaceae	2	3	3.5	0.98	100	50	0	2	0
Hibiscus fuscus	Malvaceae	2	5.5	4.88	1.29	100	0	7.5	2	0
Crotalaria incana	Papilionaceae	2	8	4.65	0.96	87.5	50	0	2	4
Clerodendrum johnstonii	Verbenaceae	2	2.5	4.75	1.32	100	0	15	1	1
Vernonia ssp galamensis	Compositae	1	1	9	0.45	100	0	10	2	0
Vernonia sp	Compositae	1	3	4.5	1.53	100	0	0	2	0
Vangueria infausta	Rubiaceae	1	1	5.5	1.19	25	0	10	1	3
Teclea simplicifolia	Rutaceae	1	5	4.3	1.4	100	0	0	1	1
Scutia myrtina	Rhamnaceae	1	5	6.3	0.86	100	100	0	1	0
Rytigynia uhligii	Rubiaceae	1	13	4.33	1.8	100	0	5	1	0
Phytolacca dodecandra	Phytolaccaceae	1	1	3	1.4	100	100	0	2	4
Nuxia congesta	Loganiaceae	1	1	10.5	1.83	100	100	25	1	1
Maytenus senegalensis	Celastraceae	1	3	3.33	1.1	100	100	0	1	0
Leucas urticiflora	Labiatae	1	11	3.9	0.14	100	0	5	11	2
Hyppoestes forskhalii	Acanthaceae	1	50	3.9	0.56	100	0	5	15	35
Hypoestes verticillaris	Acanthaceae	1	50	3.6	0.5	100	100	5	1	1
Commelina africana	Commelinaceae	1	2	2.5	1	100	0	10	1	0
Clutia abyssinica	Euphorbiaceae	1	1	4.5	1	100	100	1	1	0
Calodendrum capense	Rutaceae	1	4	4.5	1.5	100	100	5	1	0
Achyrospernum schimperi	Labiatae	1	4	5.88	0.53	35	100	0	1	0
Achyranthes aspera	Amaranthaceae	1	10	4.1	1.16	65	0	25	2	4
Abutilon engeleranum	Malvaceae	1	2	4	0.83	40	0	10	1	0

TABLE IB continued

<u>NOTE</u>

N = The number of individual plants sampled
Mbites = mean number of bites per plant
Mdiam = Mean bite diameter per plant
Mheight = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
Grade = percent grade
FreqE = Represents the number of times a plant was eaten at a station
FreqNE = Represents the number of times a plant was not eaten at a station

TABLE II: DENSITIES OF PLANTS FROM SALIENT (ABERDARES NP)

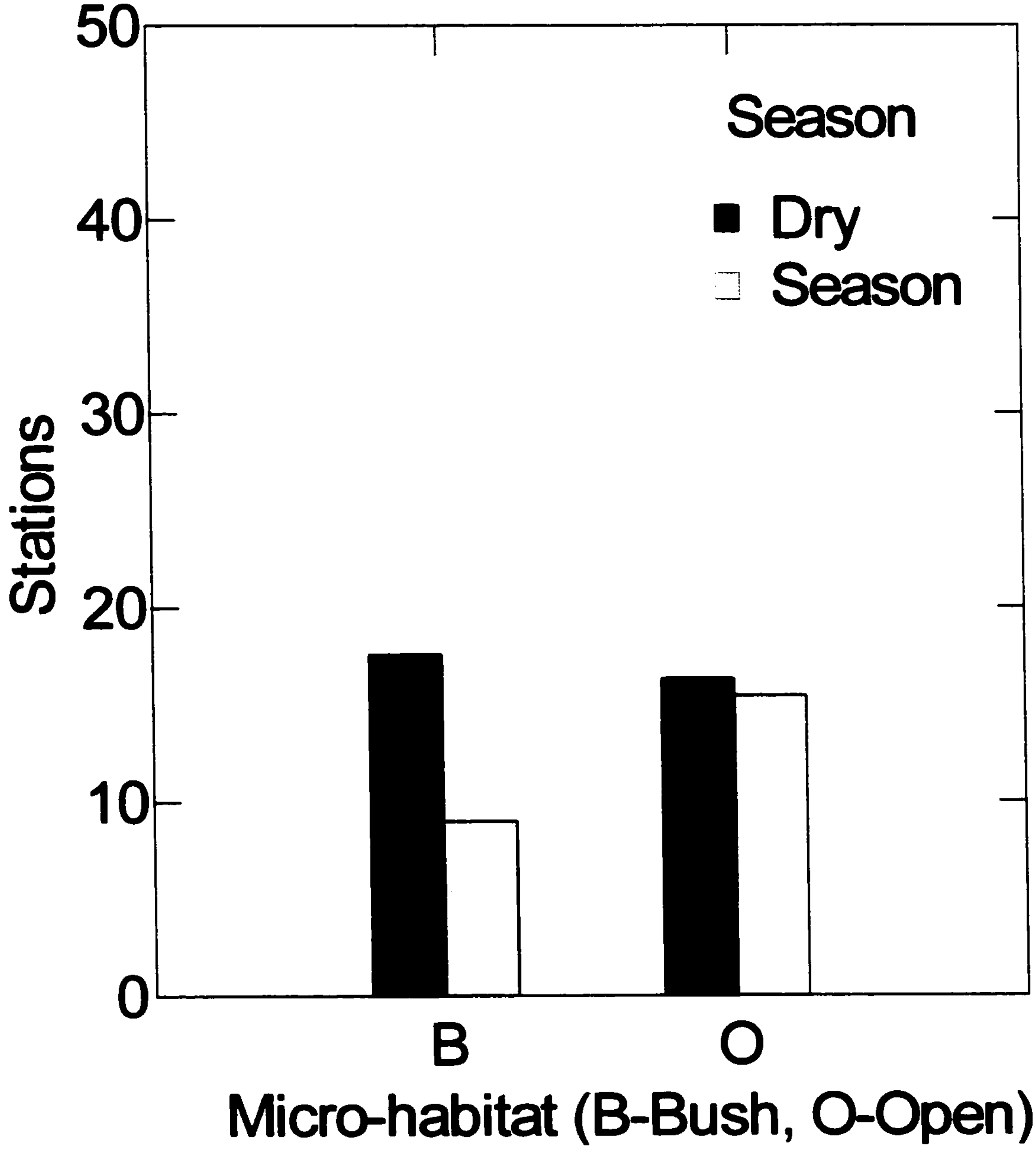
Density (plants/ha)	Number of plant species	Number of plants eaten by black rhinos	Number of plants not eaten
High >100	23	17	5
Medium 10-100	86	44	40
Low <10	36	20	19
Total	145	81	64

and 38.3% herbaceous. The food plants represent 55.9% of the plants sampled in the Salient area. Actual measurements (mean bite diameter, number of bites, height and percent utilization) were recorded from 51 species of food plants in the wet season and 54 species of food plants in the dry season. Families with at least 4 foodplants were Malvaceae (10), Compositae (11), Solanaceae (6), Labiatae (6), Rhamnaceae (4), Rutaceae (5) and Acanthaceae (8). This also represents the families with the most selected plant species.

Black rhinos did not discriminate among the plant parts they consumed. Leaves, flowers, fruits and stems were consumed from most plants selected. I did not find evidence (uprooted plants or broken branches) of extensive plant damage or mortality resulting from rhino browsing.

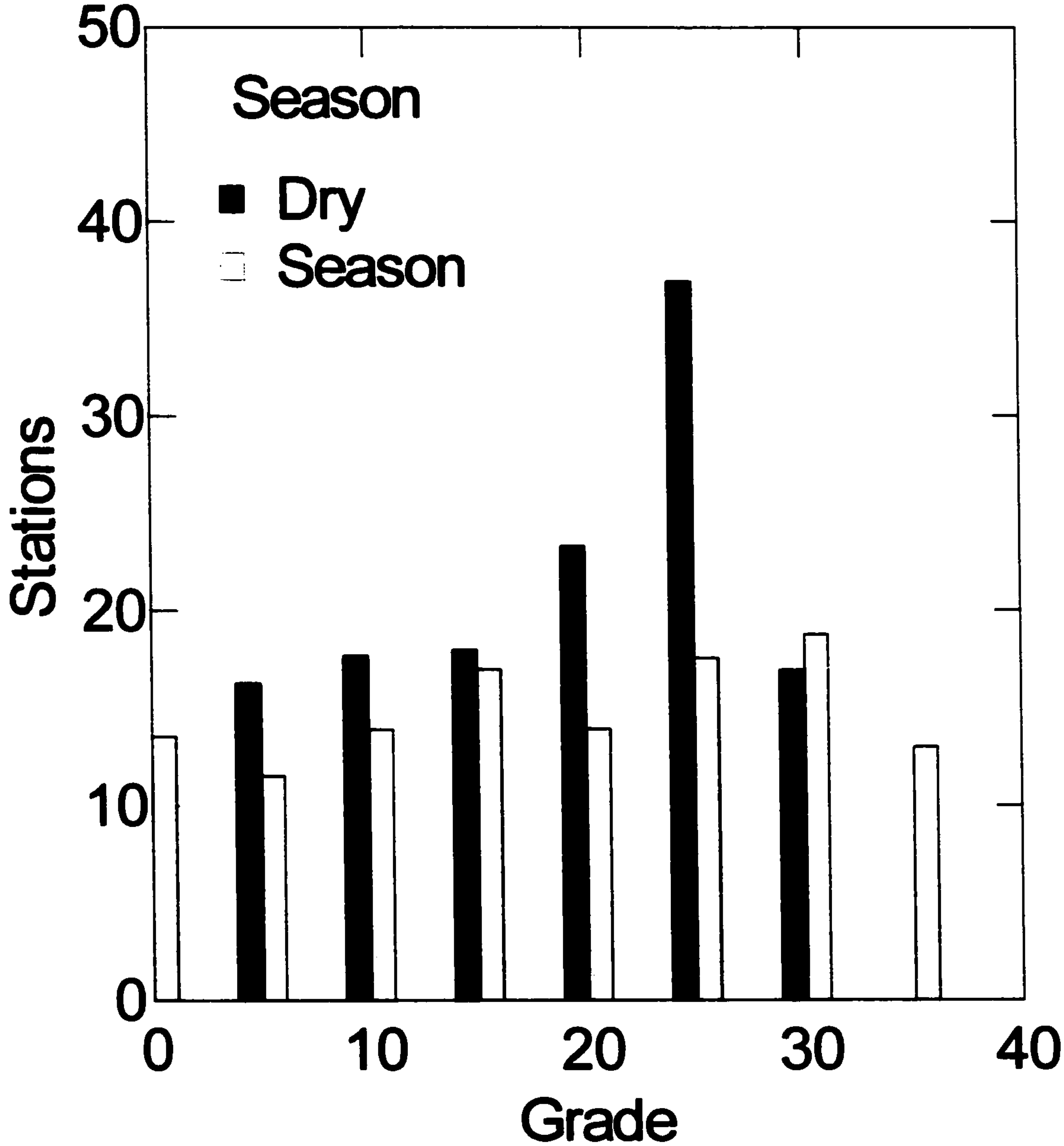
Stations: In total, 1152 individual plants (food patches) were encountered from 469 stations: 255 stations (500 food patches) in the wet season and 214 (652 food patches) in the dry season. Plants eaten from a station ranged between 1 to 9 individual plants in the wet season and 1 to 18 plants in the dry season. I sampled more stations in the open micro-habitat in the wet season, and more stations in the bush in the dry season (Figure 1a). This result is not significant. Of the 469 stations in the study area, only 11 were recorded in the forest floor. I did not observe a significant difference in the distribution of stations among grades in both seasons. However I did not encounter stations in the dry season beyond 30% grade (Figure 1b).

Figure 1a: Wet and dry season distribution of stations between micro-habitats. There was no significant difference in distribution of stations between micro-habitats.



Season
Dry
Season
Stations
0
10
20
30
40
50
B
O
Micro-habitat (B-Bush, O-Open)

Figure1b: Wet and dry season distribution of stations among grades. There was no significant difference in distribution of stations among grades.


Season
Dry
Season
Stations
Grade
0
10
20
30
40
50

Height: Black rhinos took bites from branches as high as 2.2m and as low as 0.15m in the course of the study period. The mean bite height across plants in the wet season was 1.104m (s.d = 0.459m, N= 500), and 1.04m (s.d = 0.496, N=652) in the dry season. However the average height of a bite (height weighted by number of bites per plant) was 1.23m. This represents the height where most browsing occurred. Some plants were herbs and shrubs that were below the mean height and rhinos could not browse any higher. Some plants were browsed to the ground and we took measurements of the stumps.

Bites and mean bite diameter: A total of 9600 bites were recorded from 1152 individual plants during the study period, 4989 and 4611 in the wet and dry season respectively. The number of bites per plant ranged from 1 to 136 in the wet season and 1 to 100 in the dry season. *Abutilon longicuspe, Ocimum gratissimum, Solanum aculeastrum ssp. Aculeastrum var1* (I will refer to this plant as *Solanum aculeastrum var1*), *Solanum aculeastrum ssp. aculeastrum var. acueleastrum* (I will refer to this plant as *Solanum aculeastrum var2*), *hypoestes forskahlii, senna septemtrionalis, Rhamnus prinoides, Toddalia asiatica, sida tenuicarpa* and *sida rhombifolia* contributed 73% of the total bites as well as food patches (Table Ia and Ib). There were slightly more bites in the open than bush micro-habitats during both seasons (Figure 2a). Bites were encountered from 0% grade to 35 % grade except in the dry season when we did not encounter feeding beyond 30% grade (Figure 3a).

The mean bite diameter was 5.87mm (Range=1.7mm to 21.5mm, s.d=2.19mm) in the wet season and 5.89mm in the dry season (Range=2mm to 17mm, s.d=2.02mm). Bigger bite diameters were recorded in the bush during the wet season and in the open during the dry season (Figure 2b). There was a general increase in mean bite diameter with increasing grade (Figure 3b) during both the wet and dry season.

D. Effect of plant, micro-habitat, grade and season on mean number of bites, mean bite diameter, height and percent utilization

I performed two-way analysis of variance to determine the effect of plant species, micro-habitat, grade and season on number of bites, mean bite diameter, height and percent utilization for all foodplants (Table III). The independent variables were plant, micro-habitat, grade and season and the dependent variables were bites, bite diameter, height and percent utilization.

Effect of plant: Plant species had a significant effect on mean number of bites ($p<0.003$), mean bite diameter ($p<0.0001$), height ($p<0.0001$), and percent utilization ($p<0.0001$) during both the wet and dry season. Rhinos also approached each plant species differently indicating strong preferences among food plants.

Effect of micro-habitat: There was a significant effect of micro-habitat on percent utilization ($p<0.05$), and mean bite diameter ($p<0.05$) in the wet season. Mean bite diameter was greater in the bush than in the open and percent utilization was higher in the open. There was no significant effect on mean number of bites ($p>0.05$) and height ($p>0.05$). For the dry season, there was a significant effect on height ($p<0.05$) and percent utilization ($p<0.05$). Height and percent utilization were greater in the bush than in the

Figure 2a: Wet and dry season distribution of mean number of bites among micro-habitats. Mean number of bites did not differ between micro-habitats during wet and dry season.

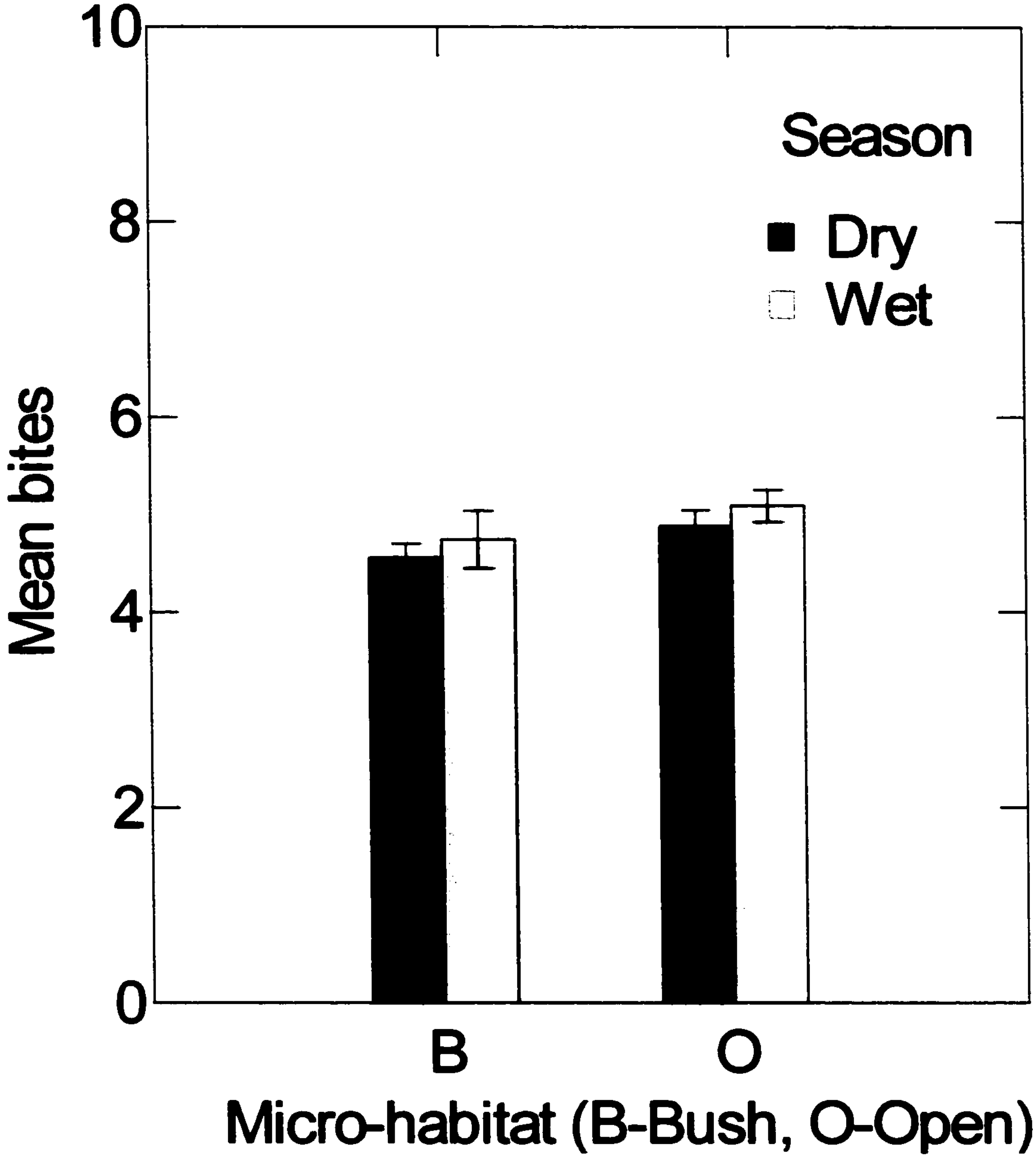
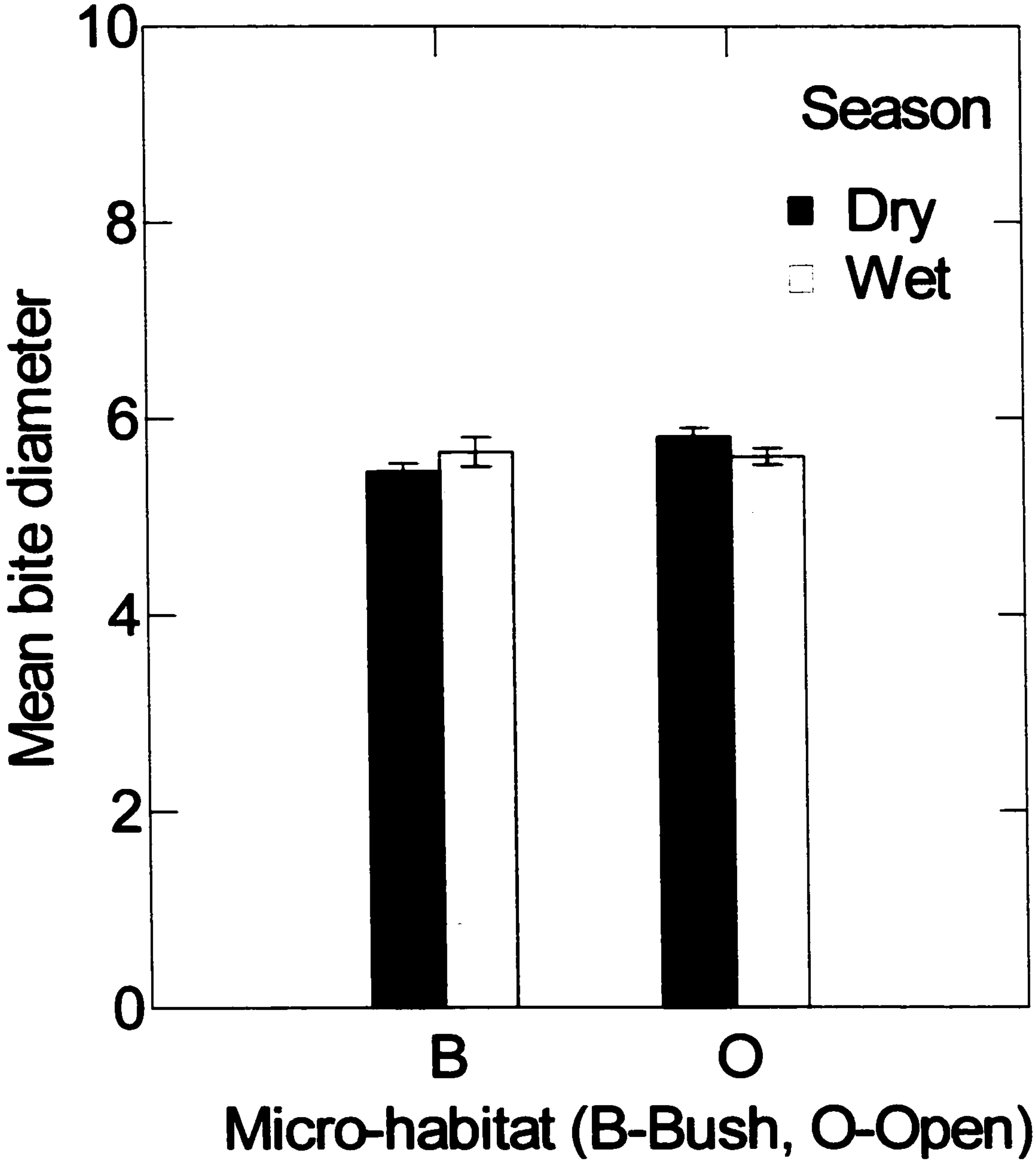

10
8
6
4
2
0
Mean bites
Season
Dry
Wet
B
O
Micro-habitat (B-Bush, O-Open)

Figure 2b: Wet and dry season distribution of mean bite diameter between micro-habitats. Mean bite diameter was greater in the bush ($p<0.05$) in the wet season. There was significant difference in the dry season.


10
8
6
4
2
0
Season
Dry
Wet
Mean bite diameter
B
O
Micro-habitat (B-Bush, O-Open)

open. There were no significant effects of micro-habitat on mean number of bites and mean bite diameter in the dry season.

Effect of grade: The mean bite diameter increased with increasing grade ($p<0.005$) in the wet season. Bite diameters did not differ significantly with increasing grade in the dry season. Grade had no significant effect on bites ($p>0.05$), height ($p>0.05$), and percent utilization ($p>0.05$) for both seasons.

Effect of season: Season had a significant effect on mean number of bites ($p<0.05$), height ($p<0.05$) and percent utilization ($p<0.0001$). Mean number of bites, height and percent utilization were greater in the wet than the dry season. There were no significant differences in mean bite diameters between seasons.

E. Effect of plant, micro-habitat, grade and season on mean number of bites and mean bite diameter of common plant species

I performed a two-way analysis of variance to determine the effect of plant species, microhabitat (bush and open), grade and season on mean number of bites and mean diameter of common plant species. I selected 10 foodplants that were highly preferred by rhinos throughout the study area and had sufficient data (N>20) for comparative purposes. These were *Ocimum gratissimum* (OCGR), *Abutilon longicuspe* (ABLO), *Sida rhombifolia* (SIRH), *Sida tenuicarpa* (SITE), *Solanum aculeastrum var 1* (SOAC), *Solanum aculeastrum var 2* (SOSE), *Senna septemtrionalis* (SEBI), *Rhamnus*

Figure 3a: Wet and dry season distribution of mean number of bites among grades. There was no significant effect of grade on mean number of bites ($p>0.05$).

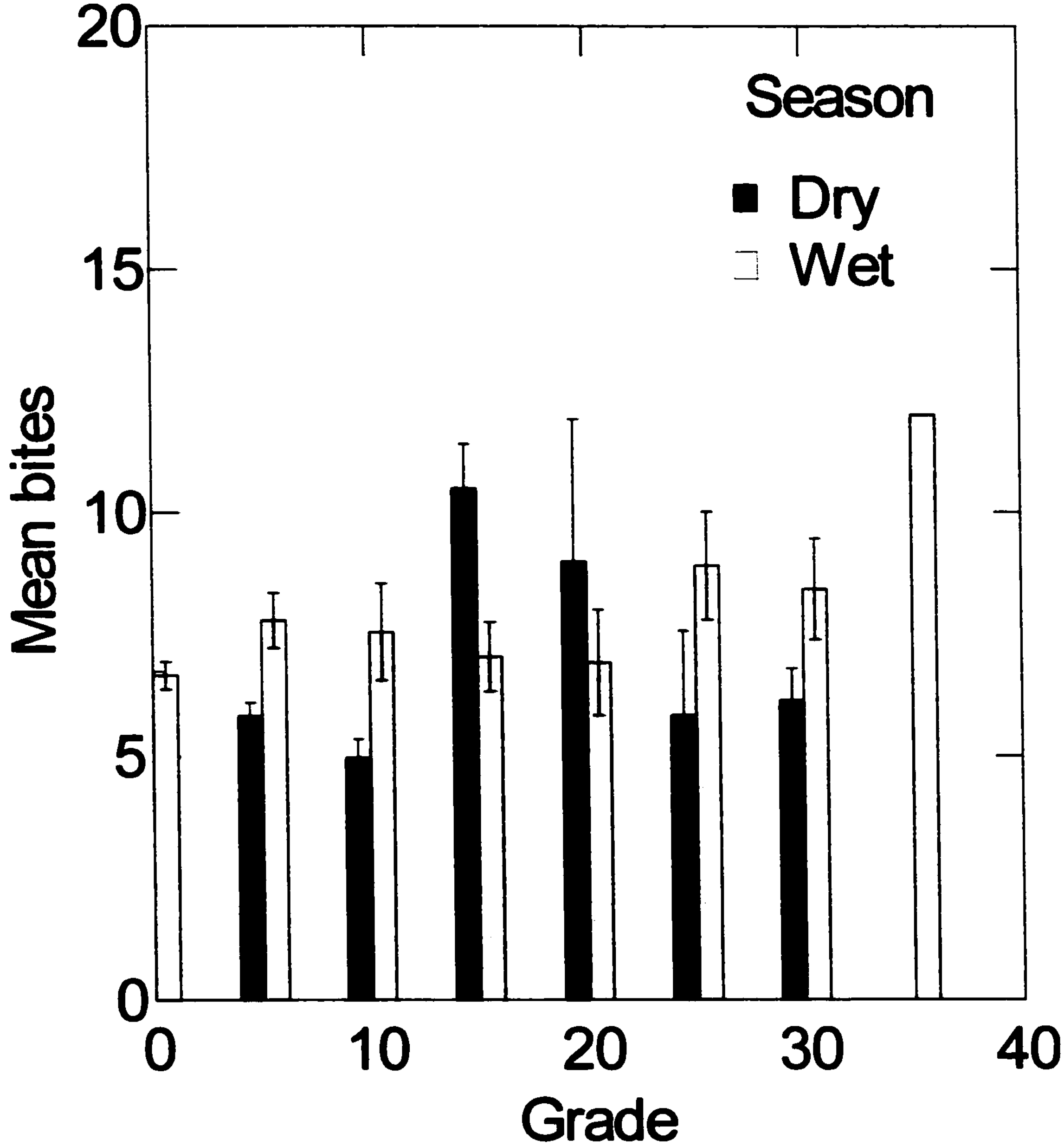
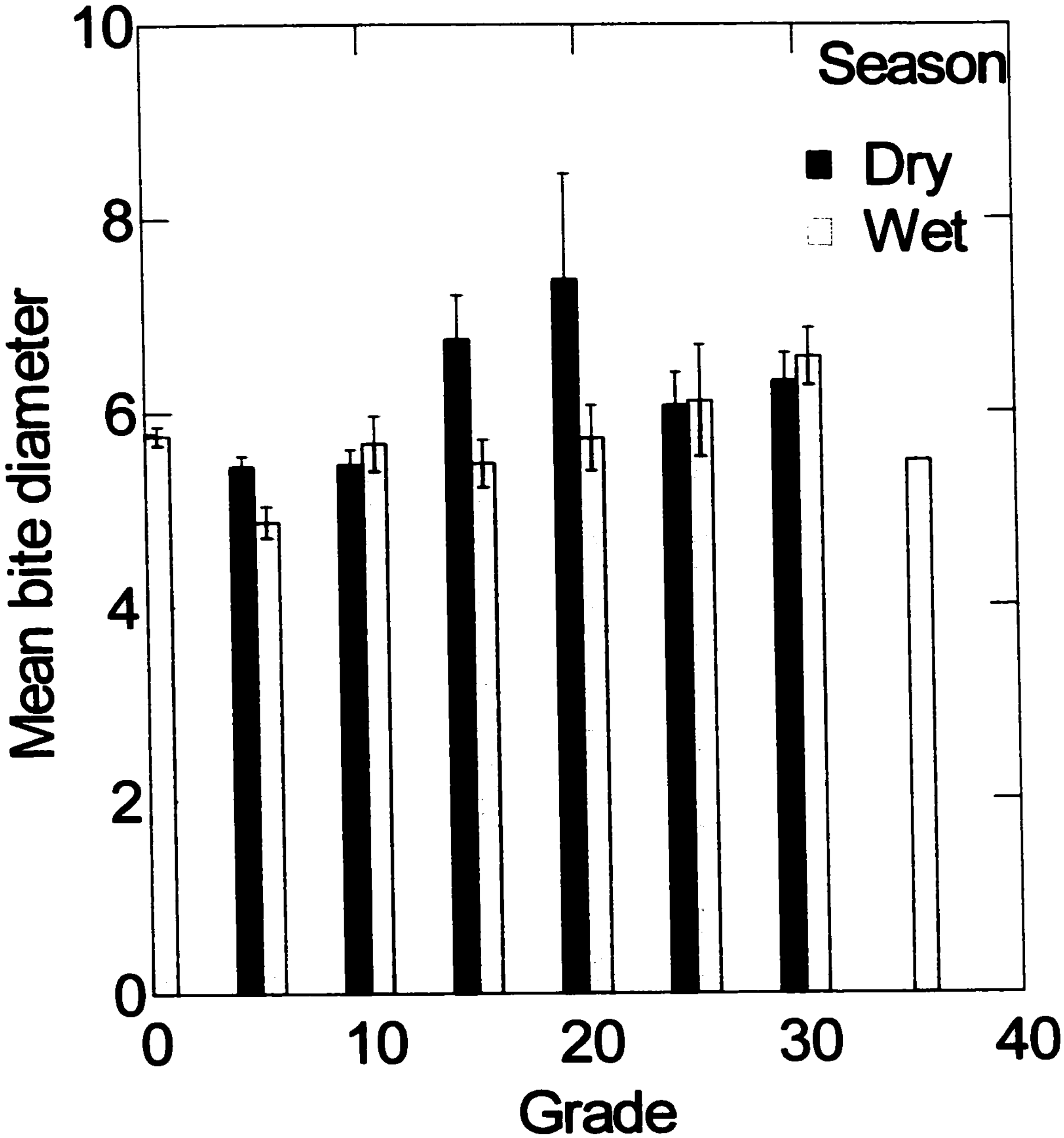

Season
Dry
Wet
Mean bites
0
5
10
15
20
Grade
0
10
20
30
40

Figure 3b: Wet and dry season distribution of mean bite diameter among grades. Mean bite diameter significantly increased with increasing grade ($p<0.05$).



Season
Dry
Wet
Mean bite diameter
Grade
0
2
4
6
8
10
0
10
20
30
40

prinoides (RHPR), *Toddalia asiatica* (TOAS), and *Hypoestes forskahlii* (HYFO).

There was a significant effect of plant species ($p<0.001$) on mean number of bites and mean bite diameters for both the wet and dry season. Our analysis did not reveal a significant effect of micro-habitat on the mean diameter and mean number of bites for all the species in the wet and dry season except four food plants (Figure 4a and 4b). The mean bite diameter of *Solanum aculeastrum var1* was greater in the bush ($p<0.05$) for both seasons. There were more bites in the open for *Solanum aculeastrum var2* ($p<0.05$), *Sida tenuicarpa* ($p<0.001$) and *Rhamnus prinoides* ($p<0.05$) in the dry season.

These plants responded somewhat differently to grade during the wet and the dry season. Grade had a significant effect on the mean bite diameters of *Abutilon longicuspe* ($p<0.05$), *Solanum aculeastrumvar2* ($p<0.05$), and *Sida rhombifolia* ($p<0.05$) in the wet season. Bite diameter increased with increasing grade. There was no significant effect of grade on mean number of bites for all species in the wet season. In the dry season, the mean number of bites decreased with increasing grade for *Abutilon longicuspe* ($p<0.05$) and *Rhamnus prinoides* ($p<0.05$). The mean bite diameter increased with increasing grade for *Solanum aculeastrum var2* ($p<0.05$) and *Sida rhombifolia* ($p<0.05$).

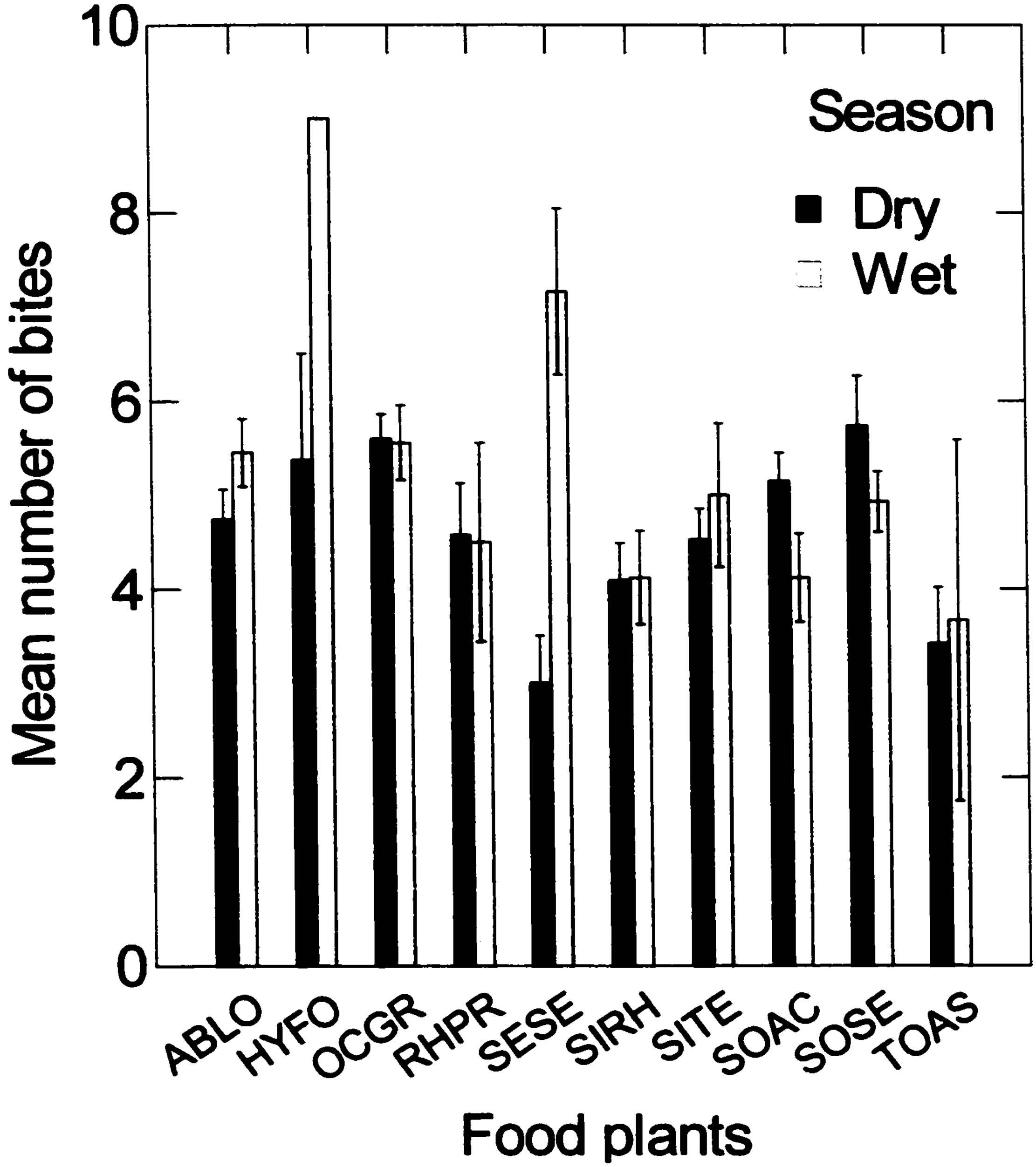
The mean number of bites was significantly higher for *Abutilon longicuspe* ($p<0.05$) and *Ocimum gratissimum* ($p<0.05$) in the wet season. We observed a significant effect of season on mean bite diameter of *Abutilon longicuspe* ($p<0.05$), *Sida rhombifolia* ($p<0.05$) and *Hypoestes forskalii* ($p<0.05$). There was a general trend towards bigger mean bite diameter in the dry season. These effects are not apparent when plants are lumped together due to changes in foodplant preferences between seasons.

TABLE III: ANALYSIS OF VARIANCE TABLE SHOWING EFFECT OF PLANT, MICRO-HABITAT, GRADE, SEASON ON BITES, MEAN BITE DIAMETER, PERCENT BROWSE AND BITE

Source	d.f	Bites		Bite diameter		Height		Percent	
		MSS	F-Ratio	MSS	F-Ratio	MSS	F-Ratio	MSS	F-Ratio
Plant	8	334.428	5.794***	95.732	33.169***	6.866	49.789***	6720.174	10.929***
Micro	1	97.349	1.687	9.830	3.406	1.447	10.492***	1870.029	3.041
Grade	1	39.944	0.692	54.265	18.801***	1.016	7.365**	62.590	0.102
Season	1	342.884	5.940*	1.520	0.527	0.160	1.159	4059.622	6.602**
Plant*season	8	63.320	1.097	7.449	2.581**	0.082	0.591	803.923	1.307
Error	849	57.722		2.886		0.138		614.894	

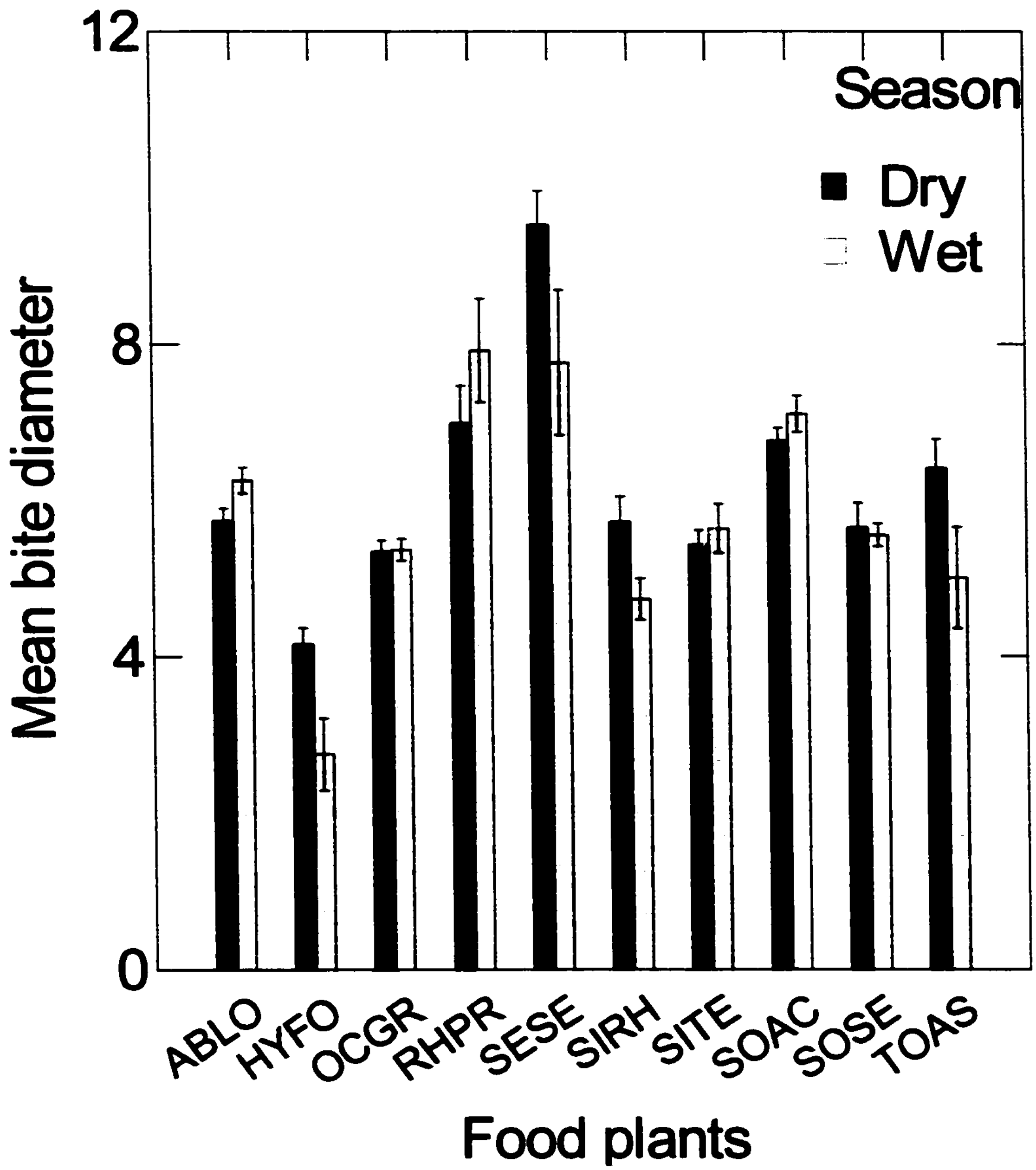
Codes: *= $p<0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$

Figure 4a: Wet versus dry season mean number of bites for common food plants. Plant had a significant effect on mean number of bites. ($p<0.001$). There were more bites in the wet season ($p<0.01$).



Season
Dry
Wet
Mean number of bites
10
8
6
4
2
0
ABLO
HYFO
OCGR
RHPR
SESE
SIRH
SITE
SOAC
SOSE
TOAS
Food plants

Figure 4b: Wet versus dry season mean bite diameter for common. Plant had a strong effect ($p<0.001$) on mean bite diameter. There was no seasonal effect on mean bite diameter ($p>0.05$).



12
8
4
0
Mean bite diameter
Season
Dry
Wet
ABLO
HYFO
OCGR
RHPR
SESE
SIRH
SITE
SOAC
SOSE
TOAS
Food plants

F. Food preference ranking

In order to rank food preference by black rhinos, I measured percent utilization at a station level. I counted how many times a plant was eaten upon encounter at a station and the times it was rejected. I used this information to compute percent preference (Table IV). Based on a rhino's decision at a station, 100% percent rank means that the plant was always eaten upon encounter and 0% means that the plant was always rejected. I multiplied percent preference with percent utilization values and came up with a utilization index value.

G. Habitat quality and utilization versus availability

I used the utilization index values (outlined at the bottom of Table IV) to compute the mean habitat quality of each plot for the 26 (10x10m) plots surveyed. An index value of 2.5 was assigned to plants that were eaten but had no actual measurements taken and 0 for those that were not eaten (Table Ia). The mean habitat quality was derived by dividing the sum of the utilization indices for each food plant represented in the plot by the total number of plants in the plot. This gave values that ranged from 1.82 to 3.27 (mean=2.36, s.d=0.35). The standard deviation explains the extent to which a rhino can be selective at the plot or habitat level.

I compared utilization versus availability using the plant densities in the study area (Table II). Black rhinos selected 25.6 % of the plant species in the high (>100 plants/ha) density category, 19.5% in the medium (10-100 plants/ha) density, and 54.9% in low (<10 plants/ha) density category. The food plants in the high-density category

TABLE IV: FOOD PREFERENCE AND PREFERENCE RANKING BETWEEN WET AND DRY SEASON IN SALIENT, ABERDARES NP

Food plant	WSE	WSNE	DSE	DSNE	WS%PREF	DS%PREF	WSUI	DSUI
Abutilon engeleranum	1	0	1	0	100	100	5	5
Clausena anisata	3	0	6	1	100	85.71	5	5
Ehretia cymosa	1	0	3	0	100	100	5	5
Leucas grandis	5	0	1	0	100	100	5	5
Senna septemtrionalis	8	0	11	0	100	100	5	5
Sida rhombifolia	10	1	20	3	90.91	86.96	5	5
Solanum aculeastrum[1]	85	10	54	2	89.41	96.43	5	5
Vernonia galamensis	3	0	2	0	100	100	5	5
Ocimum gratissimum	62	20	55	34	75.61	61.8	4	4
Abutilon longicuspe	50	2	41	24	96.15	63.08	5	4
Leonotis mollissima	2	0	2	1	100	66.67	5	4
Leucas urticifolia	1	0	13	4	100	76.47	5	4
Pentas lanceolata	5	0	4	2	100	66.67	5	4
Solanum aculeastrum[2]	35	8	15	4	81.4	78.48	5	4
Dovyalis abyssinica	4	1	3	3	80	50	5	3
Hyppoestes verticillaris	2	0	1	1	100	50	5	3
Rhamnus prinoides	8	2	12	9	80	57.14	5	3
Microglossa pyrifolia	2	0	2	7	100	22.22	5	2
Asparagus africanus	1	0	0	0	100	0	5	1
Conyza newii	1	0	0	0	100	0	5	1
Hypoestes aristata	2	0	0	0	100	0	5	1
Indigofera arrecta	3	0	0	0	100	0	5	1
Sida schimperana	4	0	0	0	100	0	5	1
Sida ternata	1	0	0	0	100	0	5	1
Solanum incanum	1	0	2	11	100	15.38	5	1
Solanum mauense	3	0	0	0	100	0	5	1
Solanum nigrum	1	0	0	0	100	0	5	1
Sp A	1	0	0	0	100	0	5	1
Tephrosia sp	1	0	0	0	100	0	5	1
Triumfetta sp	1	0	0	0	100	0	5	1
Hibiscus vitifolius	6	3	2	0	66.67	100	4	5
Leucas deflexa	13	2	11	2	66.67	84.62	4	5
Conyza bonariensis	2	1	0	0	66.67	0	4	1
Senna didymobotrya	10	14	3	1	41.67	75	3	4
Sida tenuicarpa	4	4	25	7	50	78.12	3	4
Nuxia congesta	2	2	1	1	50	50	3	3
Achyranthes aspera	2	2	2	4	50	33.33	3	2
Hyppoestes forskahlii	2	4	11	35	33.33	23.91	3	2
Crassocephalum sp	1	1	0	0	50	0	3	1
Crotalaria incana	3	2	0	0	60	0	3	1
Pavonia urens	1	1	0	0	50	0	3	0
Hibiscus fuscus	1	2	2	0	33.33	100	2	5
Erythrococca bongensis	6	13	3	18	31.57	14.29	2	1
Solanum sp	1	2	0	0	33.33	0	2	1
Toddalia asiatica	4	16	7	30	20	18.92	2	1
Urtica massaica	4	7	1	5	36.36	16.67	2	1

TABLE IV continued

Calodendrum capense	0	0	1	0	0	100	1	5
Clutia abyssinica	0	0	1	0	0	100	1	5
Commelina africana	0	0	1	0	0	100	1	5
Olea europaea	0	0	1	0	0	100	1	5
Pavonia patens	0	0	3	0	0	100	1	5
Rytigynia uhligii	0	0	1	0	0	100	1	5
Vernonia sp	0	0	2	0	0	100	1	5
Vernonia ssp galamensis	0	0	2	0	0	100	1	5
Clerodendrum johnstonii	0	0	1	1	0	50	1	3
Teclea simplicifolia	0	0	1	1	0	50	1	3
Euclea divinorum	0	0	1	3	0	25	1	2
Lantana trifolia	1	7	4	10	12.5	28.57	1	2
Phytolacca dodecandra	1	5	2	4	16.67	33.33	1	2
Senecio syringifolius	0	0	6	14	0	30	1	2
Teclea nobilis	0	0	1	3	0	25	1	2
Vangueria infausta	1	9	1	3	10	25	1	2
Vernonia auriculifera	1	21	2	4	4.55	33.33	1	2
Croton macrostachyus	1	12	0	0	7.69	0	1	1

Note:
WSE = The number of times a plant was eaten at a station when encountered in the wet season
WSNE = The number of times a plant was ignored at a station when encountered in the wet season
DSE = The number of times a plant was eaten at a station when encountered in the dry season
DSNE = The number of times a plant was ignored at a station when encountered in the dry season
WS%PREF = Percent preference in the wet season
DS%PREF = Percent preference in the dry season
WSUI = Preference ranking in the wet season
DSUI = Preference ranking in the dry season

Utilization index values:
5=80-100%, 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

represent 14.58% of the plant species in the area while those in the medium and low-density categories represent 11.11% and 31.25% of the plant species respectively.

The potential or available twig diameter was compared with the actual mean bite diameter selected in order to quantify browse availability on a plant species basis and to determine critical food plants in the study area (Table V, VIa and VIb). The categories and their importance are discussed in the methods section. 45.1% and 22.22% of the food plants fell in category 1 (plants with small actual mean bite diameter and small available twig size) in the wet and dry season respectively. Food plants in category 2 (plants with large potential twig diameter and small actual mean bite diameter) represented 11.76% in the wet and 31.48% in the dry season. Category 3 (plants with large potential twig diameter and large actual mean bite diameter) represented 43.14% of the food plants in the wet season and 44.44% in the dry season. Most of the preferred and abundant food plants fell in category 3.

TABLE V: COMPARISON BETWEEN POTENTIAL TWIG DIAMETERS AND ACTUAL MEAN BITE DIAMETERS

	Actual mean bite diameters	
Potential twig diameters	Small	Large
Small	Category1: Plants with small potential twig diameter and small actual mean bite diameter	*No plants can fall in this category*
Large	Category2: Plants with large potential twig diameter and small actual mean bite diameter.	Category3: Plants with large potential twig diameter and large actual mean bite diameter.

TABLE VIA: POTENTIAL VERSUS SELECTED TWIG DIAMETERS: WET SEASON BROWSING IN SALIENT (ABERDARES NP)
(Abundant plants are in bold)

Category1: Plants with small potential twig diameter and small actual mean bite diameter

Achyranthes aspera
Asparagus africanus
Clausena anisata
Conyza newii
Crassocephalum sp
Erythrococca bongensis
Hibiscus vitifolius
Hypoestes aristata
Hypoestes forskahlii
Hypoestes verticillaris
Indigofera arrecta
Leucas deflexa
Leucas grandis
Leucas urticifolia
Pavonia urens
Pentas lanceolata
Microglossa pyrifolia
Sida cordifolia
Solanum mauense
Solanum nigrum
Triumfetta sp
Solanum sp

Category2: Plants with large potential twig diameter and small actual mean bite diameter.

Ehretia cymosa
Lantana trifolia
Nuxia congesta
Sida cordifolia
Toddalia asiatica
Vangueria infausta

Category3: Plants with large potential twig diameter and large actual mean bite diameter.

Abutilon engeleranum
Abutilon longicuspe
Conyza bonariensis
Crotalaria incana
Croton macrostachyus
Dovyalis abyssinica
Hibiscus fuscus
Leonotis mollissima
Phytolacca dodecandra
Rhamnus prinoides
Senna didymobotrya
Senna septemptrionalis
Sida schimperana
Sida tenuicarpa
Solanum aculeastrum ssp. Aculeastrum var 1
Solanum aculeastrum ssp. aculeastrum var. aculeastrum
Solanum incanum
Sp A
Tephrosia sp
Urtica massaica
Vernonia auriculifera
Vernonia galamensis
Sida rhombifolia

TABLE VIB: POTENTIAL VERSUS SELECTED TWIG DIAMETERS: DRY SEASON BROWSING IN SALIENT (ABERDARES NP)
(Abundant plants are in bold)

Category1: Plants with small potential twig diameter and small actual mean bite diameter

Achyranthes aspera
Clausena anisata
Commelina africana
Erythrococca bongensis
Hibiscus vitifolius
Hyoestes forskahlii
Hypoestes verticillaris
Leucas urticifolia
Microglossa pyrifolia
Pavonia patens
Pentas lanceolata
Urtica massaica

Category2: Plants with large potential twig diameter and small actual mean bite diameter.

Abutilon engeleranum	*Lantana trifolia*
Calodendrum capense	*Maytenus senegalensis*
Clerodendrum johnstonii	***Ocimum gratissimum***
Clutia abyssinica	***Phytolacca dodecandra***
Crotalaria incana	*Ryrigynia uhligii*
Dovyalis abyssinica	*Teclea nobilis*
Ehretia cymosa	*Teclea simplicifolia*
Euclea divinorum	*Vernonia sp*
Juniperus procera	

Category3: Plants with large potential twig diameter and large actual mean bite diameter.

Abutilon longiscupe	***Sida rhombifolia***
Achyrospernum schimperi	***Sida tenuicarpa***
Euphorbia schimperana	***Solanum aculeastrum ssp. Aculeastrum var 1***
Hibiscus fuscus	***Solanum aculeastrum ssp. aculeastrum var. aculeastrum***
Leonotis mollissima	*Solanum incanum*
Nuxia congesta	***Toddalia asiatica***
Olea europaea	***Vangueria infausta***
Rhamnus prinoides	***Vernonia auriculifera***
Rhamnus staddo	***Vernonia galamensis***
Rhus natalensis	*Vernonia ssp galamensis*
Scutia myrtina	
Senecio syringifolius	
Senna septemtrionalis	
Senna didymobotrya	

DISCUSSION

Black rhinos inhabit a variety of habitats from sea-level to 2700m above sea level, and from extremely arid areas such as Namib desert to wet upland forested areas such as Aberdares and Mt. Kenya National Park. The rhinos in Aberdares NP have been regarded for a long time as forest dwellers. While conducting this study, we found that these rhinos prefer the more open areas of the Salient and only travel through the forested area on their way to artificial saltlicks located at the three lodges in the Park. Joubert and Ellof (1971) observed that black rhinos tend to feed in areas with 66% open visibility.

Studies in East and Southern Africa have described black rhinoceros as browsers that feed on unusually wide variety, very fibrous and in some instances highly toxic plant species. The 90 (appendix 2) food plants identified from the Salient area of Aberdares National Park falls within the range of studies in Ol Ari Nyiro (Oloo et al. 1994, 103 spp), Tsavo (Goddard 1970, 102spp), Masai Mara (Mukinya 1977, 70 spp), Ngorongoro (Goddard 1968, 91 spp), Namib desert (Loutit et. al. 1987, 74 spp; and Jourbert 1971, 106 spp). Only 49 foodplants had been identified previously by the Kenya Wildlife ecological monitoring personnel (KWS unpublished report). Although black rhinos selected 62.5% of the plant species in the Salient, only 12 food plants formed the staple diet of black rhinos there, 6 in the wet season and 11 in the dry season. *Ocimum gratissimum, Abutilon longicuspe, Sida rhombifolia, Solanum aculeastrum var1, Solanum aculeastrum var2* and *Leucas deflexa* contributed a great deal to its diet in the wet season. Black rhino expanded their diets in the dry season by adding *Sida tenuicarpa, Senna septemtrionalis, Rhamnus prinoides, Toddalia asiatica*, and *Hypoestes forskahlii* to their staple diet. The most common competitor of black rhino in Aberdares NP is the elephant.

Elephant feeding activity was observed on all but two of the common food plants (*Sida rhombifolia* and *Leucas deflexa*). It was striking that *Crotalaria agatiflora*, a very common plant in the Salient, did not show signs of browsing by black rhinos or by other large herbivores.

I used a patch use model to study the foraging behavior of wild populations of black rhinos. We considered individual trees and shrubs as food patches (Astrom et al. 1990). Bite diameters have been measured for moose (*Alces* alces) for a subsample of browse species (Shipley et. al. 1999). Extensive checklists of plant species eaten by black rhinos have been compiled but no data has been collected for bite diameters and browse intensity. Patch use was assessed by measuring browse intensity, measured by the number of bites, percent utilization and mean bite diameter per individual food plant. The results were interpreted as measures of giving-up densities (GUDs) as discussed earlier. A patch may be foraged by one or several rhinos but the GUD measure represents the GUD of the last rhino that foraged on the patch. By measuring the intensity of browse we were able to quantify food preferences and diet selection in black rhinos. To quantify costs of foraging such as predation and effects of plant secondary compounds, we compared browse intensities across plant species, micro-habitats (open and bush) and grades.

Several factors may affect intake rates once an herbivore selects a food patch. These include bite size and chewing effort (Black and Kenney 1984, Spalinger et. al. 1988). The rate at which bites can be cropped from a patch may be affected by height at which the animal feeds (Young and Isbell 1986), and may be slowed by the physical features of the plant species such as spines (Cooper and Owen-Smith 1986). Bite size is determined by the interactions between plant characteristics such as height, density and leave size (Dunham 1980, Black and Kenney 1984, Cooper and Owen-Smith 1986, and Laca et al 1992), and to some extent the amount of lignin in the plant parts browsed. Studies on free-ranging populations of moose *Alces alces* (Shipley et. al. 1999) have shown that they respond more to the characteristics of individual trees within a stand than to the composition of the stands themselves. Black rhinos appeared to pay attention to both the patch characteristics and composition of the stands. We observed that feeding stations consisted of an average of 4 food patches (food plants from same or different plant species) or one large patch. Black rhinos treated food patches within a station differently.

A. The effect of micro-habitat and grade on browse intensity and predation risk

The results from this study gave conflicting results as to which habitat is safer for black rhinos. As we predicted, bites and percent utilization was higher in the open micro-habitat than in the bush. These results translate to lower GUDs in the open (less risky habitat) than bush (more risky habitat). My prediction did not hold for the mean bite diameter, rather our results were the opposite of what we expected. The mean bite diameter was larger in the bush (low GUDs) than the open habitat, and increased with increasing grade. This means that rhinos took bigger bites in the putatively risky habitats than the safer ones. Grade had no significant effect on the number of bites. This was also contrary to our expectation.

There are four possible explanations to our results; 1) bite diameters are not a true measure of predation cost, 2) bite diameter is larger in the bush because bite size is affected by the physical characteristics of the plant. Plants may be larger in the bush than in the open, 3) there were more bites in the open than in the bush because more of the plant is accessible to rhinos in the open habitats, and 4) cost of predation is not important to the rhino. Diet optimization model by Shipley et al. (1999) showed that as time available for foraging increases, bite size decreases and animals become more selective and focus on the more nutritious tips of the twigs. This may explain why there are more bites and smaller bite diameter in the open than in the bush. If rhinos feel safer in the open, they will spend more time foraging on more nutritious parts of plants. This would be depicted by more bites and smaller bite diameters in the open micro-habitat.

B. Food preference, seasonal effect on diet choice and habitat selection:

Although black rhinos select a wide variety of foodplants, the bulk of their diets consist of very few plants. In the Salient, the family malvaceae, labiatae and solanaceae contribute a great deal of the diet. Goddard (1970) noted that in Tsavo, leguminous plants were highly preferred by black rhinos. In my study site all of the legumes present were selected except *Crotalaria agatiflora*. Some plants were encountered at many stations but eaten little. This may imply that they are not preferred by rhinos. However, some studies (Crawley 1983) suggested that herbivores may select food items that give a balanced mix of nutrients, or reduce the intake of any one plant secondary compounds. Other studies have shown that animals grow better when fed mixed diets because they obtain a more beneficial mix of nutrients (Westoby 1978; Rapport 1980; Krebs and Avery 1984; Dearing and Schall 1992).

The relative contribution of some common food plants changed between the wet and dry seasons. Common food plants exhibited fewer bites per station during the dry season. Rhinos consumed more *Abutilon longicuspe* and *Solanum aculeastrum var2* in the wet season and *Ocimum gratissimum*, *Sida tenuicarpa*, *Hypoestes forskahlii* and *Solanum aculeastrum var1* contributed more to the dry season diet. This shift in diet may be due to the relative availability and reduced palatability of plant parts or all parts in the dry season. *Abutilon longicuspe* and *Solanum aculeastrum var2* were more woody and mature in the dry season. Most plants were in their fruiting stage and the leaves were drying up. *Hypoestes forskahlii* became an important food plant in the dry season. This plant is dominant along forest edges.

As with other black rhino populations in Kenya, Ol Ari Nyiro (Oloo et. al. 1994), Tsavo (Goddard 1970) and Masai Mara (Mukinya 1977), the rhinos in the Salient have definite preferences for certain woody plant species irrespective of their abundance or size. *Senna septemtrionalis, Pentas lanceolata, Indigoferra arrecta* and *Crotalaria incana* occur at low densities but are always eaten upon encounter and thus contribute little to the diet of rhinos in terms of bulk and can only be considered choice plants. Seasonal changes diet choice and habitat selection has been observed in other rhino populations with most studies reporting drastic changes between seasons (Oloo et. al. 1994 and Jourbert 1971). However in this study, very few plants were excluded from the diet in the dry season that was part of the wet season diet. The major watering points (rivers and dams) dried out in the dry season. Most feeding in the dry season was concentrated along forest edges and along riverine areas. Although I did not collect information on ranging distances during this study, I noted that the distance between stations increased in the dry season. This coupled with fewer bites per feeding stations would imply that rhinos traveled longer distances each day during the dry season and take more time to consume the same amount of food.

C. Implications to ecological monitoring, management and conservation of black rhinos in Aberdares NP

The techniques in this study can be used to study food preferences of wild populations of black rhinoceros and the factors that affect diet choice and habitat selection. The habitat suitability index in this study is based on actual measurements. I used food preference, percent utilization data and plant densities for each plant species to estimate habitat suitability. This index can be incorporated in routine vegetation monitoring programs. Monitoring bite sizes and browse intensity for highly preferred species can form a baseline to observe habitat changes. In the case of black rhino, these measures provide an inexpensive and less time consuming way of obtaining information that can be used to make long-term decisions regarding animal translocations, expansion of sanctuaries and habitat improvements.

While assessing the status of black rhino food plants in the salient, I noted that though the park appears rich in food resources and well suited for black rhino management, only six foodplants form the bulk of rhino's diet. The species abundance in the park is low compared to other black rhino conservation areas like Nairobi and Tsavo National Park. However, plants exhibit high productivity and remain green throughout the year. *Crotalaria agatiflora* and *Vernonia auriculifera* occur at high densities but showed little or no signs of browsing. Browse height and level of competition with other herbivores is also important. We noted that there is an overlap in foodplants selected by black rhinos and elephants, and that food plants may occur in high densities but may not be available to rhinos because they exceed their browse line. The mean habitat suitability index for black rhinos across the Salient is low. These results suggest that Aberdares NP maybe a "green desert" to black rhinos.

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CHAPTER III

BLACK RHINOCEROS (*Diceros bicornis michaeli L.*) FOOD PREFERENCES AND AVAILABILITIES IN THREE PARKS IN KENYA

INTRODUCTION

Diet is one of the most important ecological characteristics of organisms. Herbivore diets vary from place to place and season to season. This is because food type, abundance and quality are influenced by environmental conditions that vary with seasons. The most important factors affecting plant productivity in savanna ecosystems are rainfall and temperature (Pratt and Gwynne 1969). Areas that experience high rainfall and moderate temperatures support higher plant productivity than hot dry areas. For most savanna ecosystems, food is more abundant in the wet season than in the dry season.

Most large herbivores select a wide variety of food plants but focus their feeding efforts on a small subset of available plants (Freeland 1991). Understanding food preferences and availability is critical for managing wildlife populations and improving their habitats. Diet selection in free-ranging herbivores has been analyzed in two ways: direct observation in the field and indirect observation through fecal analysis and feeding site observation. Although these methods have been very useful in determining the plant species utilized by herbivores, they do not indicate the nutritional and ecological factors determining diet selection and food preferences. Among hindgut fermentors, for example, there can be substantial differences in diet selection in response to variation in digestive function. Some large species such as rhinoceros and elephants are able to retain substantial amounts of fibrous material in the fermentation system, and have adopted a strategy of consuming great amounts of poorly-digestible, high fiber food (Foose 1982; Owen-Smith 1988) which can be easily traced in the fecal matter. Due to varying degrees of digestibility, some plants (e.g non-woody plants) may undergo complete digestion and therefore cannot be traced in the fecal contents. Although this method may give important information on animal diets, it may also give a false impression of food preferences.

Numerous empirical studies have shown that foraging behavior in a patch may be influenced by food availability in time and space (Rosenzweig 1981; 1987; Brown 1988; Holbrook and Schmitt 1988; Bailey et al. 1996), forage quality and quantity (Robbins 1983; Senft et al. 1985; Pinchak et al. 1991), nutritional requirements of the animal (Tilman 1980; 1982; Crawley 1983; Robbins 1983), toxins (Feeny 1968; 1970; Rhoades 1979; Provenza et al. 1984; Robbins et al 1987; 1991; Bernays 1981; Smallwood and Peters 1986; and Dearing 1997) and predation risk (Lima and Valone 1986; Brown 1988; 1992; Kotler 1984; Kotler et al. 1991; 1994). Foragers may also select food plants because they have a high encounter probability or because they lack alternative foods to choose from. Whatever the case, foragers must decide on a daily basis what food items to accept or reject depending on the prevailing conditions. Foraging theory assumes that these decisions serve to maximize fitness.

The black rhino is a browser that inhabits a wide variety of habitats ranging from arid deserts to dense forested areas. They feed mainly on woody plants and have the ability to consume very fibrous plant material. Pioneering studies on the food preferences of black rhinoceros were carried out by Goddard (1968, 1970) who described the food preferences of two rhino populations, the first one in Northern Tanzania (1964-1966) and the second one in Tsavo National Park, Kenya, (1967-1969). He observed rhinos in six habitats that ranged from grasslands, bush-grasslands to bush-woodlands and forested areas. Joubert (1971) and Loutit et al. (1987) described the food and drinking habits in the Namib desert, South West Africa and Mukinya (1977) in the grassland savanna of Masai Mara Game Reserve, Kenya. Oloo et al. (1994) examined seasonal variations in the feeding ecology of black rhinos in a wooded savanna ecosystem in Laikipia, Kenya.

In this study, I applied patch use theory to examine three aspects of the foraging ecology of free-ranging populations of black rhino: diet choice (foodplants), food preferences in time (seasonal variations, wet and dry season), and food preferences in space (habitat variations across three parks). Under diet choice, I examined the role played by food availability and background abundance in shaping dietary choices. I considered individual trees or shrubs as food patches (Astrom et al. 1990) and used intensity of browse as an index of food patch utilization. I assumed that foragers follow the decision rule outlined in the patch use model of Brown (1988). Each patch (represented here by individual foodplants) should be foraged until the food density decreases to the average return from all available patches.

I compared diets in three black rhino conservation areas that vary tremendously in food availability. Measurements were taken in two different seasons, one in the wet season when food is abundant and dry season when food is scarce. I use three useful metrics (1) total number of bites per food plant which is an indicator of how much browse a rhino obtained from a patch, (2) bite diameter which gives an idea of how much bulk a rhino harvested from individual patches, and (3) percent utilization and height which are useful measures of how hard a rhino impacted the plant and the thoroughness of foraging. I compared food consumption versus availability and percent food preference.

METHODS

A. Study sites

The study was conducted in three black rhino conservation areas in Kenya: Aberdares National Park (upland forest), Nairobi National Park (mesic savanna) and Ngulia Rhino Sanctuary (dry wooded savanna). These areas (1) represent the range of all potential habitats for black rhinos in Kenya, (2) are important black rhino conservation areas, (3) support important black rhino populations, and (4) differ in their overall food abundance and the plant species browsed by black rhinos. Feeding surveys were conducted in the wet season (Aberdares: October-November 1998, Nairobi: July-August 1998, Ngulia: December 1999), and dry season (Aberdares: August-September 1999, Nairobi: October-November 1999, Ngulia: September 1998).

Aberdares NP: The study was conducted in the Eastern part of the Park, the Salient area, which covers an area of 70 km^2, and has an estimated population of 50 black rhinos. Soils in this area are of volcanic origin with deep clay soils dominating the lower parts of the Park and granulated sandy soils in the higher areas. Several rivers (Kinaini, Muringato, Thara, Maguchi and their tributaries) drain the area. The area receives an average of 1000mm of rainfall with two marked peaks in March-May and October-December depicting a bimodal distribution. The vegetation in this area is characterized by bamboo zone, forest and scrubland with glades of open grassland. The dominant tree species are *Podocarpus spp, Croton macrostachyus,* and *Cassipourea malossana.* Shrubs include *Crotalaria incana, Solanum aculeastrum, Abutilon longicuspe, Toddalia asiatica* and *Vernonia auricufera.* This area holds the highest density of herbivores in the Park. Large herbivores include African buffalo *Syncerus caffer*, African elephant *Loxodonta africana*, water-buck *Kobus ellipsiprymnus*, bush-buck *Tragelaphus scriptus*, bongo *Tragelaphus euryceros,* giant forest-hog *Hylochoerus meinertzhageni,* and warthog *Phacochoerus aethiopicus.* Predators include lion *Panthera leo*, spotted hyena *Crocuta crocuta* and leopard *Panthera pardus T*

Nairobi NP: Nairobi NP occupies an area of 114.8km ^{2} and supported 60 black rhinos at the time of the study. The soils in the area are derived from volcanic rocks of the middle Tertiary. Tertiary sediments cover the southern part of the Park while black clay soils with calcareous and non-calcareous clays derived from Alluvium dominate the other parts of the Park. The area is drained by Athi-Mbagathi Rivers. Several dams have been built to supply water throughout the Park. The area has two rainy seasons with precipitation peaks in April-May and November-December, and a mean annual rainfall of 900mm. Over 90% of the Park is open grassland with scattered trees and bushland, the rest is covered by a riverine woodland and bushland, and a forested area. The major plant associations are *Themeda-Pennisetum* grassland with scattered *Acacia* and *Balanites spp.* Large herbivores include wildebeest *Connochaetes gnou*, common zebra *Equus burchelli*, giraffe *Giraffa camelopardalis*, eland *Taurotragus oryx*, African buffalo *Syncerus caffer,* Coke's hartebeest *Alcelaphus buselaphus,* impala *Aepyceros melampus*, Grant's gazelle *Gazella granti*, Thompson's gazelle *Gazella thomsoni*, water-buck *Kobus ellipsiprymnus*, bush-buck *Tragelaphus scriptus* and warthog *Phacochoerus aethiopicus.* Major predators include lion *Panthera leo*, spotted hyena *Crocuta crocuta,* leopard *Panthera pardus T* and cheetah *Acinonyx jubatus.*

Ngulia rhino Sanctuary (Tsavo West NP): Ngulia Rhino Sanctuary, located in Tsavo West NP, occupies an area of 73 Km^2. The area is enclosed by an fence that is designed to contain and establish a breeding nucleus of rhinos. This is a region of bush-grassland with scattered trees; the complexity of the vegetation has increased with elephants and fire over the past decades. The elephant damage has greatly affected the *Acacia-Commiphora* woodland, and wooded bushlands have been converted into open grasslands in many parts of the Park. Soils developed from recent volcanic rocks show a wide range in depth, color and drainage condition. Most soils have sandy-clay texture. This area is drained by Tsavo River. Average annual rainfall varies from 200-700mm and is bimodal in distribution, with peaks in March-June and November-December. At the time of the study there were approximately 45 rhinos. Large herbivores include common zebra *Equus burchelli*, giraffe *Giraffa camelopardalis*, African buffalo *Syncerus caffer*, African elephant *Loxodonta africana*, and lesser kudu *Tragelaphuus imberbis*. Predators include lion *Panthera leo*, spotted hyena *Crocuta crocuta,* leopard *Panthera pardus T* and cheetah *Acinonyx jubatus.*

B. Plant survey

I randomly selected 10 x 10m plots throughout the study areas to estimate densities of woody and herbaceous plants. The vegetation types as depicted by plant associations were categorized for each study area. The first plot in each vegetation type was selected and the subsequent plots were mapped using the first plot as the starting point. Distances among plots was determined by driving I Km from the first plot. The plots were established 10m away from the roadside. I identified and counted all woody and herbaceous plants (excluding grasses) present in the plots. Plant surveys were conducted in the wet season in Aberdares and Nairobi National Park, and in the wet and dry seasons in Ngulia. Ngulia experiences a dramatic vegetation change between the wet and dry season. These data estimate the plant densities and availability to black rhinos in the area. The data is also important in evaluating the marginal value of foods across parks. The marginal value of food is expected to vary inversely with background abundance. These data will also be used to compare utilization versus availability of food in the area, and to evaluate the overall quality of the habitat for black rhinos.

C. Feeding Surveys

Previous studies on the ranging patterns of black rhinoceros have shown that they reside in home ranges that vary in size depending on water and food availability and densities of conspecifics in the area (Kiwia 1989). With the help of rhino surveillance personnel in the Parks, I mapped current black rhino home ranges in the three parks. I used these areas for identifying black rhino feeding activity in the wet and dry season for each Park.

Feeding tracks were established in the rhino home ranges, the length of which was determined by the size of the home range. I grouped feeding sites into stations along a feeding track. Stations were stratified by appearance of plants browsed by rhinos. Unlike the plant survey these feeding stations do not represent a random sampling of plants. Rather, they represent a stratification of plants by the rhino's presence and their decision to feed. Once I entered the home range, I looked for footprints along game tracks and watering points, and for rhino feeding activity. Usually, this meant walking along actual rhino tracks. The first feeding site we located was recorded as the first station. Feeding stations were set up such that they were at least 10m apart. It was easy to distinguish black rhino feeding activity because of their characteristic way of cutting browse. They use the upper prehensile lip to pull twigs into the mouth where they are cut off cleanly at the proximal end of the molars. Plants browsed by black rhino have a pruned look.

The following data was recorded at a station: (1) all plants browsed, (2) number of bites per individual food plant, (3) the diameter of fresh twig bites, (4) the height of the tallest branch browsed, (5) percentage of branches browsed per plant (0 – 100%, estimated at increments of 10%), (6) the parts eaten and, (7) the condition of the plant (green, dry, uprooted etc). All plants that were not eaten within a 5m radius from the station were identified. These are plants that the rhino actually encountered but rejected as feeding opportunities.

RESULTS

A. General

The wet and dry season results are summarized in Table VIIa, VIIb, VIIIa, VIIIb, IXa, and IXb. All the plants surveyed are listed along with family names. The columns that follow the family name represent the data recorded from black rhino food plants only. The last column shows the plant densities from the 10x10m plots.

B. Plant Densities

Aberdares NP: A total of 26 (10x10m) plots were sampled throughout the Salient area of Aberdares National Park during the wet season. At least 144 plant species from 51 families were sampled (Table VIIa). 57% of all plants sampled were browsed by black rhinos. Food Plants with the highest densities include, *Abutilon longicuspe, Ocimum gratissimum, Sida rhombifolia, Senna didymobotrya, Erythrococca bongensis, Urtica massaica, Sida tenuicarpa, Crotalaria incana, Toddalia asiatica, Hypoestes forskahlii, Vernonia auriculifera, Arudinaria alphina, Vangueria infausta, Phytolacca dodecandra, Lantana triflora, Hypoestes verticillaris, Conyza newii* and *Crassocephalum sp.*

Nairobi NP: I sampled a total of 29 plots throughout the park. At least 175 plant species from 34 families were sampled during the wet season (Table VIIIa). 65% of the plants I sampled were utilized by black rhinos. Food plants with the highest densities include *Abutilon mauritianum, Acalypha fruticosum, Phyllanthus fischeri, Aspilia pluriseta, Hibiscus flavifolius, Commelina benghalensis, Plechtranthus caninus, Fuersta africana, Solanum incanum, Ocimum kituensis, Ageratum conyzoides, Justicia anagalloides and Hypoestes verticillaris.*

TABLE VIIA:WET SEASON BLACK RHINO FOODPLANTS FROM SALIENT (ABERDARES NP)

Plant name	Family name	N	mean-bites	mean-diam	mean-height	%browsed	%preference	preference ranking
Abutilon longicuspe	Malvaceae	89	8.8	6.26	1.37	70	91.67	5
Ocimum gratissimum	Labiatae	80	12	5.36	1.19	70	77.5	4
Solanum aculeastrum	Solanaceae	121	6.9	6.5	1.15	66	88.78	5
Sida rhombifolia	Malvaceae	41	5.9	4.74	0.55	84	95.26	5
Leucas urticifolia	Labiatae	20	13.6	4.64	0.91	68	100	5
Senna septemtrionalis	Caesalpiniaceae	11	13.5	9.14	1.12	96	100	5
Senna didymobotrya	Caesalpiniaceae	10	9.2	7.79	1.39	67	41.67	3
Indigofera arrecta	Papilionaceae	9	9.6	3.66	0.62	85	100	5
Solanum incanum	Solanaceae	8	4.1	6.77	0.55	96	100	5
Rhamnus prinoides	Rhamnaceae	8	4.5	7.92	1.51	76	80	5
Erythrococca bongensis	Euphorbeaceae	7	27.3	3.65	1.76	57	30	2
Pentas lanceolata	Rubiaceae	6	10	4.35	0.65	88	100	5
Vernonia galamensis	Compositae	5	5.6	7.15	1.19	54	100	5
Urtica massaica	Urticaceae	5	6.6	5.64	0.84	92	36.36	2
Sida tenuicarpa	Malvaceae	5	9	5.64	0.29	88	100	5
Leucas grandis	Labiatae	5	8.6	5.47	1.03	92	86.67	5
Crotalaria incana	Papilionaceae	5	8	6.18	1	78	60	5
Toddalia asiatica	Rutaceae	4	7.3	5.01	0.85	44	20	2
Sida schimperana	Malvaceae	4	5.5	8.21	0.46	89	100	5
Dovyalis abyssinica	Flacourtiaceae	4	16	5.64	1.74	63	80	5
Achyranthes aspera	Amaranthaceae	4	7.3	5.01	0.85	44	100	5
Solanum mauense	Solanaceae	3	6.3	5.07	0.34	67	100	5
Hibiscus vitifolius	Malvaceae	3	44.7	3.27	1.48	83	100	5
Hibiscus callyphylus	Malvaceae	3	15.3	4.52	1.68	98	100	5
Clausena anisata	Rutaceae	3	5.3	4.65	1.5	77	100	5
Pluchia ovalis	Compositae	2	3.5	3.45	1.32	75	100	5
Nuxia congesta	Loganiaceae	2	8	4.85	1.23	65	50	3
Leonotis mollissima	Labiatae	2	2.5	7.06	1.01	65	100	5
Hyppoestes verticillaris	Acanthaceae	2	3	4.25	0.84	30	100	5
Hypoestes aristata	Acanthaceae	2	14.5	2.75	1.1	68	100	5

TABLE VIIA continued

Hibiscus fuscus	Malvaceae	2	10	6.6	0.64	75	100	5
Croton macrostachyus	Euphorbeaceae	2	3	16.2	1.03	35	100	5
Conyza bonariensis	Compositae	2	3	5.55	0.56	100	66.67	4
Vernonia auriculifera	Compositae	1	3	8.5	1.67	100	4.55	1
Vangueria infausta	Rubiaceae	1	4	3.25	1	100	10	1
Triumfetta sp	Tiliaceae	1	6	4.5	0.37	80	100	5
Tephrosia sp	Papilionaceae	1	16	6.1	1.39	100	100	5
Sp A	not identified	1	6	6.8	0.4	100	100	5
Solanum sp	Solanaceae	1	6	3.8	0.89	60	100	5
Solanum nigrum	Solanaceae	1	18	5	0.52	90	100	5
Sida cordifolia	Malvaceae	1	6	2.9	0.37	100	100	5
Phytolacca dodecandra	Phytolaccaceae	1	4	8.25	1.08	25	16.67	1
Pavonia urens	Malvaceae	1	22	4.1	0.98	100	50	3
Leucas urticifolia	Labiatae	1	16	3.7	0.63	100	100	5
Lantana trifolia	Verbenaceae	1	3	3.17	1.4	60	12.5	1
Ehretia cymosa	Boraginaceae	1	6	4.8	0.68	100	100	5
Crassocephalum sp	Compositae	1	8	5.4	1.17	60	100	5
Conyza newii	Compositae	1	8	3.7	0.92	95	100	5
Blepharis maderaspatensis	Acanthaceae	1	30	3	1.4	50	33.33	2
Asparagus africanus	Asparagaceae	1	1	4.5	0.64	100	100	5
Abutilon mauritianum	Malvaceae	1	14	7.5	1.66	90	100	5

<u>NOTE</u>

N = The number of individual plants sampled
Mean-bites = mean number of bites per plant
Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
Grade = percent grade

TABLE VIIA continued

% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

TABLE VIIB: DRY SEASON BLACK RHINO FOOD PLANTS FROM SALIENT (ABERDARES NP)

Plant name	Family name	N	mean-bites	mean-diam	mean-height	%browsed	%preference	P-ranking
Ocimum gratissimum	Labiatae	108	7.8	5.35	1.13	74.35	61.8	4
Solanum aculeastrum	Solanaceae	94	6.57	6.76	1.12	71.76	96.45	5
Abutilon longicuspe	Malvaceae	66	6.64	5.74	1.29	75.38	60.08	3
Sida tenuicarpa	Malvaceae	63	5.83	5.55	0.4	82.84	81.25	4
Sida rhombifolia	Malvaceae	44	4.73	7.53	0.56	89.55	92	5
Senna septemtrionalis	Caesalpiniaceae	23	9.57	10.26	1.08	91.52	100	5
Rhamnus prinoides	Rhamnaceae	22	6.05	6.98	1.44	80.46	64.71	3
Leucas urticifolia	Labiatae	22	8.32	4.4	0.91	92.04	88.24	2
Hyoestes forskahlii	Acanthaceae	22	32.82	4.16	0.76	88.64	30	3
Toddalia asiatica	Rutaceae	20	3.85	6.4	1	59.75	24.39	1
Rhamnus staddo	Rhamnaceae	13	5.46	6.03	1.73	91.15	100	5
Senecio syringifolius	Compositae	11	7.56	7.38	1.27	64.09	50	2
Olea europaea	Oleaceae	10	8.4	5.81	1.61	96.5	100	5
Hibiscus callyphylus	Malvaceae	8	14.88	4.43	1.31	72.5	70	5
Solanum incanum	Solanaceae	7	4.14	6.48	0.45	97.14	60	2
Lantana trifolia	Verbenaceae	6	3.5	4.81	1.36	93.33	33.33	2
Erythrococca bongensis	Euphorbeaceae	6	5.17	3.93	1.18	84.17	30.43	2
Dovyalis abyssinica	Flacourtiaceae	6	7.5	4.68	1.43	91.67	42.86	3
Clausena anisata	Rutaceae	6	2	4.82	1.21	100	75	5
Leonotis mollissima	Labiatae	5	3.6	6.53	1.27	76	100	5
Euclea divinorum	Ebenaceae	5	6.2	4.73	0.93	87	100	5
Senna didymobotrya	Caesalpiniaceae	4	9.25	8.83	1.03	65	60	4
Rhus natalensis	Anacardiaceae	4	1.75	6.44	0.81	100	100	5
Pentas lanceolata	Rubiaceae	4	4.25	4.76	0.48	97.5	57.53	4
Ehretia cymosa	Boraginaceae	4	5	5.78	1.17	100	100	5
Vernonia galamensis	Compositae	3	6	7.08	0.53	90	100	5
Solanecio angulatus	Compositae	3	7.33	5.1	1.58	65	100	5
Vernonia auriculifera	Compositae	2	3.5	9.43	0.97	100	33.33	2
Urtica massaica	Urticaceae	2	2	5.25	0.89	82.5	16.67	5
Teclea nobilis	Rutaceae	2	4.5	3.18	1.34	100	25	4

TABLE VIIB continued

Pluchia ovalis	Compositae	2	5	4.54	1.53	80	28.57	4
Pavonia patens	Malvaceae	2	35.5	3.75	0.98	100	100	5
Juniperus procera	Cypressaceae	2	3	3.5	0.98	100	100	5
Hibiscus fuscus	Malvaceae	2	5.5	4.88	1.29	100	100	5
Crotalaria incana	Papilionaceae	2	8	4.65	0.96	87.5	40	4
Clerodendrum johnstonii	Verbenaceae	2	2.5	4.75	1.32	100	33.33	3
Vernonia ssp galamensis	Compositae	1	1	9	0.45	100	100	5
Vernonia sp	Compositae	1	3	4.5	1.53	100	100	5
Vangueria infausta	Rubiaceae	1	1	5.5	1.19	25	25	2
Teclea simplicifolia	Rutaceae	1	5	4.3	1.4	100	50	3
Scutia myrtina	Rhamnaceae	1	5	6.3	0.86	100	100	5
Rytigynia uhligii	Rubiaceae	1	13	4.33	1.8	100	100	5
Phytolacca dodecandra	Phytolaccaceae	1	1	3	1.4	100	100	5
Nuxia congesta	Loganiaceae	1	1	10.5	1.83	100	100	5
Maytenus senegalensis	Celastraceae	1	3	3.33	1.1	100	100	5
Leucas deflexa	Labiatae	1	11	3.9	0.14	100	100	5
Hyppoestes verticillaris	Acanthaceae	1	50	3.9	0.56	100	100	5
Euphorbia schimperana	Euphorbiaceae	1	4	6.13	0.2	100	100	5
Commelina africana	Commelinaceae	1	2	2.5	1	100	100	5
Clutia abyssinica	Euphorbiaceae	1	1	4.5	1	100	100	5
Calodendrum capense	Rutaceae	1	4	4.5	1.5	100	100	5
Blepharis maderaspatensis	Acanthaceae	1	50	3.6	0.5	100	50	5
Achyrospermum schimperi	Labiatae	1	4	5.88	0.53	35	100	5
Achyranthes aspera	Amaranthaceae	1	10	4.1	1.16	65	33.33	5
Abutilon mauritianum	Malvaceae	1	2	4	0.83	40	100	5

<u>NOTE</u>

N = The number of individual plants sampled

Mean-bites = mean number of bites per plant

TABLE VIIB continued

Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
Grade = percent grade
% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

TABLE VIIIA: WET SEASON BLACK RHINO FOOD PLANTS FROM NAIROBI NP

Plant name	Family name	N	mean-bites	mean-diam	mean-height	%browsed	%preference	preference ranking
Abutilon mauritianum	Malvaceae	63	21.78	6.64	1.15	87.54	100	5
Aeschynomene schimperi	Papilionaceae	53	37.79	8.11	1.19	83.3	100	5
Acalypha fruticosum	Euphorbiaceae	53	18.38	4.67	1.33	91.68	100	5
Acacia kirkii	Mimosaceae	53	18.38	4.66	1.33	91.67	100	5
Acacia gerrardii	Mimosaceae	53	18.38	4.67	1.33	91.67	100	5
Achyranthes aspera	Amaranthaceae	51	18.69	6.02	0.71	76.57	96.43	5
Phyllanthus fischeri	Euphorbiaceae	49	19.86	7.69	1.38	83.47	100	5
Rhus natalensis	Anacardiaceae	35	15.42	7.86	1.21	55	100	5
Carissa edulis	Apocynaceae	27	5.37	8.44	1.21	23.7	85.19	5
Grewia similis	Tiliaceae	26	8.89	4.69	0.94	74	100	5
Scutia myrtina	Rhamnaceae	25	6.08	7.12	0.99	62.2	100	5
Ocimum gratissimum	Labiatae	24	19.41	6.92	0.91	75.83	80	5
Lippia kituensis	Verbenaceae	20	18.85	8.25	1.18	89.25	82.35	5
Aspilia pluriseta	Compositae	19	16.35	4.42	0.65	46.84	55.56	3
Aspilia mosambicensis	Compositae	17	16.35	6.35	1.45	71.47	65.22	4
Lantana camara	Verbenaceae	15	33.67	8.67	0.97	79.33	100	5
Hibiscus flavifolius	Malvaceae	14	3.07	4.47	0.94	49.64	72.22	4
Olea europaea	Oleaceae	13	15.54	9.15	1.62	71.92	100	5
Leucas grandis	Labiatae	13	14.39	5.85	0.87	90	100	5
Grewia tembensis	Tiliaceae	13	12	6.31	0.97	84.23	66.67	4
Acacia etbaica	Mimosaceae	13	7.77	8.77	0.98	82.69	100	5
Acacia brevispica	Mimosaceae	12	5.92	7.08	0.97	80	90	5
Pavonia patens	Malvaceae	11	10.55	5.36	1	78.18	100	5
Acacia seyal	Mimosaceae	11	10.55	10.73	1.18	88.18	100	5
Maytenus senegalensis	Celastraceae	10	1.9	6.8	1.02	47	100	5
Dovyalis caffia	Flacourtiaceae	10	17.2	8.5	1.25	63	100	5
Nasea lythroides	Lythraceae	7	13.43	6.86	0.66	85.71	100	5
Lippia javanica	Verbenaceae	7	6.57	5.71	0.67	35.71	31.82	2
Indigofera volkensii	Papilionaceae	7	22.71	3	0.63	62.86	100	5
Commelina benghalensis	Commelinaceae	7	23.43	5	0.81	85	100	5

TABLE VIIIA continued

Vernonia lasiopus	Compositae	6	8.17	9.33	0.8	89.18	100	5
Pavonia urens	Malvaceae	6	10	4.83	1.02	65	100	5
Indigofera arrecta	Papilionaceae	6	17.67	5.67	0.73	67.5	100	5
Hibiscus fuscus	Malvaceae	6	11.33	5	0.88	86.67	85.71	5
Monechma debile	Acanthaceae	5	9.6	3.4	0.64	38	100	5
Leonotis ocymifolia	Labiatae	5	1.2	4.2	1.08	49	100	5
Gomphorcarpus semilunatus	Asclepiadaceae	5	6.6	5.8	1.16	47	83.33	5
Euphorbia bongensis	Euphorbiaceae	5	1.2	4.2	0.5	39	100	5
Dombeya burgessiae	Sterculiaceae	5	13.6	6	0.8	91	100	5
Ziziphus mucronata	Rhamnaceae	4	5.5	4.25	0.73	63.75	80	5
Triumfetta rhomboides	Sterculiaceae	4	7.25	7	0.75	91.25	100	5
Tragia brevidens	Euphorbiaceae	4	3	6.25	0.75	61.25	100	5
Tagetes minuta	Compositae	4	3.75	4	0.55	77.5	100	5
Plectranthus caninus	Labiatae	4	10	2	1.65	60	100	5
Ochna holstii	Ochnaceae	4	10.25	6	1.07	60	80	5
Hypoestes triflora	Acanthaceae	4	8.25	3.25	1.2	70	100	5
Fuerstia africana	Labiatae	4	6	3	0.53	65	100	5
Clerodendrum myricoides	Verbenaceae	4	1.25	6	1	55	100	5
Acacia stuhlmannii	Mimosaceae	4	3	7.25	1.03	36.25	80	5
Acacia melifera	Mimosaceae	4	3	7.25	1.03	36.25	100	5
Acacia drebanolobium	Mimosaceae	4	11	2.75	7.75	1.18	20	2
Warbugia ugandensis	Canellaceae	3	2.67	9	0.97	40	100	5
Solanum incanum	Solanaceae	3	3.3	6.67	0.67	33.33	21.43	2
Psiadia punctulata	Compositae	3	11	6.67	0.63	56.67	25	2
Polygonum setosulum	Polygonaceae	3	11	6.67	0.63	56.67	75	4
Ocimum kituensis	Labiatae	3	3	3.67	0.77	26.67	14.29	1
Lawsonia inermis	Lythraceae	3	4	6	0.87	63.33	100	5
Indigofera schimperi	Papilionaceae	3	10	4.67	1.33	85	100	5
Allophylus rubifolius	Sapindaceae	3	3.33	5.33	1.2	66.67	100	5
Ageratum conyzoides	Compositae	3	2.67	3	0.63	46.67	50	3
Sida ovata	Malvaceae	2	5.5	3	0.75	45	100	5

TABLE VIIIA continued

Sarcostemma viminale	Asclepiadaceae	2	4.5	5	0.75	75	100	5
Rhynchosia minima	Papilionaceae	2	19.5	5	0.85	55	100	5
Rhus terminervus	Anacardiaceae	2	7.5	5	0.95	40	100	5
Ormocarpum sp	Papilionaceae	2	3.5	9.5	0.75	55	100	5
Microglossa densiflora	Compositae	2	52.5	6	0.6	95	100	5
Maerua decumbens	Capparaceae	2	22	7.5	1.1	90	100	5
Lantana trifolia	Verbenaceae	2	4.5	6.5	1	50	100	5
Jasminium abyssinica	Oleaceae	2	4	3.5	1.35	55	100	5
Hermannia uhligii	Sterculiaceae	2	22	6.5	0.7	80	100	5
Heliotropium steudneri	Boraginaceae	2	4.5	3	0.5	50	100	5
Grewia bicolor	Tiliaceae	2	34.5	9	1.2	92.5	100	5
Gnidia subcordata	Thymeleaceae	2	7.5	2.5	0.55	65	100	5
Euclea divinorum	Ebenaceae	2	11	9	1.75	77.5	66.67	4
Elaedendron buchananii	Celastraceae	2	5.5	6	0.6	62.5	100	5
Cyprus renschii	Cyperaceae	2	19.5	8.5	0.7	90	100	5
Croton dichogamous	Euphorbiaceae	2	13.5	8.5	1.3	45	28.57	2
Crotalaria brevidens	Papilionaceae	2	12	3.5	0.85	72.5	100	5
Cordia monoica	Boraginaceae	2	4	6	0.65	75	100	5
Commiphora schimperi	Burseraceae	2	4	6	0.65	75	100	5
Barleria erathemoides	Acanthaceae	2	2	4	0.9	65	100	5
Albizia amarus	Mimosaceae	2	30	6.5	1.5	95	100	5
Waltheria indica	Sterculiaceae	1	3	3	1	80	100	5
Verbena bonariensis	Verbenaceae	1	4	4	1	50	100	5
Tephrosia hildebrandtii	Papilionaceae	1	5	4	0.6	90	100	5
Teclea simpliciflora	Rutaceae	1	8	7	1.2	80	100	5
Teclea nobilis	Rutaceae	1	16	15	1.5	85	100	5
Sphaeranthus suaveolens	Compositae	1	2	0.8	0.5	65	100	5
Schrebera alata	Oleaceae	1	25	6	1.2	90	100	5
Rhamnus staddo	Rhamnaceae	1	13	7	1	80	100	5
Pupalia lappacea	Amaranthaceae	1	4	4	1.2	60	100	5
Phyllanthus schimperi	Euphorbiaceae	1	34	11	0.5	90	100	5
Nicotiana glauca	Solanaceae	1	4	3	0.5	85	100	5

TABLE VIIIA continued

Nepeta azurea	Labiatae	1	3	10	0.6	100	83.33	5
Leucas glabrata	Labiatae	1	5	6	1.1	90	100	5
Kalanchoe sp	Crassulaceae	1	1	12	0.6	100	100	5
Justicia flava	Acanthaceae	1	22	3	1.2	50	100	5
Justicia anagalloides	Acanthaceae	1	10	4	1.2	50	100	5
Indigofera swaziensis	Papilionaceae	1	18	10	0.5	80	100	5
Hypoestes verticillaris	Acanthaceae	1	60	6	1.5	60	100	5
Hibiscus calyphylus	Malvaceae	1	14	7	1	90	100	5
Hibiscus aponeurus	Malvaceae	1	1	6	1.2	20	100	5
Gutenbergia cordeifolia	Compositae	1	6	3	0.5	50	100	5
Gomphorcarpus stenophylus	Asclepiadaceae	1	4	5	0.6	80	50	3
Englerastrum scandens	Compositae	1	33	10	0.5	90	100	5
Cussonia sp	Araliaceae	1	8	10	1.5	90	100	5
Crotalaria keniensis	Papilionaceae	1	4	6	0.6	45	100	5
Conyza sumatrensis	Compositae	1	13	6	0.5	80	100	5
Conyza stricta	Compositae	1	6	6	0.9	90	100	5
Cissus quadrangularis	Euphorbiaceae	1	7	16	0.9	95	100	5
Capparis tomentosa	Capparaceae	1	3	5	0.5	100	100	5
Bidens pilosa	Compositae	1	53	3	0.5	100	100	5
Becium obovatum	Labiatae	1	2	2	0.5	100	100	5
	Sterculiaceae							

<u>NOTE</u>

N = The number of individual plants sampled
Mean-bites = mean number of bites per plant
Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

TABLE VIIIB: DRY SEASON BLACK RHINO FOOD PLANTS FROM NAIROBI NP

Plant name	Family name	N	mean-bites	mean-diam	mean-height	%browsed	%preference	preference ranking
Phyllanthus fischeri	Euphorbiaceae	262	9.5	5.46	1.15	85.97	76.79	4
Acacia kirkii	Mimosaceae	142	7.27	8.59	0.7	89.3	96.63	5
Gnidia subcordata	Thymeleaceae	112	4.3	9.54	1.05	93.2	87.6	5
Acalypha fruticosum	Euphorbiaceae	81	13	4.86	1.24	93.36	93.75	5
Lippia kituensis	Verbenaceae	53	8.98	5.4	1.28	85.11	83.87	5
Grewia tembensis	Tiliaceae	40	4.98	5.3	0.64	94.75	100	5
Acacia stuhlmannii	Mimosaceae	39	30.64	7.57	0.76	53.33	93.75	5
Acacia gerrardii	Mimosaceae	39	6.44	8.19	0.72	93.72	100	5
Acacia xanthophloea	Mimosaceae	34	7.9	9.37	0.74	84.06	88.87	5
Aspilia mosambicensis	Compositae	31	6.74	6.82	1.38	94.26	90	5
Carissa edulis	Apocynaceae	30	7.87	6.65	1.06	93.8	74.07	4
Acacia melifera	Mimosaceae	28	8.1	6.62	0.71	66.7	85.71	5
Solanum incanum	Solanaceae	27	2.74	6.14	0.68	92.52	60.87	4
Rhus natalensis	Anacardiaceae	26	4.65	6.6	0.86	87.19	53.33	3
Hibiscus flavifolius	Malvaceae	24	3.71	4.71	0.8	97.92	70.83	4
Acacia drebanolobium	Mimosaceae	22	2.91	6.65	0.2	50	100	5
Maytenus heterophylla	Celastraceae	20	6.1	6.52	0.79	99.75	100	5
Achyranthes aspera	Amaranthaceae	18	7.28	6.16	0.48	97.94	100	5
Dovyalis caffia	Flacourtiaceae	16	19.13	5.52	1.51	66.38	100	5
Aspilia pluriseta	Compositae	16	9.63	5.98	0.82	87.56	71.43	4
Scutia myrtina	Rhamnaceae	15	4.87	5.61	1.27	70	47.62	3
Lantana camara	Verbenaceae	13	8.46	6.65	1.29	84.46	83.33	5
Triumfetta rhomboides	Sterculiaceae	10	6.1	11.32	0.58	100	100	5
Pavonia patens	Malvaceae	9	2.56	5.41	0.96	92.56	77.78	4
Olea europaea	Oleaceae	8	4.63	5.2	1.4	89.38	100	5
Lippia javanica	Verbenaceae	8	7.75	5.3	0.87	80	34.62	2
Indigofera arrecta	Papilionaceae	8	5.12	5.16	0.69	100	100	5
Dombeya burgessiae	Sterculiaceae	8	4	5.51	0.74	100	100	5
Capparis tomentosa	Capparaceae	7	13.71	6.06	0.49	91.57	100	5
Rhus terminervus	Anacardiaceae	6	7	8.6	0.29	70	83.33	5

TABLE VIIIB (continued)

Asparagus africana	Smilacaceae	6	2.83	5	0.75	100	100	5
Asparagus flagellaris	Smilacaceae	6	2.3	5	0.75	100	100	5
Balanites aegyptiaca	Balanitaceae	6	4	7.65	0.49	72.5	80	5
Maytenus senegalensis	Celastraceae	6	4.83	6.29	1.03	86.67	100	5
Sida rhombifolia	Malvaceae	6	3.16	6.03	0.27	100	100	5
Sida tenuicarpa	Malvaceae	6	8.5	4.08	0.29	100	100	5
Hibiscus fuscus	Malvaceae	6	2.83	5.4	0.91	100	100	5
Brachaelena sp	Compositae	6	3.33	5.47	0.99	100	100	5
Ocimum gratissimum	Labiatae	5	3.2	5.56	0.82	83.2	18.18	1
Grewia similis	Tiliaceae	5	2	5.54	1.01	100	87.5	5
Acacia brevispica	Mimosaceae	5	3.8	6.41	0.84	100	100	5
Ocimum kituensis	Labiatae	4	1.5	10.37	0.39	100	25	2
Turraea mombassana	Meliaceae	4	3.7	4.98	1.25	73.25	100	5
Lycium europaeum	Solanaceae	4	5.5	6.15	0.24	94.5	100	5
Ormocarpum kirkii	Papilionaceae	4	1.5	10.38	0.39	100	100	5
Allophylus rubifolius	Sapindaceae	4	9	6.83	0.245	82.5	100	5
Vernonia lasiopus	Compositae	3	3.33	7.73	0.59	100	100	5
Ochna holstii	Ochnaceae	3	6	5.67	0.82	100	37.5	2
Leucas grandis	Labiatae	3	3.33	5.96	0.98	83.33	100	5
Croton dichogamous	Euphorbiaceae	3	4	5.75	1.18	100	100	5
Acacia seyal	Mimosaceae	3	4.67	7.17	0.83	90	100	5
Hibiscus calyphylus	Malvaceae	2	3.5	4.8	1.28	83.5	100	5
Elaedendron buchananii	Celastraceae	2	2	4	1.17	83.5	15.38	1
Cordia monoica	Boraginaceae	2	7.5	6.8	0.55	66.5	9	1
Commelina benghalensis	Commelinaceae	2	2	8.25	0.5	100	100	5
Acacia etbaica	Mimosaceae	2	4	3.91	0.71	100	100	5
Calpurnea aurea	Papilionaceae	1	8	6.9	0.8	100	96.77	5
Ziziphus mucronata	Rhamnaceae	1	6	6.5	0.92	100	100	5
Astrpomea kyoscyamoides	Convolvulaceae	1	4	4.99	0.1	100	100	5
Verbena bonariensis	Verbenaceae	1	1	5	1	100	100	5
Schrebera alata	Oleaceae	1	11	6.4	0.84	22	100	5
Rhamnus staddo	Rhamnaceae	1	2	6.5	0.72	100	100	5

TABLE VIIIB continued

Jasminium abyssinica	Oleaceae	1	1	5	0.58	100	100	5
Euclea divinorum	Ebenaceae	1	2	7.5	1.25	100	100	5
Commiphora schimperi	Burseraceae	1	16	4	0.2	100	100	5
Aeschynomene schimperi	Papilionaceae	1	8	8.2	0.9	81	100	5
Abutilon mauritianum	Malvaceae	1	1	9	1.52	100	50	3
Nasea lythroides	Lythraceae	1	8	5.4	0.6	100	50	3

NOTE

N = The number of individual plants sampled
Mean-bites = mean number of bites per plant
Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% open = percent open
% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

TABLE IXA: WET SEASON BLACK RHINO FOOD PLANTS FROM NGULIA RHINO SANCTUARY (TSAVO WEST NP)

Plant name	Family name	N	mean-bites	mean diam	mean-height	%browsed	%preference	preference ranking
Duosperma kilimandscharica	Acanthaceae	88	12.31	4.17	1.01	88.52	100	5
Sericomopsis pallida	Amaranthaceae	75	12.95	4.81	0.5	93.4	93.33	5
Ochna inermis	Ochaceae	61	30.05	5.31	1.2	58.36	72.09	4
Premna holstii	Verbenaceae	60	12.05	5.41	1.13	59.5	36.75	5
Grewia villosa	Tiliaceae	40	5.63	6.33	0.73	93.25	64.29	4
Solanum incanum	Solanaceae	36	4.86	4.47	0.54	94.17	65.52	4
Grewia bicolor	Tiliaceae	26	12.58	6.86	0.92	94.04	85	5
Grewia nematopus	Tiliaceae	20	4.35	5.9	1.04	86.25	58.33	3
Lannea alata	Anacardiaceae	17	15.53	9.82	1.32	97.65	92.31	5
Commiphora africana	Burseraceae	16	9.88	8.67	1.24	51.56	52.17	3
Hermannia uhligii	Sterculaceae	14	7.86	4.93	0.42	93.21	75	4
Commiphora madagascariensis	Burseraceae	14	18.57	8.69	1.17	59.29	80	5
Erythroclamys spectabilis	Labiatae	13	9.77	5.43	0.92	79.23	36.84	2
Combretum exalatum	Combretaceae	11	7	4.11	1.35	70	69.23	4
Catunaregum spinosa	Rubiaceae	10	7.5	5.51	1.03	79.5	100	5
Sida ovata	Malvaceae	8	5.25	3.78	0.46	91.25	77.78	4
Melia volkensii	Meliaceae	8	6.13	7.86	1.26	81.25	87.5	5
Barleria teitensis	Acanthaceae	8	4.63	3.6	0.44	85	100	5
Tephrosia villosa	Papilionaceae	6	8	4.92	0.31	85.83	66.67	4
Premna resinosa	Verbenaceae	4	8	4.41	0.83	67.5	17.86	1
Erythrococca bongensis	Euphorbiaceae	4	7.25	3.55	0.71	77.5	4.17	1
Acacia tortilis	Mimosaceae	4	3.75	5.58	0.93	68.75	37.5	2
Acacia brevispica	Mimosaceae	4	3.75	5.58	0.93	68.75	66.67	4
Solanum renschii	Solanaceae	3	5	5.73	0.83	100	100	5
Sericomopsis hildebrandtii	Amaranthaceae	3	44	2	0.28	100	40	3
Grewia tembensis	Tiliaceae	3	4.67	4.22	0.6	66.67	75	4
Ehretia teitensis	Boraginaceae	3	12.2	6.3	1.24	20	22.22	2
Tragia ukambensis	Euphorbiaceae	2	4.5	6.55	0.42	100	100	5
Cadaba fainosa	Capparaceae	2	8.5	4.18	1.52	70	40	3
Abutilon mauritianum	Malvaceae	2	4.5	2.58	0.64	47.5	25	2
Tinnea aethiopica	Labiatae	1	8	3.8	0.3	20	50	3

TABLE IXA continued

Hibiscus canabinus	Malvaceae	1	15	3	0.5	75	100	5
Echbolium revolutum	Acanthaceae	1	17	5.3	0.62	100	66.67	4
Cassia abbreviata	Caesalpinaceae	1	7	3.5	0.16	95	100	5
Boscia coriaceae	Capparaceae	1	2	5.25	1.67	10	2	1
Bauhinia taitensis	Caesalpinaceae	1	5	5.5	1.3	40	14.29	1
Barleria spinosa	Acanthaceae	1	15	4	0.67	60	100	5

NOTE
N = The number of individual plants sampled
Mean-bites = mean number of bites per plant
Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

TABLE IXB: DRY SEASON BLACK RHINO FOOD PLANTS FROM NGULIA RHINO SANCTUARY (TSAVO WEST NP)

Plant name	Family name	N	mean-bites	mean-diam	mean-height	%browsed	%preference	preference ranking
Tephrosia villosa	Papilionaceae	112	10.25	5.77	0.6	100	100	5
Duosperma kilimandscharica	Acanthaceae	62	21.82	5.08	0.97	92.17	98	5
Grewia bicolor	Tiliaceae	60	10.94	5.79	1.15	88.75	100	5
Hibiscus canabinus	Malvaceae	52	8.04	5.75	0.89	96.73	100	5
Grewia nematopus	Tiliaceae	37	7.68	5.62	1.14	87.97	100	5
Ochna inermis	Ochaceae	26	13.12	4.81	1.02	76.35	100	5
Abutilon fruticosa	Malvaceae	25	7.84	5.56	0.68	92.4	100	5
Grewia villosa	Tiliaceae	22	9.82	5.27	0.96	87.96	100	5
Acacia tortilis	Mimosaceae	22	12.23	7.78	1.4	60	100	5
Waitheria indica	Sterculaceae	20	12.2	5.1	0.72	86.5	100	5
Helinus mystacinus	Rhamnaceae	19	16.79	4.56	0.78	93.42	100	5
Combretum apiculatum	Combretaceae	18	9.06	6.83	1.23	87.5	100	5
Premna resinosa	Verbenaceae	13	18.85	6.62	1.36	83.85	100	5
Solanum incanum	Solanaceae	12	5.08	6.17	0.975	73.33	38.46	2
Indigofera arrecta	Papilionaceae	8	7.13	5.5	0.85	83.13	100	5
Astripomea lyoscyamoides	Convolvulaceae	8	7.13	8.5	0.66	92.5	100	5
Premna holstii	Verbenaceae	7	7.57	5.71	1.31	84.29	100	5
Catunaregum spinosa	Rubiaceae	7	19.14	6.86	1.14	94.29	100	5
Barleria teitensis	Acanthaceae	7	4.43	5.57	0.99	80	100	5
Melia volkensii	Meliaceae	6	9.33	7	1	96.67	100	5
Sericomopsis pallida	Amaranthaceae	5	26	5.2	0.62	87	100	5
Combretum exalatum	Combretaceae	5	6.4	4.2	0.92	90	100	5
Melhania velutina	Sterculaceae	4	4.5	4	0.98	82.5	100	5
Grewia tembensis	Tiliaceae	4	5.25	5.75	1.1	90	100	5
Boscia angustifolia	Capparaceae	4	6.5	7	0.93	100	100	5
Ruellia megachlamys	Acanthaceae	3	8.33	3.33	0.73	76.67	100	5
Hibiscus micranthus	Malvaceae	3	2	4.33	0.67	100	100	5
Abutilon sp	Malvaceae	3	6	7.33	0.5	100	100	5
Strychnos decussata	Loganiaceae	2	7	7	1	70	100	5
Sida ovata	Malvaceae	2	8.68	4.83	0.54	91.32	100	5
Croton sp	Euphorbiaceae	2	10.5	4.5	0.85	100	100	5

TABLE IXB continued

Cassia abbreviata	Caesalpinaceae	2	5	5.5	0.85	100	100	5
Acalypha fruticosum	Euphorbiaceae	2	14.5	3	0.75	100	100	5
Acacia brevispica	Mimosaceae	2	6	4.5	0.85	100	100	5
Sterculia africana	Sterculaceae	1	7	8	1.3	100	100	5
Solanum renschii	Solanaceae	1	12	6	1.1	90	100	5
Ocimum americanum	Labiatae	1	37	6	1	100	100	5
Ipomea hildebrandtii	Convolvulaceae	1	10	7	0.5	100	100	5
Indigofera spinosa	Papilionaceae	1	4	4	1	100	100	5
Hoslundia opposita	Labiatae	1	2	5	1	70	100	5
Helinus integrifolius	Rhamnaceae	1	3	4	0.5	100	100	5
Ehretia teitensis	Boraginaceae	1	15	7	1	40	100	5
Echbolium revolutum	Acanthaceae	1	2	5	0.6	100	100	5
Delonix elata	Caesalpinaceae	1	1	15	0.6	100	100	5
Cordia somalensis	Boraginaceae	1	1	9	0.5	100	100	5
Cordia monoica	Boraginaceae	1	1	5	1.4	30	100	5
Commelina latifolia	Commelinaceae	1	2	2	0.5	100	100	5
Boscia coriaceae	Capparaceae	1	75	4	1.1	100	100	5
Bauhinia taitensis	Caesalpinaceae	1	12	3	0.6	90	100	5
Barleria spinosa	Acanthaceae	1	1	9	0.5	100	100	5
Albizia sp	Mimosaceae	1	2	5	1.1	20	100	5

NOTE
N = The number of individual plants sampled
Mean-bites = mean number of bites per plant
Mean-diam = Mean bite diameter per plant
Mean-height = The mean bite height across plants
%browsed = Represents the mean percent utilization at the plant level
% preference = The number of times (as a percentage) a plant was eaten at a station when encountered
Preference ranking = Utilization index: 5=80-100%), 4=60-80%, 3=40-60%, 2=20-40%, 1=0-20%

Ngulia Sanctuary: I sampled 21 plots in the wet and 31 plots in the dry season. There were 80 plant species in the dry season from 22 families and 69 plant species from 20 families in the wet season (Table IXa and IXb). 54% and 64% of the plants I sampled were browsed by black rhinos in wet and dry season respectively. Food plants with the highest densities include *Sericomopsis pallida, Premna holstii, Grewia villosa, Solanum incanum, Grewia bicolor, Grewia nematopus, Hermannia uhligii, Sida ovata, Barleria teitensis, Tephrosia villosa, Erythrococca bongensis, Sericomopsis hildebrandtii, Tragia ukambensis, Bauhinia taitensis, Barleria spinosa* and *Echbolium revolutum.*

C. Feeding surveys

Black rhinos selected a wide variety of food plants in all of the three parks. They did not show discrimination among the plant parts they consumed. Leaves, flowers, fruits and stems were consumed from most plants selected.

Aberdares NP: In total, 1152 individual plants (food patches) were encountered from 469 stations: 255 stations (500 food patches) were encountered in the wet season and 214 (652 food patches) in the dry season. At least 82 plant species from 33 families were eaten by black rhinos in the Salient area of Aberdares National Park during the wet and 54 plants from 25 families in the dry season (Table VIIa and VIIb). 62% of the plants selected were woody and 38% herbaceous. Families having at least 4 foodplants included Malvaceae, Compositae, Solanaceae, Labiatae, Rhamnaceae, Rutaceae and Acanthaceae. The plants that contributed significantly to the rhino's diet during wet and dry season were *Abutilon longicuspe, Ocimum gratissimum, Solanum aculeastrum ssp. Aculeastrum* *var. 1, Solanum aculeastrum ssp. Aculeastrum var. acueleastrum, Senna septemtrionalis, Sida tenuicarpa and Sida rhombifolia. Hypoestes forskahlii, Rhamnus prinoides, Toddalia asiatica* were consumed in larger proportions during the dry season (Table VIIa and VIIb).

Nairobi NP: I measured a total of 2188 individual food plants from 851 stations in the course of this study from 342 stations (865 food plants) in the wet season and 509 stations (1323 food plants) in the dry season. At least 113 plant species were eaten in the wet season and 68 in the dry season (Table VIIIa and VIIIb). Thirty four families were represented in the black rhino diet. 84% of the plants selected in the wet season were woody and 16% herbaceous. The majority (92%) of the plants selected in the dry season were woody and only 4% were herbaceous. Families with at least 4 food plants included Malvaceae, Papilionaceae, Labiatae, Compositae, Verbenaceae, Sterculaceae, Euphorbiaceae and Acanthaceae. *Abutilon mauritianum, Aeschynomene schimperi, Acalypha fruticosum, Achyranthes aspera, Phyllanthus fischeri, Rhus natalensis, Carissa edulis, Gnidia subchordata, Acacia xanthphloea, Acacia stuhlmannii, Acacia gerardii, Acacia kirkii, Olea europaea,* and *Lippia kituensis* contributed significantly to the rhino's diet in the park (Table VIIIa and VIIIb). *Acacia xanthophloea, Acacia stuhlmanii, Gnidia subchordata, Rhus natalensis* and *Olea europaea* were browsed more in the wet than the dry season while *Abutilon mauritianum, Aeschynomene schimperi* and *Achyranthes aspera* were eaten in the wet season.

Ngulia Sanctuary: A total of 1217 individual plants were measured from 603 stations throughout the sanctuary: 198 stations (590 food plants) in the wet and 405 stations (627 food plants) in the dry season. At least 37 plant species were selected by black rhinos in the wet season and 51 in the dry season. Woody plants formed the bulk of rhino diets in the wet and dry season (wet: 86% woody, 14% herbaceous: dry 92% woody and 8% herbaceous). Three families (Malvaceae, Tiliaceae and Acanthaceae) had at least 4 food plants. The bulk of rhino's diet in wet and dry season came from of *Duosperma kilimandscharica, Sericomopsis pallida, Ochna inermis, Premna holstii, Solanum incanum, Grewia bicolor, Grewia nematopus, Grewia villosa, Acacia tortilis* and *Combretum exalatum* (Table IXa and IX). *Tephrosia villosa, Hibiscus canabinus,* and *Waitheria indica* were important in the dry season.

D. Bites, bite diameter, height and percent browse

Aberdares NP: The mean number of bites per plant was 9.22 in the wet season and 7.65 in the dry season (Wet season: Range = 1 to 136, s.d = 10.94, dry season: Range = 1 to 100, s.d = 9.9). The mean bite diameter was 5.87mm (Range = 1.7mm to 21.5mm, s.d = 2.19mm) in the wet season and 5.89mm in the dry season (Range =2mm to 17mm, s.d = 2.02mm). The biggest bites were taken from *Solanum aculeastrum, Senna septemtrionalis, Senna didymobotrya, Rhamnus prinoides, Sida tenuicarpa, Abutilon longicuspe* and *Croton macrostachyus.* Black rhinos took bites from branches as high as 2.2m and as low as 0.15m during the study period. The mean bite height across plants in the wet season was 1.10m (s.d = 0.46m), and 1.04m (s.d = 0.5) in the dry season.

Nairobi NP: The mean number of bites was 15.75 (Range =1-300, s.d = 23.03) in the wet season and 7.98 (Range = 1-171, s.d = 10.38) in the dry season. The mean bite diameter was 6.7 mm (Range = 1-20, s.d = 2.7mm) in the wet season and 6.7mm (Range = 2-23, s.d = 8.12mm) in the dry season. Some of the big bites were from *Aeschynomene schimperi, Abutilon mauritianum, Phyllanthus fischeri, Rhus natalensis, Carissa edulis, Lantana camara, Olea europaea, Acacia kirkii, Acacia stuhlmannii, Acacia seyal, Gnidia subchordata* and *Dovyalis caffia.* Black rhinos took bites from branches as high as 1.7m and as low as 0.1m during the study period. The mean bite height across plants in the wet season was 1.04m (s.d = 0.43m), and 0.92m (s.d = 0.5) in the dry season.

Ngulia sanctuary: Mean number of bites was 11.25 (Range = 6-160, s.d = 14.79) in the dry season and 12.18 in the wet season (Range = 1-192, s.d = 15.54). The mean bite diameter was 5.67 mm (Range = I-18, s.d = 1.85) in the dry season and 5.39mm (Range = 1-20, s.d = 2.07) in the wet season. Bigger bites were taken from *Acacia tortilis, Grewia bicolor, Grewia villosa, Commiphora madagascariensis, Commiphora Africana, Melia volkensii* and *Catunaregum spinosa.* The mean height for rhino bites was 0.9m (s.d = 0.37m) in the dry season and 0.9m (s.d = 0.43m) in the wet season.

TABLE X: COMMON FOOD PLANTS USED FOR ANOVA

Aberdares NP	Nairobi NP	Ngulia Sanctuary
Abutilon longicuspe	*Acacia gerrardii*	*Acacia tortilis*
Leucas urticifolia	*Acacia kirkii*	*Duosperma kilimandscharica*
Ocimum gratissimum	*Acalypha fruticosum*	*Grewia bicolor*
Rhamnus prinoides	*Aspilia mosambicensis*	*Grewia nematopus*
Senna septemtrionalis	*Carissa edulis*	*Grewia villosa*
Senna rhombifolia	*Lippia kituensis*	*Ochna inermis*
Sida tenuicarpa	*Phyllanthus fischeri*	*Premna holstii*
Solanum aculeastrum[1]	*Rhus natalensis*	*Sericomopsis pallida*
Solanum aculeastrum[2]	*Scutia myrtina*	*Solanum incanum*
Toddalia asiatica	*Solanum incanum*	*Tephrosia villosa*

TABLE XI: ANALYSIS OF VARIANCE TABLE TO TEST THE EFFECT OF PLANT AND SEASON ON BITES, MEAN BITE DIAMETER, HEIGHT AND PERCENT BROWSE

Park	Source	df	Bite		Bite diameter		Height		Percent	
			MSS	F-Ratio	MSS	F-Ratio	MSS	F-Ratio	MSS	F-Ratio
ANP	Plant	9	321.720	5.570***	89.557	30.335***	6.996	49.749***	6687.169	10.860***
	Season	1	451.962	7.825**	0.762	0.258	0.008	0.056	5326.981	8.651**
	Plant*season	9	74.244	1.285	8.651	2.930**	0.043	0.308	757.858	1.296
	Error	851	57.755		2.952		0.141		615.765	
NNP	Plant	9	1041.900	8.799***	180.054	36.868***	2.660	16.218***	13641.206	29.798***
	Season	1	2697.820	23.364***	121.345	24.847***	1.294	7.889***	34215.327	74.741***
	Plant*season	9	345.330	2.991**	26.276	5.380***	0.573	3.495***	4032.049	8.808***
	Error	965	115.468		4.884		0.164		457.788	
NGU	Plant	9	1770.340	7.164***	24.023	10.930***	1.986	24.484***	6381.612	4.649***
	Season	1	188.130	0.761	9.487	4.316*	2.289	28.215***	1324.766	0.965
	Plant*season	9	1067.887	4.403***	13.593	6.184***	0.451	5.554***	1848.035	0.209
	Error	764	247.106		2.198		0.081		72.617	

Codes: *= $p<0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$

ANP = Aberdares NP, NNP =Nairobi NP, NGU = Ngulia Rhino Sanctuary

E. Effect of plant and season on bites, bite diameter, percent utilization and height for common food plants

I performed a two-way analysis of variance to test for the effect of plant and season on mean number of bites, mean bite diameter, percent utilization and height for common food plants (Table X and XI). For this analysis I used plants that were highly preferred by black rhinos and those that had at least 10 eaten individuals during both seasons. Plant had a significant effect on all variables in all parks ($p<0.001$). Black rhinos approached food plants differently.

In Aberdares, season had a significant effect on mean number of bites and percent browse ($p<0.01$), and no effect on mean bite diameter and height. Mean number of bites was higher in the wet season and percent utilization was higher in the dry season. Only mean bite diameter showed a strong plant-season interaction. In Nairobi NP, season had a strong effect on all variables ($p<0.001$) and there was a strong plant-season interaction. There were more and bigger bites in the wet season than in the dry season. Percent utilization was higher in the dry season whereas browse height was lower. In Ngulia, there was a strong effect of season on height ($p<0.001$) and mean bite diameter ($p<0.05$). Black rhinos selected bigger bites and taller twigs in the dry season. There were no significant differences in mean number of bites and percent utilization between seasons. Strong plant-season interaction were observed for all variables except percent utilization.

F. Food preference ranking

In order to rank food preference by black rhinos, I measured percent utilization at a station. For the station level, I counted how many times a plant was eaten upon encounter at a station and the times it was rejected. I used this information to compute percent preference (Table VIIa, VIIb, VIIIa, VIIIb, IXa and IXb) based on a rhino's decision at a station. 100% percent means that the plant was always eaten upon encounter and 0% means that the plant was always rejected. I also came up with a utilization index scale 1 to 5 (See above tables for the categories). A utilization index of 5 means the food plant is highly preferred while 1 is least preferred. Some of the plants with 100% preference were encountered and consumed once because they were rare (density less than 50 plants/ha)

I did not observe dramatic diet changes in Aberdares between the wet and dry season. The highly preferred plants included *Senna septemtrionalis, Crotalaria incana, Solanum aculeastrum, Abutilon longicuspe, Sida tenuicarpa* and *Sida rhombifolia.* Most food plants maintained the same preference ranking in the wet and dry season. The only notable difference was *Hypoestes forskhalii* that was highly preferred in the dry season and *Abutilon longicuspe* that dropped from a utilization index value of 5 in the wet season to 4 in the dry season.

I observed some seasonal shifts in food preferences in Nairobi NP. Among the most preferred food plants were *Abutilon mauritianum, Aeschynomene schimperi, Acacia kirkii Acacia gerrardii, Acalypha fruticosum, Phyllanthus fischeri* and *Gnidia subchordata. Rhus natalensis, Carissa edulis, Olea europaea* and *Phyllanthus fischeri* were highly selected in the wet than the dry season. *Acacia xanthophloea, Acacia stuhlmanii, Gnidia subchordata* and *Aspilia mosambicensis* were highly preferred in the dry season and mostly ignored in the wet season.

TABLE XII: MEAN HABITAT SUITABILITY INDEX

Plot no.	Aberdares	Nairobi	Ngulia
1	2.11	1.00	1.80
2	2.26	4.83	1.77
3	2.31	4.79	1.67
4	2.31	2.76	2.47
5	2.76	4.10	3.61
6	2.13	4.05	4.22
7	2.58	4.09	2.48
8	2.42	4.46	1.66
9	2.67	4.15	2.92
10	2.13	4.80	1.94
11	2.48	5.00	2.29
12	2.16	3.84	2.39
13	2.04	4.21	2.17
14	2.32	4.62	2.69
15	2.37	4.35	2.11
16	2.40	4.11	3.32
17	2.97	3.74	2.19
18	2.00	3.73	1.50
19	2.77	4.85	2.79
20	2.76	4.74	4.02
21	1.82	4.94	2.65
22	2.04	4.89	-
23	1.85	4.87	-
24	3.27	4.84	-
25	2.28	5.00	-
26	2.05	3.03	-
27	-	4.76	-
28	-	4.95	-
29	-	4.81	-
mean	2.356	4.287	2.509
Variance	0.123	0.735	0.582
STDEV	0.350	0.857	0.763

There were dramatic shifts in food preferences between the wet and the dry season in Ngulia. The highly preferred plants included *Duosperma kilimandscharica, Grewia bicolor, Grewia villosa, Hibiscus canabinus, Tephrosia villosa, Ochna inermis, Premna holstii, Sericomopsis pallida Catunaregum spinosia, Indigofera arrecta, Melia volkensii,* and *Acacia tortilis. Acacia tortilis, Grewia villosa, Ochna inermis, Premna holstii* and *Tephrosia villosa* were more preferred in the dry than in the wet season. *Solanum incanum* was more preferred in the wet than in the dry season.

G. Plant utilization versus availability

I compared percent utilization with food plant availabilities using the plant densities in the study area. I log transformed the plant densities and performed a regression analysis. Percent utilization (percent browse per plant) decreased with increasing plant densities in Nairobi ($p<0.05$) and increased with increasing plant densities in Ngulia ($p<0.05$). There was a weak trend in Aberdares, percent utilization generally decreased ($p=0.08$) with increasing plant densities.

H. Habitat suitability index

To determine habitat suitability and quality for black rhinos, I used the utilization index scale of 1 to 5 to compute the mean habitat suitability index of all plots surveyed. A utilization index value of 2.5 was assigned to plants that were eaten but had no actual measurements taken and 0 for those that were not eaten. The mean habitat suitability index was derived by dividing the sum of the utilization indices for each food plant represented in the plot by the total number of plants in the plot (Table XII). The mean habitat suitability index was highest in Nairobi (4.289) followed by Ngulia (2.509) and lowest in Aberdares (2.356). However, the variance was highest in Nairobi (0.582) and lowest in Aberdares (0.123).

DISCUSSION

By following black rhino's feeding tracks, I was able to identify the plants they ate and those they rejected upon actual encounter. I was also able to count the number of bites, measure bite sizes, height and estimate percent utilization at a food plant level. By grouping food patches into stations, I was able to analyze the decisions made by a foraging rhino at a station level when it encounters food patches that differ in browse quantity and quality. Such decisions include what patches to accept. how much to harvest from an accepted patch and which patches to reject upon encounter. This information enabled us to quantify food preferences using the decisions made by a black rhino at a station. Plant densities provided a way of estimating food plant densities and testing how utilization is influenced by background abundance of food. I was able to estimate habitat suitability for black rhino by combining food preferences and plant densities.

A. Plant and feeding surveys:

The species richness recorded in the 10x10m plots closely corresponds with results from ecological monitoring data collected by Kenya Wildlife Service (KWS) from the three study sites (source: KWS unpublished reports). The plant densities recorded from this study differs slightly from other surveys because we used 10x10m plots while

KWS ecological monitoring team uses point-centered quarter (PCQ) method, and also because we restricted our plant sampling to black rhino home ranges.

Black rhino diet was composed of a wide range of plants, those that occur in high densities and those that were very rare. Woody plants contributed more to their diet than herbaceous plants. We recorded more food plants in all the areas covered in this study than previously recorded (Aberdares NP: KWS unpublished reports; Nairobi NP: Muya and Oguge 1999, Waweru 1985; Ngulia: Goddard 1970). This was because we followed black rhino's feeding tracts rather than using random sampling techniques that have been used in the past. Waweru (1985) recorded some grass species in black rhino's diet in Nairobi NP. This finding is contrary to our findings. I found that while rhinos try to browse prostrate herbs that are embedded in grasses they accidentally clip grasses surrounding the herb. I did not include these grasses or any plants that were clipped accidentally by black rhinos.

Aberdares NP: Although black rhino selected 82 and 54 plant species in the wet and dry season respectively, the bulk of its diet was made up of only 12 food plants (*Abutilon longicuspe, Ocimum gratissimum, Sida tenuicarpa, Sida rhombifolia, Solanum aculeastrum ssp. Aculeastrum var. 1, Solanum aculeastrum ssp. Aculeastrum var.2, Senna septemtrionalis, Hypoestes forskahlii, Rhamnus prinoides, Toddalia asiatica, Achyranthes aspera* and *Leucas deflexa*). The proportions of food plants in the diet differed between seasons (Table VIIa and VIIb). Black rhinos included more food patches (individual food plants) in the dry season from the plant species selected and also increased percent utilization. Exceptions to this were *Abutilon longicuspe* and *Solanum aculeastrum ssp. Aculeastrum var.2.* These plants were eaten less in the dry season probably because they dried out and became less nutritious. *Abutilon longicuspe* was at its flowering stage and had fewer leaves in the dry than in the wet season. Surprisingly, very abundant plants like *Vernonia auriculifera* and *Crotalaria agatiflora* were not eaten by black rhino or any other large herbivores in the park.

Three vegetation types are found in the salient, forest characterized by tall trees and little undergrowth that extends to the bamboo zone, bushland characterized by woody shrubs and herbaceous plants and open glades characterized by grassland areas. I found most feeding activity in the bushland habitat and forest edges. The bushland habitat may be preferred because it supports most of the food plants selected by black rhinos. I recorded only five stations in the forest during the entire study period. However, there was a movement of rhinos through the forest floor. I believe these tracks are made by rhinos on their way to salt licks located in the two lodges. More feeding activity was recorded in the forest edge and riverine areas during the dry season. This may be because the plants contained more moisture in these areas than areas that are far from water. Most of the dams and streams dried out in the dry season and we also observed that the distance between feeding stations increased as well in the dry season. This means rhinos walked long distances in the dry season than in the wet season in search of moist food and water. Black rhinos range did not extend beyond the bamboo zone.

Nairobi NP: Although the plants browsed by back rhino in this park occurred at moderate to high densities, their distribution throughout the park was not uniform. Different areas support different plant associations. The open grassland areas support mainly *Acacia drebanolobium, Acacia gerrardii, Acacia seyal, Acacia mellifera, Aspilia* *pluriseta, Achyranthes aspera, Hibiscus flavifolius and Hibiscus aponeurus. Rhus natalensis, Olea europaea, Gnidia subchordata, Ocimum gratissimum, Leucas grandis, Lantana camara, Dovyalis caffia, Lippia kituensis* and *Lippia javanica* occur mainly in the bushland and forested areas. The riverine and swampy areas support *Acacia kirkii Acacia stuhlmanii, Acacia xanthophloea, Phyllanthus fischeri, Acalypha fruticosum, Aspilia mosambicensis, Psiadia punculata, Abutilon mauritianum, Carissa edulis* and *Aeschynomene schimperi.*

Food plants were utilized in differing proportions in the wet and dry season (Table VIIIa and VIIIb). Food availability seemed to play a greater role in this regard. In general, more food patches were utilized in the dry season than in the wet season. *Acacia gerrardii, Acacia kirkii, Acacia seyal, Ocimum gratissimum, Lantana camara, Dovyalis caffia, Lippia kituensi, Phyllanthus fischeri, Acalypha fruticosum, Aspilia mosambicensis, Carissa edulis* and *Dovyalis caffia* were available all year round and that may explain why black rhinos included them in their wet and dry season diets. Some food plants (for example *Rhus natalensis, Olea europaea,* and *Hibiscus flavifolius*) were present all year round but were eaten more in the wet than the dry season. These plants may have been ignored in the dry season because they became more fibrous. *Gnidia subchordata, Acacia stuhlmani,* and *Acacia xanthophloea* were heavily utilized in the dry season although they appeared green all year round. I cannot provide an immediate reason to this observation. *Abutilon mauritianum, Aeschynomene schimperi* and *Achyranthus aspera* were utilized in the wet season because they were absent in the dry season. Only young plants of *Acacia drebanolobium* were eaten by black rhinos. The older plants were rarely eaten because of the presence of galls that harbor ants that protects the plant from herbivory. The hooked spines of *Acacia mellifera* may be deter rhinos from eating much of the plant. Other acacias have straight long spines that do not seem to hinder black rhinos because they heavily browse them throughout the park. Herbaceous plants contributed a great deal to the wet season diet. Most herbs were absent in the dry season forcing black rhinos to depend on woody plants. Some food plants (e.g *Grewia similis, Grewia bicolor, Acacia brevispica, Jasminium abyssinica* and *Teclea simpliciflora*) occurred at low densities but were always eaten when encountered. These are important food plants because they may supply important nutrients to a rhino's diet. *Psiadia punctulata* occurs in high densities but was rarely eaten. This plant maybe unpalatable because the leaves contain a very sticky substance that emits a noxious smell when crushed.

The riverine bushland and forest edge are critical habitats for black rhinos in the Park. These habitats support most of the critical food plants (those that occur in high to moderate densities and are highly utilized), and sustains plant growth throughout the year. In fact, these habitats are critical to black rhino's survival in the dry season. Open grassland areas support herbaceous food plants in the wet season but black rhinos may face competition from the large numbers of grazing ungulates in the park.

Ngulia Sanctuary: Ngulia receives low rainfall during the year (approx 400mm) and experiences long dry spells. This low rainfall coupled with high temperatures is not adequate to support plant growth throughout the year. The vegetation in this area undergoes a dramatic change between seasons. Green vegetation disappears completely in most areas of the sanctuary in the dry season and rhinos concentrate their feeding in the western and northern area of the sanctuary where the vegetation remains green. The three water holes supply water throughout the dry season. During the wet season, a green flush of palatable herbs and shrubs appears and black rhinos redistribute themselves to all parts of the sanctuary. Water is also available throughout the sanctuary.

The plant densities reported in this study differ significantly between seasons. This is because I restricted our plant surveys to black rhino homeranges. I sampled more plots from a smaller area (western and northern parts of the sanctuary) in the dry season. Rhinos were spread out during the wet season and the plant surveys covered most parts of the sanctuary. Some woody plants maybe under-represented or entirely missed in the dry season because we were unable to identify them without leaves. I did not encounter most herbs during this study because I collected our data at the beginning of the wet season and the vegetation had not had a chance to recover from the prolonged drought of 1998.

The seasonal shifts in browse utilization can be largely attributed to lack of forage in the dry season. Classical optimal diet theory emphasizes expansion in diet breadth in response to decreased availability of favored food types (Stephens and Krebs 1986). In accordance to this prediction, black rhinos increased their range of palatable plant species in the dry season (Table IXa and IXb). They included the least palatable dry woody plant parts. Besides diet expansion, they accepted higher proportions of preferred food plants in the dry season as well as the ones less preferred in the wet season (e.g *Premna resinosa, Bauhinia taitensis,* and *Boscia coriaceae*). The key food plants in the dry season included *Duosperma kilimandscharica, Tephrosia villosa, Waitheria indica, Hibiscus canabinus, Premna holstii. Abutilon fruticosa, Grewia bicolor, Grewia villosa, Grewia nematopus, Acacia Tortilis* and *Ochna inermis.* Most of these plants were available in the wet season as well except for *Waitheria indica, Hibiscus canabinus* and *Abutilon fruticosa* that were virtually absent in the wet season. Notable additions to rhino's wet season diet were *Commiphora Africana* and *Commiphora madagascariensis.* These plants may have been too dry to be included in the dry season's diet.

Black rhino food plants were very abundant and evenly distributed throughout the sanctuary, unlike in Aberdares and Nairobi NP. The only limitation was rainfall that affects plant growth in the dry season. This may affect the health and body weights of individual rhinos and the overall performance of the population in the dry season. I did not monitor body changes during this study. Shortage of food in the dry season was aggravated by elephant influx into the sanctuary from surrounding areas of the park in the dry season. There was a great deal of overlap between Elephant and rhino diets in this area.

B. Bites, mean bite diameter, height and percent browse

In general, black rhinos took more bites from fewer food patches in the wet season. However, the opposite was true in the dry season. Rhinos took fewer bites from more food patches and percent utilization increased in the dry season. Food patches offered less food in the dry season than in the wet season. In an effort to cope with decreasing amounts of food, rhinos needed to harvest food from more patches. That meant that rhinos had to visit more patches in the dry season than in the wet season. In general, mean bite diameter and height did not change with season for most food plants.

A close look at the effect of plant and season on common food plants revealed significant differences among plant species. Browsing intensity may be affected by bite size and chewing effort (Spalinger et al. 1988), the height at which the animal feeds, physical features of the plant species such as spines (Cooper and Owen-Smith 1986) and to some extent the amount of fiber in the plant. Black rhinos approached plant species and food patches differently in each of our study sites. Food plants selected by rhinos differed in size (herbs, trees and shrubs), physical characteristics (levels of branching, presence of spines and fiber content) and amount of food resources available. These factors may have played a role in diet choice by rhinos. Rhinos tend to harvest more food and select bigger bites from large food patches. However, there were instances when fewer bites or smaller bite sizes or both were selected from large food patches.

Food patches contained more food in the wet than the dry season. Smaller bite diameters were selected in the dry season because most plants became dry and very woody. Bigger bite diameters were selected from plant species with soft stems like *Senna septemtrionalis, Sida rhombifolia, Duosperma kilimandscharica, Premna holstii,* and *Tephrosia villosa.* In Nairobi NP, plant height was reduced as a result of rhino browsing in the dry season. The effect was greater in short shrubs like *Acalypha fruticosa, Phyllanthus fischeri, Aspilia mosambicensis* and young *Acacia* plants. In Ngulia sanctuary, percent utilization was higher in the wet than dry season.

C. Food preference ranking

A preferred food plant is one which is utilized proportionately more frequently by black rhinos than its abundance in the available environment. As with other black rhino populations in Africa (Oloo et al. 1994, Goddard 1969, 1970, Loutit et al. 1982, Joubert 1974), it is clear that black rhinos have definite preference for certain food plants, irrespective of size and abundance. Some highly preferred food plants are small and occur in low densities and can only be considered choice plants. Such plants include *Crotalaria incana, Indigofera arrecta, Jasminium abyssinica, Grewia similis, Rhamnus staddo, Melia volkensii* and *Cassia abbreviate.* Seasonal changes in food preferences can be attributed to changes in palatability, plant chemistry and availability.

D. Plant utilization versus availability

The marginal value of food decreases as food becomes more abundant. Marginal value of food should be higher in the dry season when food abundance decreases and in more arid areas where food is scarcer. This was the case in all areas in the dry season when percent utilization increased. In Aberdares and Nairobi NP, percent utilization decreased with increasing plant densities. Percent utilization increased as plant densities increased in Ngulia. Black rhino harvested more food from food patches as they became available in Ngulia. The marginal value of food was likely higher in Ngulia during the dry season than in Aberdares and Nairobi NP.

F. Habitat suitability index

To determine a suitable habitat for black rhino, I considered the mean habitat suitability index, variance and number and densities of preferred food plants. The variance explains the extent to which a rhino can be selective at the plot or habitat level. The variance also gives an indication of how variable habitats were and their distribution in the park. Ngulia sanctuary appears to be the most suitable habitat for the black rhino followed by Nairobi, and Aberdares the least suitable. This is further demonstrated by the population growth rate of black rhinos in the three areas. In Aberdares, black rhino numbers increased from an estimated population of 40 in 1995 to approximately 45 in 2000 (r=0.024). During the same period, an increase in black rhino population was recorded in Nairobi where numbers rose from 52 to 62 (r=0.2384), and in Ngulia from an estimated 35 in 1995 to 48 in 2000 (r=0.274).

Nairobi has a higher mean habitat suitability index value and a high variance. But food plants were clumped along riverine areas and forest edges that are located far from each other. Rhinos must walk across open grassland areas with little or no suitable food before they encounter suitable food plants. Food plants in Aberdares NP grow in close association with plants that are not eaten by black rhinos. The relatively high numbers of plants that were not selected by black rhinos lowered the mean habitat suitability index value in Aberdares NP.

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CHAPTER IV

EVALUATING MEAN BITES AND BITE DIAMETERS OF BLACK RHINOCEROS *Diceros bicornis michaeli L.*

INTRODUCTION

Herbivores make foraging decisions daily that affect their fitness and the productivity of the plants they eat. For large mammalian herbivores, these decisions occur at various scales: landscape, habitat and food patch scales. At a landscape scale, a forager must select habitats that contain a suite of suitable food patches. At the habitat scale, foragers must decide what food patches to accept and how much food to harvest from selected food patches depending on the prevailing conditions. For browsing herbivores, these decisions include selecting bite sizes and number of bites to harvest from selected food patches. The decisions made by herbivores at the level of a bite affect their nutrient intake and thus their fitness (Spalinger and Hobbs 1992, Shipley et al. 1999).

Ecologists view decisions made by animals while foraging in terms of optimizing some currency that relates to their fitness, relative to various mechanical and physiological constraints (MacArthur and Pianka 1966, Stephens and Krebs 1986). The currency can be a component of the food (for example food quality or quantity) that is valuable to the animal and can be measured directly or indirectly. The animal should be able to recognize the valued forage component and behave in such a way to maximize its intake or minimize loss of currency (Hanley 1997). Rates of dry matter intake or digestible energy intake have been considered the likely alternative currencies by which herbivores operate (Hanley 1984, Belovsky 1986, Shipley and Spalinger 1995).

In nature there exists a variety of habitats each containing a mosaic of food patches within which food items vary in density, size and profitability. The marginal-value theorem (MVT; Charnov 1976) has been applied to understand movements of foragers among food patches and the amount of time or energy devoted to harvest food from accepted patches. MVT predicts that long-term intake rate is maximized upon leaving a patch when the marginal rate of gain in the patch is equals the average rate from all available patches in the habitat. This theory assumes that a forager experiences diminishing returns while harvesting food from a patch, and moving to a new patch is costly in terms of time and energy (Laca et al. 1994). Therefore as distance between patches increases, foragers would be expected to spend more time in each patch.

The models proposed by MacAthur and Pianka (1966) and Charnov (MVT; 1976) restrict energy-maximizing activity to foraging alone; that is, they do not consider other factors which influence fitness. However, numerous empirical studies have shown that the foraging behavior of an animal in a patch is influenced by other aspects of fitness. Most notably, the behavior of an animal in a patch may be influenced by the cost of predation (Kotler 1984, Brown 1988, Holbrook and Schmitt 1988, Kotler et al. 1991, Brown 1992), the metabolic costs expended during foraging, and the cost of not performing other fitness-enhancing activities such as mating (missed opportunity costs, sensu Brown 1988). Brown (1988, 1992) showed that a forager that is behaving optimally should exploit a food patch so long as its energy gain (H) from the patch exceeds its metabolic (M), predation (P), and missed opportunity (MOC) costs of foraging. A forager that is behaving optimally should leave the patch when these costs exactly balance the benefits (Harvest rate (H) = M + P + MOC.). Patches with equal costs of foraging should be foraged to the same quitting harvest rate (Valone and Brown 1989).

Factors affecting diet choice differ from one habitat to another, and between different food patches (Senft et al. 1987). Most work on diet choice has focused on diet choice among different food types and patches. Few studies have examined the characteristics of bites selected by herbivores (Shipley and Spalinger 1992, 1995, Shipley et al. 1999). Bite sizes selected by large mammalian herbivores is influenced by the morphology of the animal's mouth and its foraging behavior (Pastor et al. 1999) and the morphological characteristics of the plants they eat (Cooper and Owen-Smith 1986, Spalinger et al. 1988). Determining the size of bites selected by herbivores depends on understanding the relative value of potential bites taken from a continuum of potential bite sizes available on a particular food plant. The relative value of a particular bite depends on the ratio of the nutritional value and the time it takes to extract the nutrients from the bite (Belovsky 1978, Owen-Smith 1993). A browsing herbivore can increase its rate of dry matter intake by selecting bigger bites because big bites require fewer interruptions in chewing to harvest new bites (Spalinger and Hobbs 1992, Shipley and Spalinger 1992, Gross et al. 1993). While big bites offer more food, they usually encompass more fibrous parts of the plant which in turn reduce the digestibility of the ingested food (Vivas et al. 1991) and hence the amount of energy gained (Spalinger et al. 1986, Robbins et al 1987). Therefore a trade-off exists between food quality and food intake; selecting small highly nutritious bites reduce the rate at which food is harvested and big bites reduce the rate at which food can be digested. Shipley and Spalinger (1995) suggest that a bite itself is the result of an optimization process.

As part of a larger study on applying foraging theory to diet choice and habitat selection of black rhinoceros, I sought to evaluate the significance of bites and bite diameters selected by black rhinoceros. Previous studies have shown that the black rhinoceros is predominantly a browser (Goddard 1968, 1970, Jourbert and Eloff 1971, Loutit et al. 1987, Oloo et al. 1994). It feeds mainly on woody plants, some forbs and herbaceous plants. I applied patch use model to explain the patch use behavior of black rhinos. Individual trees and shrubs formed food patches (Astrom et al. 1990). The intensity of browse depicted by bite diameters and number of bites from a patch served as an index of food patch utilization. Each patch should be foraged until the food density has decreased to the average rate of return from all available patches. The density of food remaining in a depletable food patch after a foraging activity, described as the giving-up density (GUD, sensu Brown 1988), indicates the forager's assessment of that patch with respect to patch quality and associated costs of foraging. An efficient forager leaves a low GUD. In this study, the browsing intensity (bite diameters and number of bites) served as a measure of GUD. High browse intensity (bigger bite diameters and more bites per patch) indicates a low GUD.

I am going to compare the mean number of bites, percent browse and mean bite diameters for selected black rhino food plants across different habitats and seasons. Specifically, I will examine the effect of plant species, season (wet and dry) and park on bites, percent browse and mean bite diameters. I will also compare how mean bite diameters vary with plant size and abundance. The mean number of bites and bite diameter was used to estimate the amount of food harvested from patches and the GUD.

Mean bite diameter also served as an indicator of food utilization versus availability. This was done by comparing the potential or available twig diameter on all plant species eaten with the actual mean bite diameter selected by rhinos.

METHODS

The data used in this study is part of a larger study that we conducted in 1998 and 1999 in three black rhino conservation areas in Kenya. These are Aberdares National Park (NP), Nairobi NP, and Ngulia Rhino Sanctuary in Tsavo West NP. See Chapter III for description of study sites and data collection methods.

A. Evaluation of mean number of bites and mean bite diameters

For this study, I selected a total of 45 food plants; 15 from each study area (Refer to Table XIII for food plant list and summary of data collected from each food plant). These are food plants that had at least 15 measured values (N=15), that is, rhinos encountered and ate them on at least 15 occasions. The measurements obtained from the selected food plants were, number of bites per individual plant, percent browse, bite diameter of at least 5 twigs per plant and densities from 10 x10m plots.

Plant densities were used to estimate background food abundance in the parks, and to compare how bites and mean bite diameter vary with food abundance. I measured the basal diameter for some food plants in Ngulia Rhino Sanctuary. This provided a relative measure of plant sizes and was used to determine the relationship between mean bite diameter and plant size.

B. Food plant availabilities versus utilization

The mean bite diameter was used as an indication of how black rhinos utilized various food plants given their availabilities. To do this, I compared the potential or available twig diameter on a plant species basis with the actual mean bite diameter selected by black rhinos. All the food plants identified during the entire study period were used. This enabled us to determine the critical food plants in the study area. Plants were grouped into three categories depending on their potential or available twig diameters and the actual mean bite diameters. I chose a mean bite diameter of 5.5mm (the median value for mean bite diameter) to be the dividing line between small and large bite diameter. The first category were food plants with small (<5.5mm) actual mean bite diameter due to their small twig size. These plants, high quality at low quantity, may be valuable to rhinos but do not offer much offtake due to their small stature. The second category were food plants with large (>5.5mm) potential twig diameter and small actual mean bite diameter. These plants, high quantity at low quality, may not be particularly valuable to black rhinos and may be fed on less in the presence of preferred plants. The third category were food plants that have a large (>5.5mm) potential twig diameter and large actual mean bite diameter. These are high quality-high quantity plants and are critical because they are preferred by black rhinos and offer large amounts of browse material. See Table XV for categories.

TABLE XIII: LIST OF SELECTED FOOD PLANTS ALONG WITH THEIR MEAN NUMBER OF BITES, MEAN BITE DIAMETER AND DENSITY

Plant species	WS bites	DS bites	WS diam	DS diam	Density	Park
Abutilon longicuspe (ABLO)	8.8	6.64	6.26	5.74	310	ANP
Erythrococca bongensis (ERBO)	27.3	5.17	3.65	3.93	180	ANP
Hyoestes forskahlii (HYFO)	3	32.82	4.25	4.16	1270	ANP
Leucas urticifolia (LEUR)	13.6	8.32	4.64	4.4	40	ANP
Ocimum gratissimum (OCGR)	12	7.8	1.19	5.35	610	ANP
Pentas lanceolata (PELA)	10	4.25	4.35	4.76	350	ANP
Rhamnus prinoides (RHPR)	4.5	6.05	7.92	6.98	70	ANP
Senna didymobotrya (SEDY)	9.2	9.25	7.79	8.83	100	ANP
Senna septemtrionalis (SESE)	13.5	9.57	9.14	10.26	10	ANP
Sida rhombifolia (SIRH)	5.9	4.73	4.74	7.53	430	ANP
Sida tenuicarpa (SITE)	9	5.83	5.64	5.55	500	ANP
Solanum aculeastrum[1] (SOAC)	5.6	6.57	7.53	6.76	60	ANP
Solanum aculeastrum[2] (SOSE)	8.1	7.96	5.55	5.65	70	ANP
Solanum incanum (SOIN)	4.1	4.14	6.77	6.48	0	ANP
Toddalia asiatica (TOAS)	7.3	3.85	5.01	6.4	160	ANP
Acacia tortilis (ACTO)	3.75	12.23	5.58	7.78	10	NGU
Barleria teitensis (BATE)	4.63	4.43	3.6	5.57	238	NGU
Catunaregum spinosa (CASP)	7.5	19.14	5.51	6.86	0	NGU
Combretum exalatum (COEX)	7	6.4	4.11	4.2	43	NGU
Duosperma kilimandscharica (DUKI)	12.31	21.82	4.17	5.08	57	NGU
Grewia bicolor (GRBI)	12.58	10.94	6.86	5.79	133	NGU
Grewia nematopus (GRNE)	4.35	7.68	5.9	5.62	119	NGU
Grewia villosa (GRVI)	5.63	9.82	6.33	5.27	214	NGU
Melia volkensii (MEVO)	6.13	9.33	7.86	7	0	NGU
Ochna inermis (OCIN)	30.05	13.12	5.31	4.81	57	NGU
Premna holstii (PRHO)	12.05	7.57	5.41	5.71	195	NGU
Premna resinosa (PRRE)	8	18.85	4.41	6.62	33	NGU
Sericomopsis pallida (SEPA)	12.95	26	4.81	5.2	186	NGU
Solanum incanum (SOIN)	4.86	5.08	4.47	6.17	1228	NGU
Tephrosia villosa (TEVI)	8	10.25	4.92	5.77	176	NGU
Acacia gerrardii (ACGE)	18.38	6.44	6.2	8.19	10	NNP
Acacia kirkii (ACKI)	18.38	7.27	7.5	8.59	34	NNP
Acalypha fruticosum (ACFR)	18.38	13	4.67	4.86	252	NNP
Achyranthes aspera (ACAS)	18.69	7.28	6.02	6.16	59	NNP
Aspilia mosambicensis (ASMO)	16.35	6.74	6.35	6.82	52	NNP
Carissa edulis (CAED)	5.37	7.87	8.44	6.65	45	NNP
Indigofera arrecta (INAR)	17.67	5.12	5.67	5.16	10	NNP
Lantana camara (LACA)	33.67	8.46	8.67	6.65	38	NNP
Lippia kituensis (LIKI)	18.85	8.98	8.25	5.4	28	NNP
Maytenus heterophylla (MASE)	1.9	6.1	6.8	6.52	7	NNP
Ocimum gratissimum (OCGR)	19.41	3.2	6.92	5.56	93	NNP
Phyllanthus fischeri (PHFI)	19.86	9.5	7.69	5.46	186	NNP
Rhus natalensis (RHNA)	15.42	4.65	7.86	6.6	69	NNP
Scutia myrtina (SCMY)	6.08	4.87	7.12	5.61	41	NNP
Solanum incanum (SOIN)	3.3	2.74	6.67	6.14	127	NNP

WS bites=Wet season mean number of bites, DS bites=Dry season mean number of bites, WS diam=Wet season mean bite diameter, DS diam=Dry season mean bite diameter

ANP=Aberdares National Park, NGU=Ngulia Rhino Sanctuary, NNP= Nairobi NP

C. Food off-take

To estimate the amount of food harvested from food patches, I used data from 5 plant species from each of the study sites. I collected a total of 10 sprigs from 5 individual plants of the same species (2 sprigs from each food plant) that showed signs of browsing by black rhinos. Sprigs were cut off at the biggest bite diameter selected from the particular plant species by black rhinos. These sprigs were then divided into 4 equal segments. The diameter of each segment was measured (in mm). The samples were dried in a 60°C oven for 24 hours. Leaves and stems from each segment were separated and the weight recorded in grams. These data, combined with mean number of bites, was used to estimate the amount of food harvested from the selected plant species.

RESULTS

A. Effect of plant species, season and park on mean number of bites, percent browse and mean bite diameter

I performed a two-way analysis of variance to determine the effect of plant species, season and park on mean number of bites, percent browse and mean bite diameter. Plant, season and park were the independent variable and number of bites, percent browse and mean bite diameter were the dependent variables (Table XIVa and XIVb).

Plant had a significant effect on mean bites and mean bite diameter in all parks ($p<0.001$). Black rhinos approached food plants differently with respect to bites and mean bite sizes in the wet and dry season (Figure 5a, 5b, 6a, 6b, 7a and 7b). This translates into different GUDs for all food plants. In Aberdares, Season had a significant effect on mean number of bites and percent browse ($p<0.05$). More bites were selected in the wet season than in the dry season but percent utilization was higher in the dry season. This means that for most plants the GUDs were lower in the dry season than in the wet season. Season had no significant effect on mean bite diameters in Aberdares. There was a strong plant-season interaction in Aberdares for bites and mean bite diameter ($p<0.01$).

In Nairobi, season had a significant effect on all variables ($p<0.001$). Black rhinos selected more and bigger bite sizes in the wet season than in the dry season. Percent utilization was higher in the dry season and there was also a strong plant-season interaction ($p<0.001$). Although the mean number of bites and bite diameters were higher in the wet season, black rhinos harvested more food (high percent browse) in the dry season. Thus the GUD was lower in the dry season than in the wet season.

Black rhinos behaved somewhat differently in Ngulia Rhino Sanctuary. They selected bigger bite diameters in the dry season than in the wet season ($p<0.001$). The mean number of bites and percent utilization did not differ significantly between seasons. Although this result is not significant, rhinos cropped more and bigger bites in the dry season thus realizing lower GUDs in the dry season than in the wet season. Strong plant-season interaction was observed in all variables except percent utilization.

Park had a significant effect on mean number of bites, percent browse and mean bite diameter ($p<0.001$). Overall, Nairobi NP had the highest mean number of bites and mean bite diameter in the wet season whereas Ngulia Rhino sanctuary had the highest in the dry season. Aberdares NP had the lowest mean number of bites for both season and

TABLE XIVA: ANALYSIS OF VARIANCE: EFFECT OF PLANT SPECIES AND SEASON ON BITES, BITE DIAMETER AND PERCENT BROWSE

Park	Source	d.f.	Bite		Bite diameter		Percent	
			MSS	F-Ratio	MSS	F-Ratio	MSS	F-Ratio
ANP	Plant	14	398.073	4.777***	74.369	28.156***	5153.247	6.499***
	Season	1	312.296	3.748	4.980	1.885	6046.752	7.626***
	Plant*season	14	204.006	2.448**	5.544	2.099**	738.389	0931
	Error	911	83.329		2.641		792.886	
NNP	Plant	14	945.844	6.839***	122.699	25.840***	9040.956	20.139***
	Season	1	6743.379	48.762***	118.063	24.864***	48455.681	107.935***
	Plant*season	14	5.3.035	3.637***	19.556	19.556***	3600.874	8.021***
	Error	1125	138.293		4.748		448.935	
NGU	Plant	14	1207.835	4.961***	22.144	9.949***	4237.304	3.199***
	Season	1	547.340	2.248	12.971	5.828*	2084.537	1.574
	Plant*season	14	729.879	2.998***	10.577	4.752***	1324.700	1.000
	Error	818	243.478		2.226		1324.700	

Codes: *= $p<0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$

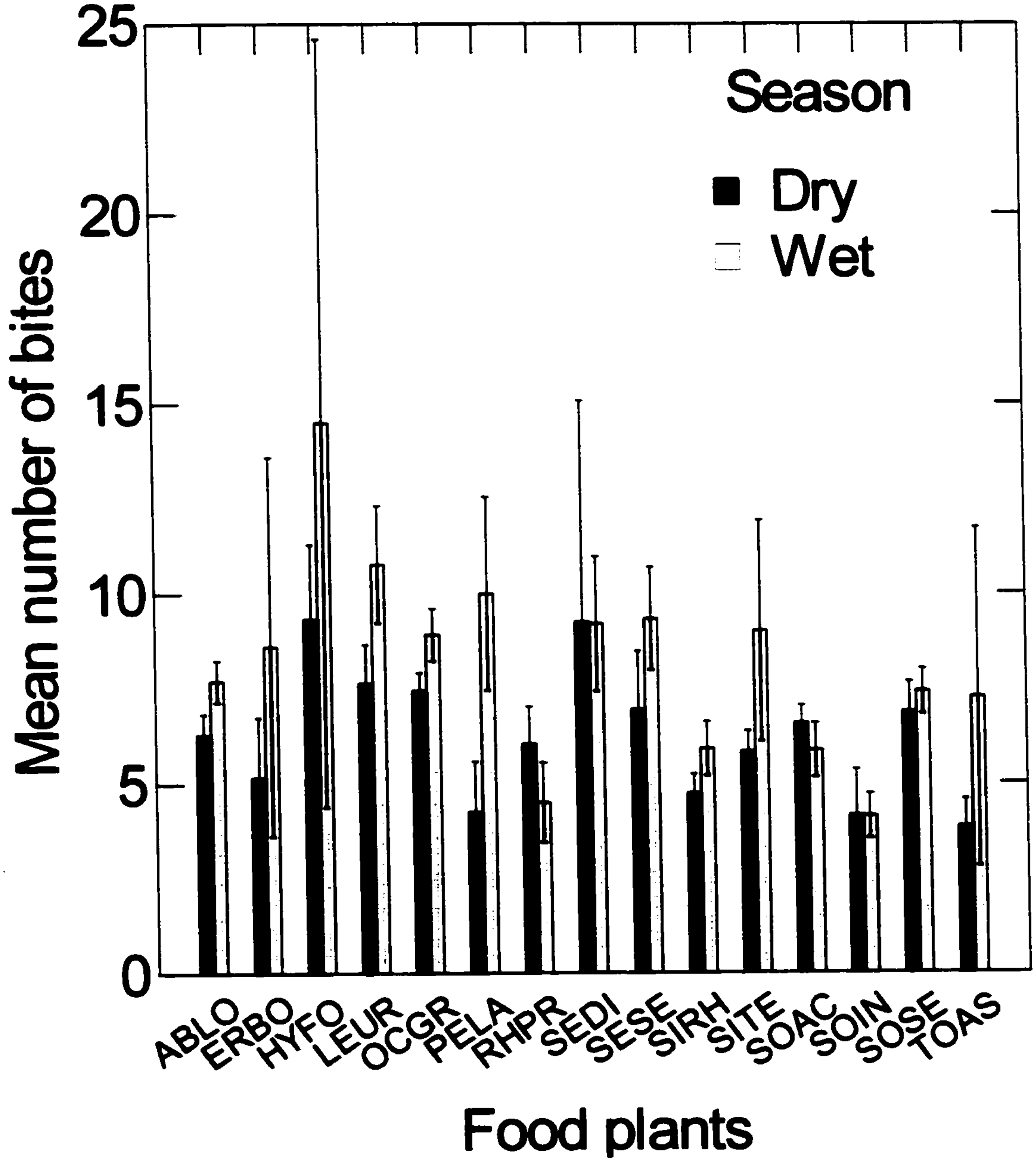
ANP = Aberdares NP, NNP =Nairobi NP, NGU = Ngulia Rhino Sanctuary

TABLE XIVB: EFFECT OF PARKS ON BITES, BITE DIAMETER AND PERCENT BROWSE

Source	d.f.	Bites		Bite Diameter		Percent	
		MSS	F-ratio	MSS	F-ratio	MSS	F-ratio
Park	2	3913.589	17.210***	575.275	25.406***	18589.741	16.478***
Error	4554	227.395		22.643		1128.131	

Codes: *= $p<0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$

Figure 5a: Wet versus dry season mean number of bites for food plants that were eaten at least 15 times upon encounter by black rhinos in Aberdares NP. Plant had a significant effect on mean number of bites ($p<0.001$). More bites were selected in the wet season ($p<0.05$) and there was a strong plant-season interaction ($p<0.01$).



25
20
15
10
5
0
Mean number of bites
Season
Dry
Wet
ABLO
ERBO
HYFO
LEUR
OCGR
PELA
RHPR
SEDI
SESE
SIRH
SITE
SOAC
SOIN
SOSE
TOAS
Food plants

Figure 5b: Wet versus dry season mean bite diameter for food plants that were eaten at least 15 times upon encounter by black rhinos in Aberdares NP. Plant had a significant effect on mean bite diameter ($p<0.001$). Season had no effect on mean bite diameter ($p>0.05$) and there was a strong plant-season interaction ($p<0.01$).

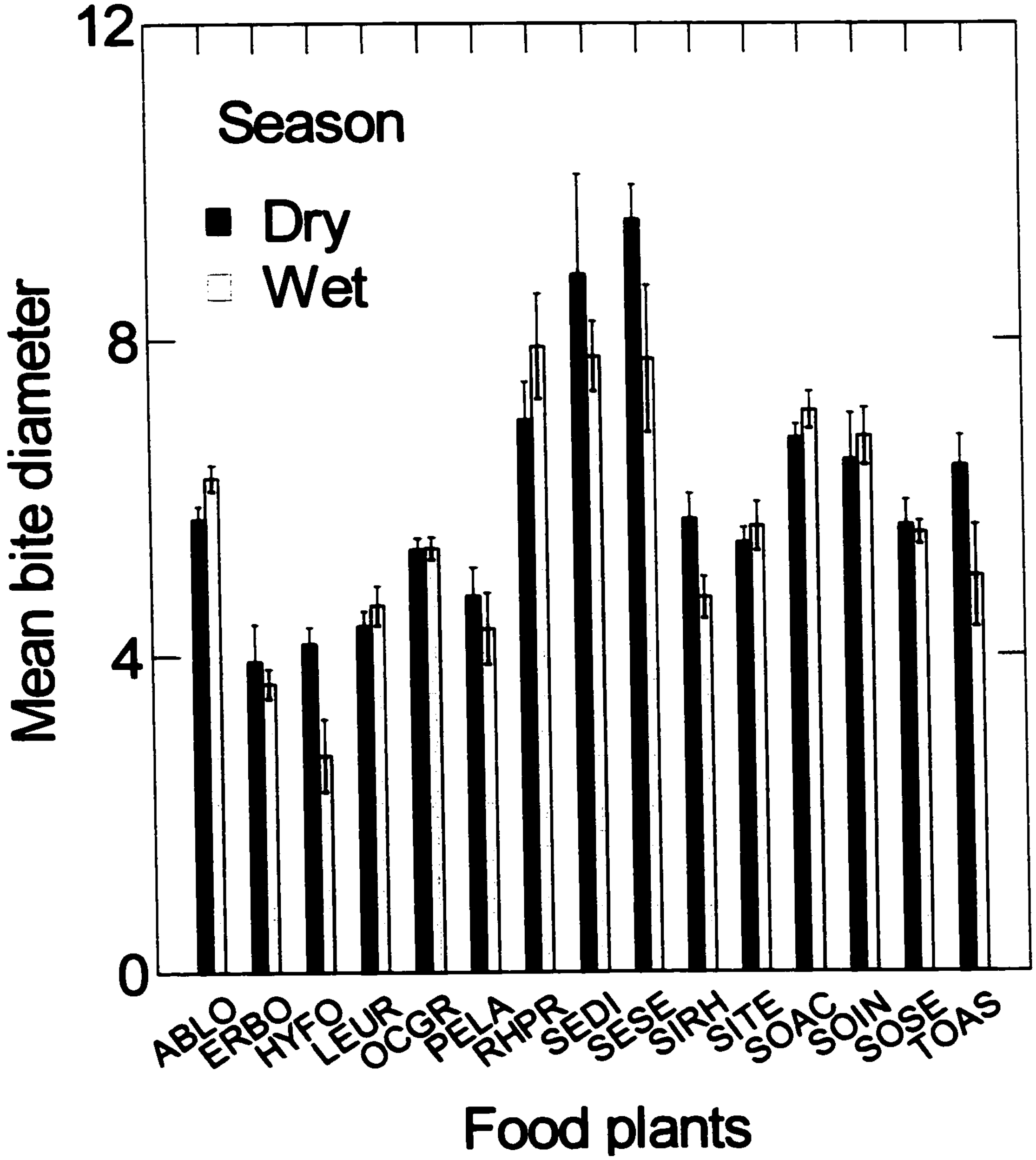

12
8
4
0
Season
Dry
Wet
Mean bite diameter
ABLO
ERBO
HYFO
LEUR
OCGR
PELA
RHPR
SEDI
SESE
SIRH
SITE
SOAC
SOIN
SOSE
TOAS
Food plants

Figure 6a: Wet versus dry season mean number of bites for food plants that were eaten at least 15 times upon encounter by black rhinos in Nairobi NP. Plant had a significant effect ($p<0.001$) on mean number of bites. More bites were selected in the wet season ($p<0.001$). And there was a significant plant-season interaction ($p<0.001$).

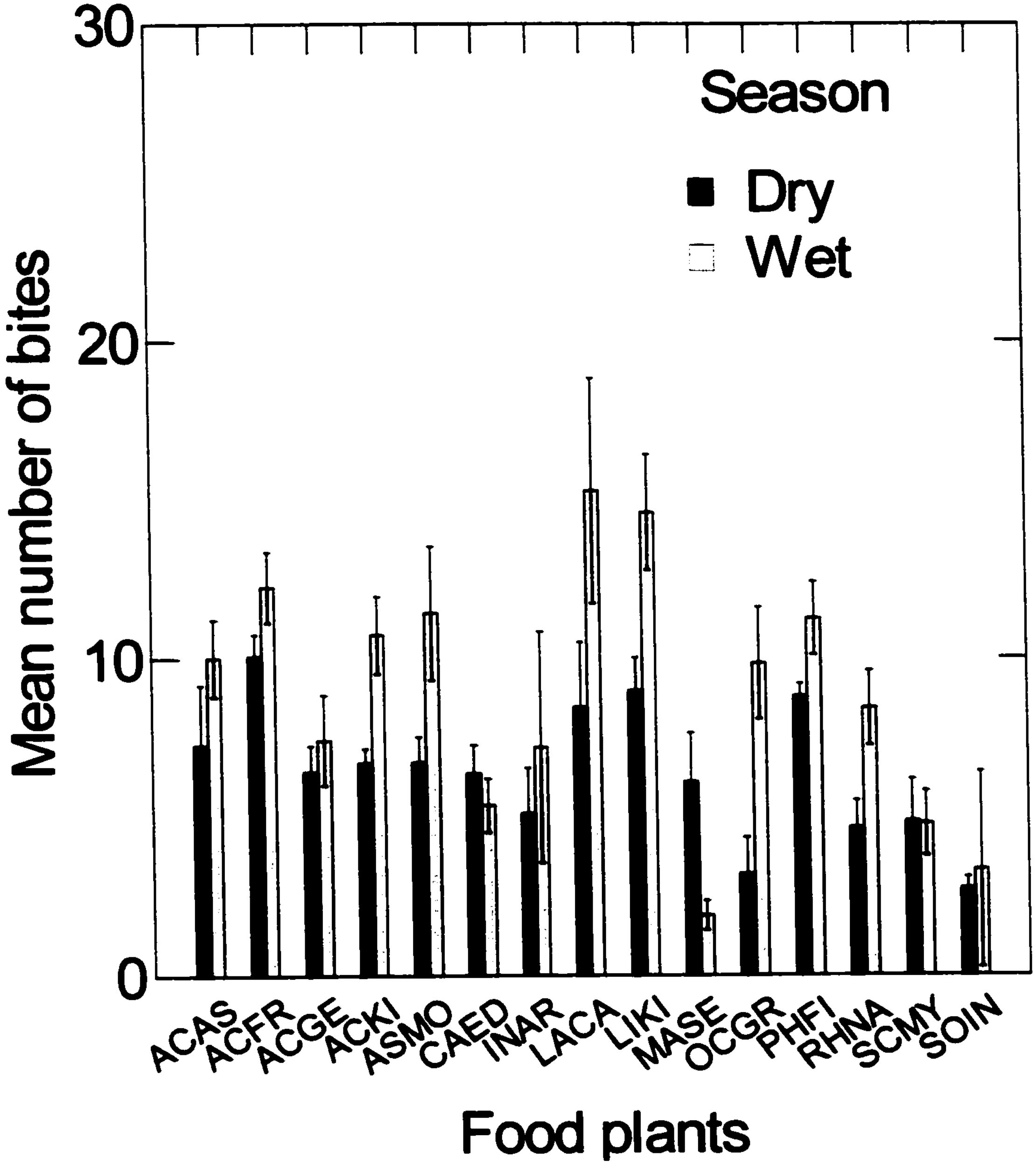
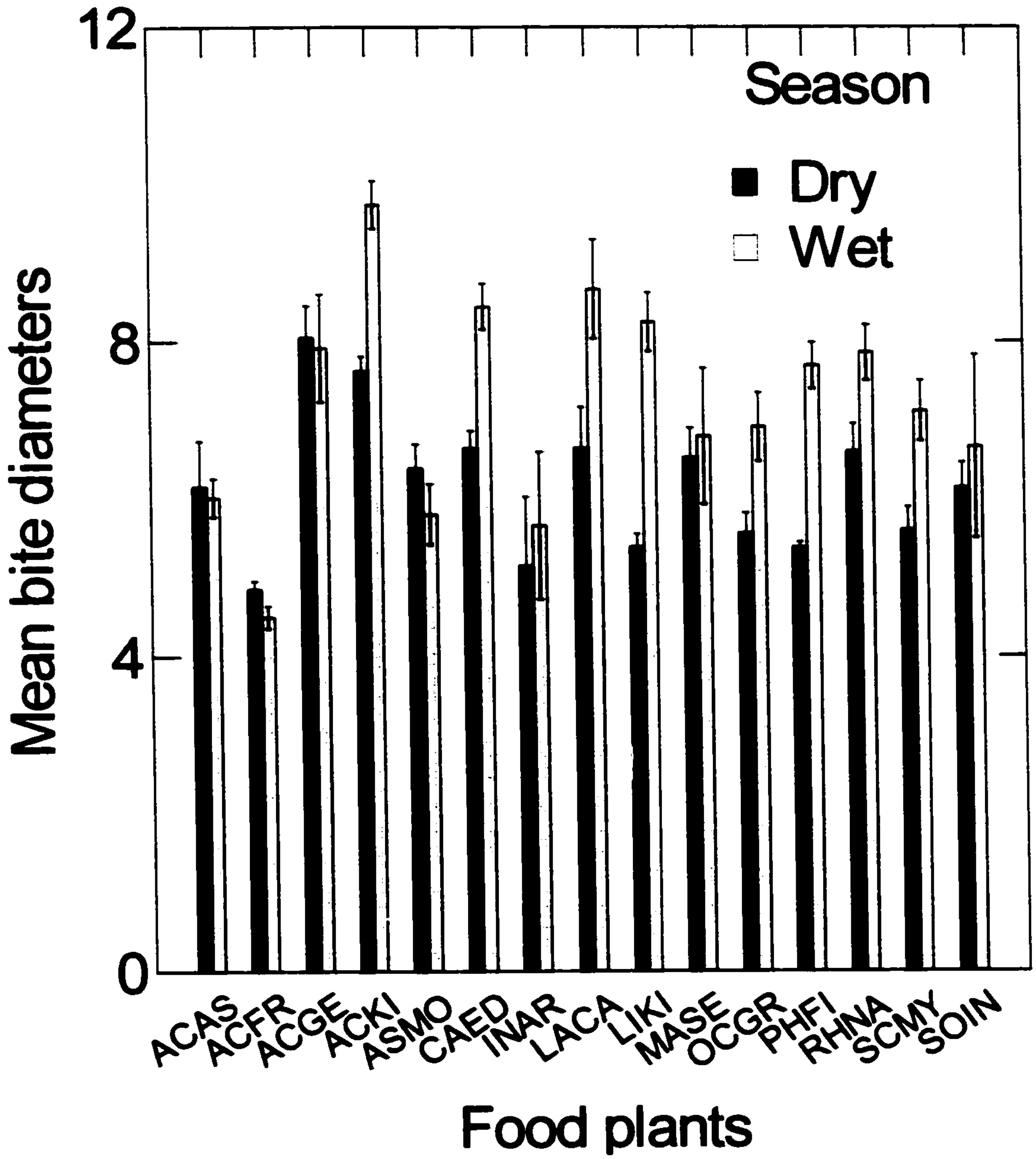

30
20
10
0
Mean number of bites
Season
Dry
Wet
ACAS
ACFR
ACGE
ACKI
ASMO
CAED
INAR
LACA
LIKI
MASE
OCGR
PHFI
RHNA
SCMY
SOIN
Food plants

Figure 6b: Wet versus dry season mean bite diameter for food plants that were eaten at least 15 times upon encounter by black rhinos in Nairobi NP. Plant had a significant effect on mean bite diameter ($p<0.001$). Bigger bites were selected in the wet season ($p<0.001$) and there was a significant plant-season interaction ($p<0.001$).



12
8
4
0
Mean bite diameters
Season
Dry
Wet
ACAS
ACFR
ACGE
ACKI
ASMO
CAED
INAR
LACA
LIKI
MASE
OCGR
PHFI
RHNA
SCMY
SOIN
Food plants

Figure 7a: Wet versus dry season mean number of bites for food plants that were eaten at least 15 times upon encounter by black rhinos in Ngulia rhino sanctuary. Plants responded differently (0.001) during both seasons. Mean number of bites did not differ between seasons ($p>0.05$) but there was a strong plant-season interaction ($p<0.001$).

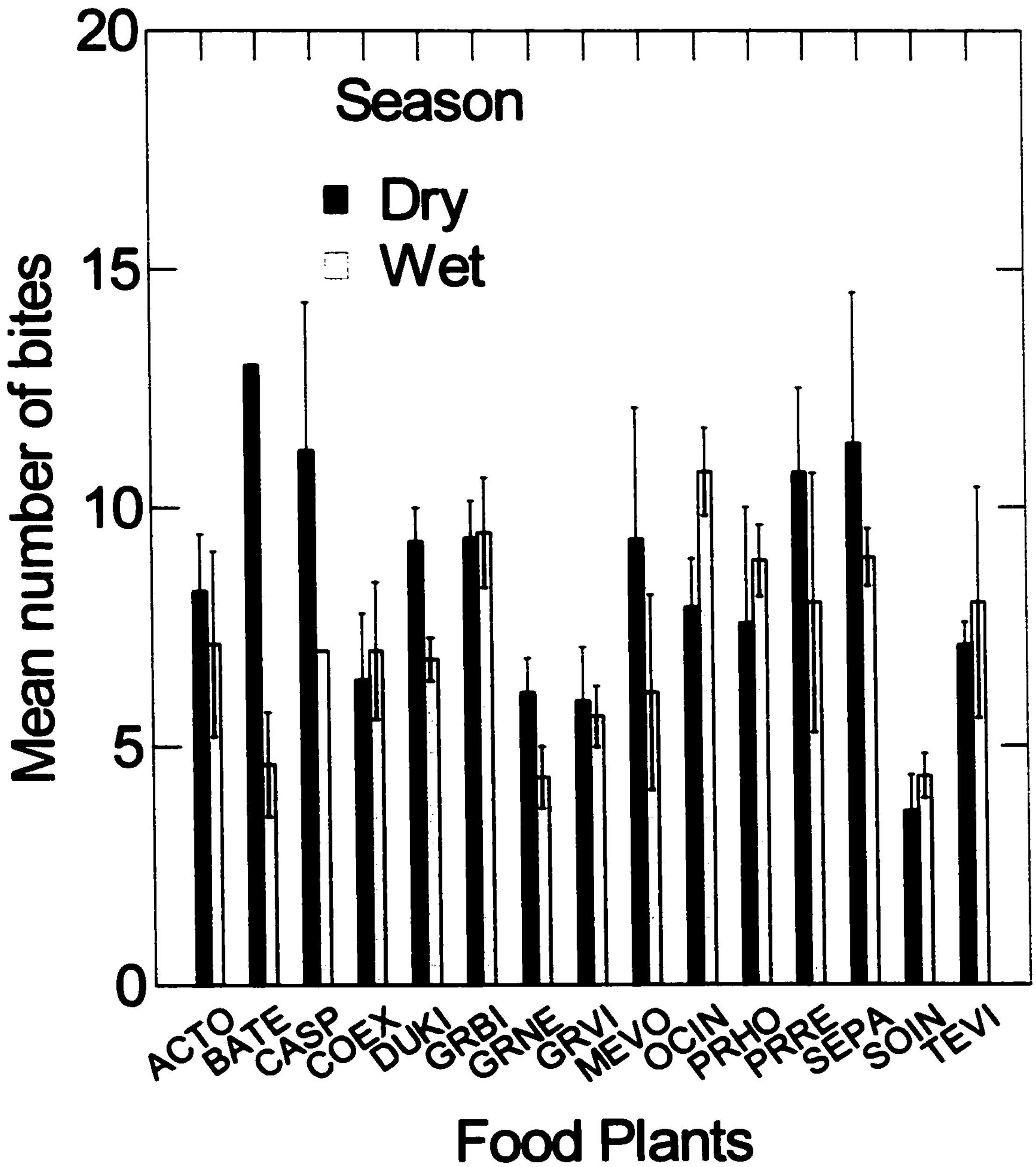
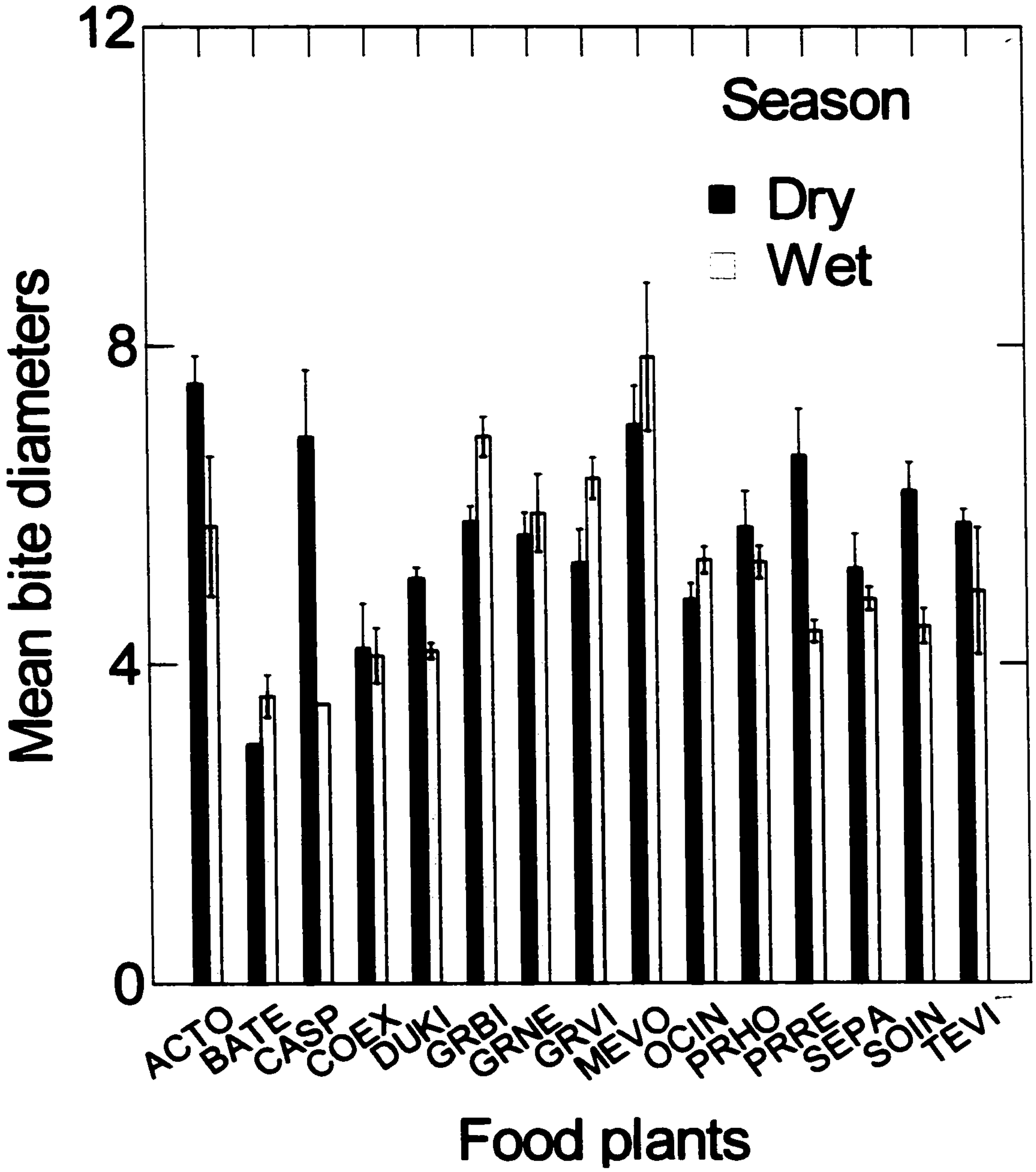

Season
Dry
Wet
Mean number of bites
0
5
10
15
20
ACTO
BATE
CASP
COEX
DUKI
GRBI
GRNE
GRVI
MEVO
OCIN
PRHO
PRRE
SEPA
SOIN
TEVI
Food Plants

Figure 7b: Wet versus dry season mean bite diameter for food plants that were eaten at least 15 times upon encounter by black rhinos in Ngulia rhino sanctuary. Plant had a significant effect on mean bite diameter ($p<0.001$). Bigger bite diameters were selected in the dry season ($p<0.001$) there was a strong plant-season interaction ($p<0.001$).


12
8
4
0
Season
Dry
Wet
Mean bite diameters
ACTO
BATE
CASP
COEX
DUKI
GRBI
GRNE
GRVI
MEVO
OCIN
PRHO
PRRE
SEPA
SOIN
TEVI
Food plants

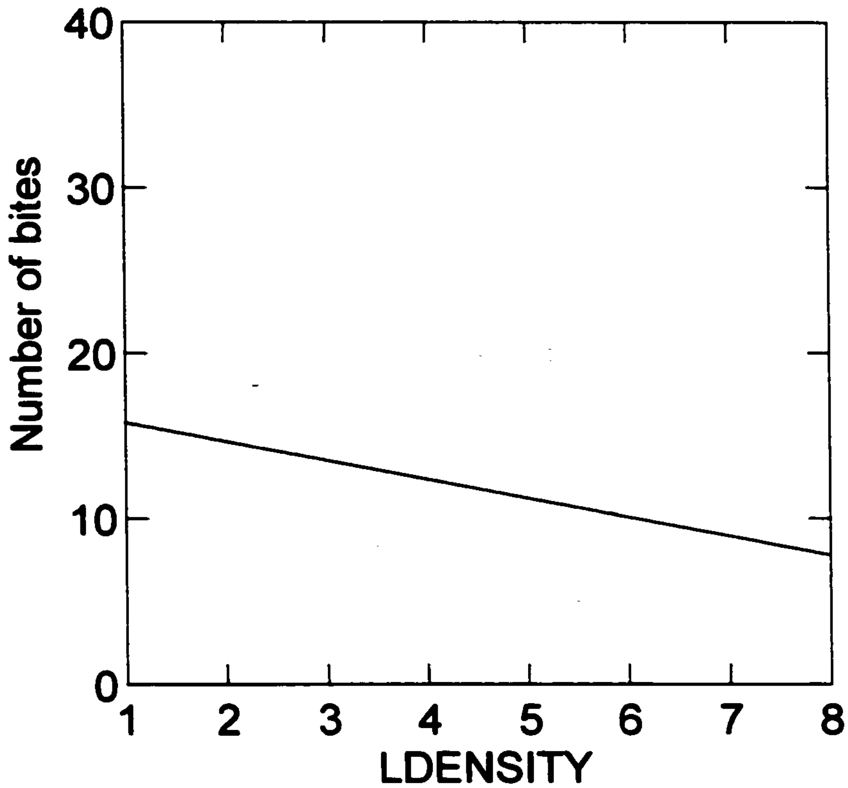
lowest mean bite diameter in the dry season. Ngulia Rhino Sanctuary had the lowest mean bite diameter in the wet season. Rhinos, therefore experienced a low GUD in Nairobi during the wet season and a low GUD in Ngulia during the dry season, Aberdares GUDs being higher for both the wet and dry seasons.

B. Effect of food abundance on mean number of bites, percent browse and mean bite diameter

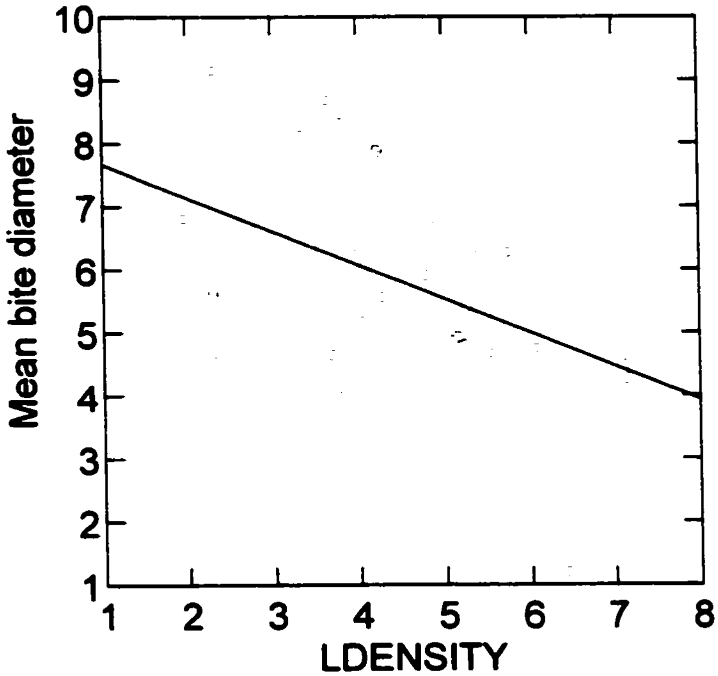
Data on plant densities was obtained and used to compare food plant abundance with mean number of bites and mean bite diameter. Plant densities were log transformed and a regression analysis conducted. Density served as the independent variable. Mean number of bites and mean bite diameter were the independent variables.

Food abundance had a significant effect on mean bite diameter ($P<0.01$) and percent utilization ($p<0.05$), and no effect on mean number of bites (Figure 8a) when data from all the parks was lumped. Overall, mean bite diameter and percent browse decreased with increasing plant densities (Figure 8b). This generally means that as food becomes more abundant, the GUD increases and vise versa. There was no effect of species abundance on mean number of bites for all parks. However, different results were observed for individual parks. Mean bite diameter decreased with increasing food abundance in Aberdares ($p<0.01$) only. Percent browse decreased with increasing plant densities in Nairobi ($p<0.05$) and increased with increasing species densities in Ngulia ($p<0.05$). There was a weak trend in Aberdares, percent browse generally decreased ($p=0.08$) with increasing species densities. Therefore the GUD increased with increasing

Figure 8a: Food plant density versus mean number of bites. Plant density had no effect on mean number of bites.


40
30
20
10
0
Number of bites
1
2
3
4
5
6
7
8
LDENSITY

8b Food plant density versus mean bite diameter. Mean bite diameter decreased with increasing plant densities ($p<0.01$).


Mean bite diameter
LDENSITY
1
2
3
4
5
6
7
8
9
10

species abundance in Aberdares and Nairobi, and decreased with increasing food abundance in Ngulia.

C. Effect of plant size on mean bite diameter

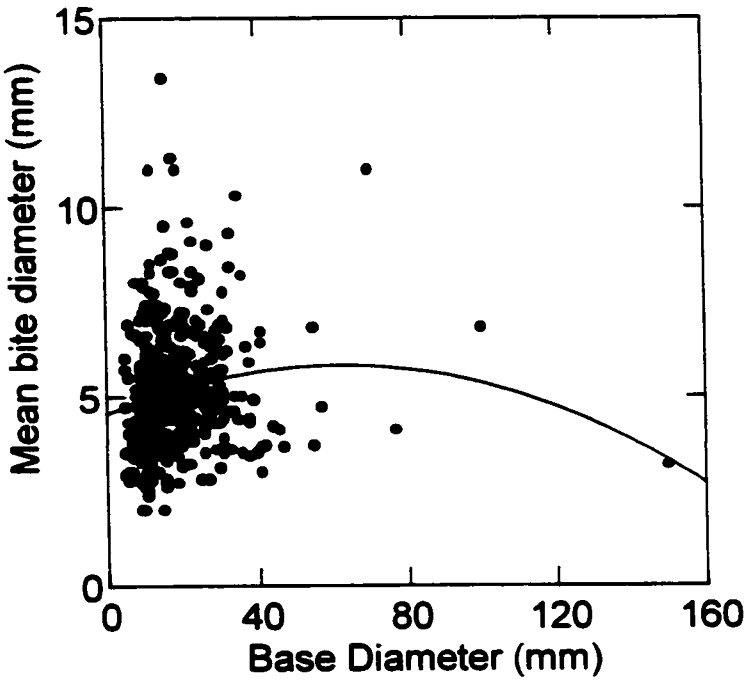
Basal stem (or trunk) diameter was measured for some food plants in Ngulia Rhino Sanctuary. These data was used to determine the relationship between plant size and mean bite diameter for the selected food plants. I then performed a regression analysis with mean bite diameter as the dependent variable and basal diameter the independent variable.

Plant size did not have a strong effect on the mean bite diameter selected by black rhinos for the plants I selected in Ngulia Rhino Sanctuary (P=0.069) (Figure 9). I observed a weak trend, mean bite diameter generally increased with increasing basal diameter upto a certain point after which it leveled off.

D. Food plant availabilities versus utilization

Potential twig diameter was compared with the bite diameter selected by black rhinos for all the food plants identified during the two year study period (Table XV, XVa, XVb and XVc). In Aberdares NP, 43.14% of the plants fell into category 1, 13.72% into category 2 and 43.14% into category 3 during the wet season. During the dry season, 30.36% fell into category 1, 26.79% into category 2 and 42.86% into category 3. *Nuxia congesta, Toddalia asiatica, Vangueria infausta* and *Sida rhombifolia* moved from category 2 in the wet season into category 3 in the dry season. *Abutilon longicuspe,*

Figure 9: Basal diameter versus mean bite diameter. There is a weak trend, mean bite diameter (p=0.069). Bite diameter increased with increasing basal diameter upto a certain point after which it leveled off.



Mean bite diameter (mm)
15
10
5
0
0
40
80
120
160
Base Diameter (mm)

Crotalaria incana, Dovyalis abyssinica and *Phytolacca dodecandra* moved from category 3 in the wet season to category 2 in the dry season.

In Nairobi NP, 28.95% of the plants fell into category 1, 9.65% into category 2 and 61.4% into category 3 during the wet season. During the dry season, 19.18% of the plants fell into category 1, 20.55% in category 2 and 60.27% in category 3. *Acacia drebanolobium, Capparis tomentosa* and *Gnidia subcordata* moved from category 2 in the wet season to category 3 in the dry season. *Lippia javanica, Lippia kituensis, Olea europaea* and *Phyllanthus fischeri* shifted from category 3 in the wet season to category 2 in the dry season.

In Ngulia during the wet season, 32.56% of the plants fell into category 1, 30.99% in category 2 and 37.21% in category 3. During the wet season, 33.33% of the plants fell into category 1, 13.73% in category 2 and 52.94% in category 3. *Grewia tembensis, Premna holstii* and *Premna resinosa* moved from category 2 in the wet season to category 3 in the dry season. *Grewia villosa* and *Acacia brevispica* moved from category 3 in the wet season to category 2 in the dry season.

E. Food off-take

A regression analysis was conducted to determine the relationship between the selected bite diameter and the weight of leaves and stems. Bite diameter had a significant effect on the amount of food harvested ($p<0.001$). Estimated food off-take increased non-linearly with increasing bite diameter (Figure 10).

The GUD (estimated amount of food harvested from the patches) were different for all food plants used for this study (Table XVI). Black rhinos experienced the lowest GUD (highest estimated off-take) from Nairobi NP and the highest GUD from

TABLE XV: CATEGORIES OF FOOD PLANT AVAILABILITIES VERSUS UTILIZATION

	Actual mean bite diameter	
Potential twig diameters	Small	Large
Small	Category 1: plants with small potential twig diameter and small actual mean bite diameter	No plant can fall in this category
Large	Category 2: plants with large potential twig diameter and small actual mean bite diameter	Category 3: plants with large potential twig diameter and large actual mean bite diameter

TABLE XVA: ABERDARES NP POTENTIAL TWIG DIAMETER VERSUS ACTUAL BITE DIAMETER

Category	Wet season	Both seasons	Dry season
Category 1	*Asparagus africanus* *Conyza newii* *Crassocephalum sp* *Ehretia cymosa* *Hibiscus vitifolius* *Indigofera arrecta* *Leucas grandis* *Pavonia urens* *Solanum mauense* *Solanum nigrum* *Solanum sp* *Triumfetta sp*	*Achyranthes aspera* *Blepharis maderaspatensis* *Clausena anisata* *Erythrococca bongensis* *Hibiscus callyphylus* *Hypoestes forskahlii* *Hyppoestes verticillaris* *Leucas urticifolia* *Pentas lanceolata* *Pluchia ovalis*	*Clutia abyssinica* *Commelina africana* *Hibiscus fuscus* *Leucas deflexa* *Pavonia patens* *Urtica massaica* *Vernonia sp*
Category 2	*Hibiscus vitifolius* *Nuxia congesta* *Sida rhombifolia* *Toddalia asiatica* *Vangueria infausta*	*Lantana trifolia* *Ocimum gratissimum*	*Abutilon mauritianum* *Calodendrum capense* *Clerodendrum johnstonii* *Crotalaria incana* *Dovyalis abyssinica* *Euclea divinorum* *Juniperus procera* *Maytenus senegalensis* *Phytolacca dodecandra* *Rytigynia uhligii* *Solanecio angulatus* *Teclea nobilis* *Teclea simplicifolia*
Category 3	*Abutilon mauritianum* *Conyza bonariensis* *Crotalaria incana* *Croton macrostachyus* *Dovyalis abyssinica* *Hibiscus fuscus* *Phytolacca dodecandra* *Sida schimperana* *Tephrosia sp* *Urtica massaica* *Vernonia galamensis*	*Abutilon longicuspe* *Leonotis mollissima* *Rhamnus prinoides* *Senna didymobotrya* *Senna septemtrionalis* *Sida rhombifolia* *Sida tenuicarpa* *Solanum aculeastrum var 1* *Solanum aculeastrum var 2* *Solanum incanum* *Vernonia auriculifera*	*Achyrospermum schimperi* *Ehretia cymosa* *Euphorbia schimperana* *Nuxia congesta* *Olea europaea* *Rhamnus staddo* *Rhus natalensis* *Scutia myrtina* *Senecio syringifolius* *Toddalia asiatica* *Vangueria infausta* *Vernonia galamensis* *Vernonia ssp galamensis*

TABLE XVB: NAIROBI NP POTENTIAL TWIG DIAMETER VERSUS ACTUAL BITE DIAMETER

Categories	Wet season	Both seasons	Dry season
Category 1	*Ageratum conyzoides* *Allophylus rubifolius* *Barleria erathemoides* *Becium obovatum* *Bidens pilosa* *Commelina benghalensis* *Crotalaria brevidens* *Euphorbia bongensis* *Fuerstia africana* *Gomphorcarpus stenophylus* *Gutenbergia cordeifolia* *Heliotropium steudneri* *Hypoestes triflora* *Indigofera schimperi* *Indigofera volkensii* *Justicia anagalloides* *Justicia flava* *Monechma debile* *Nicotiana glauca* *Plectranthus caninus* *Pupalia lappacea* *Rhynchosia minima* *Sarcostemma viminale* *Sida ovata* *Sphaeranthus suaveolens* *Tagetes minuta* *Tephrosia hildebrandtii* *Waitheria indica*	*Acalypha fruticosum* *Hibiscus flavifolius* *Hibiscus fuscus* *Verbena bonariensis*	*Asparagus africana* *Asparagus flagellaris* *Astrpomea kyoscyamoides* *Commiphora schimperi* *Grewia tembensis* *Hibiscus calyphylus* *Nasea lythroides* *Pavonia patens* *Sida tenuicarpa* *Turraea mombassana*

TABLE XVB continued

Category 2	*Acacia drebanolobium* *Aspilia pluriseta* *Capparis tomentosa* *Gnidia subcordata*	*Grewia similis* *Pavonia patens* *Pavonia urens* *Jasminium abyssinica* *Ziziphus mucronata* *Rhus terminervus* *Ocimum kituensis*	*Acacia etbaica* *Brachaelena sp* *Elaedendron buchananii* *Indigofera arrecta* *Lippia javanica* *Lippia kituensis* *Olea europaea* *Phyllanthus fischeri*
Category 3	*Acacia etbaica* *Albizia amarus* *Cissus quadrangularis* *Clerodendrum myricoides* *Commiphora schimperi* *Conyza stricta* *Conyza sumatrensis* *Cordia monoica* *Crotalaria keniensis* *Cussonia sp* *Cyprus renschii* *Elaedendron buchananii* *Englerastrum scandens* *Gomphorcarpus semilunatus* *Grewia bicolor* *Grewia tembensis* *Hermannia uhligii* *Hibiscus aponeurus* *Hibiscus calyphylus* *Hypoestes verticillaris* *Indigofera arrecta* *Indigofera swaziensis* *Kalanchoe sp*	*Abutilon mauritianum* *Acacia brevispica* *Acacia gerrardii* *Acacia kirkii* *Acacia melifera* *Acacia seyal* *Acacia stuhlmannii* *Achyranthes aspera* *Aeschynomene schimperi* *Aspilia mosambicensis* *Carissa edulis* *Croton dichogamous* *Dombeya burgessiae* *Dovyalis caffia* *Euclea divinorum* *Lantana camara* *Maytenus senegalensis* *Ochna holstii* *Ocimum gratissimum* *Rhamnus staddo* *Rhus natalensis* *Triumfetta rhomboides* *Vernonia lasiopus* *Schrebera alata*	*Acacia drebanolobium* *Acacia xanthophloea* *Allophylus rubifolius* *Balanites aegyptiaca* *Calpurnea aurea* *Capparis tomentosa* *Commelina benghalensis* *Cordia monoica* *Gnidia subcordata* *Grewia similis* *Leucas grandis* *Lycium europaeum* *Maytenus heterophylla* *Ocimum kituensis* *Ormocarpum kirkii* *Rhus terminervus* *Schrebera alata* *Ziziphus mucronata*

Category 3 continued	*Lantana trifolia* *Lawsonia inermis* *Leucas glabrata* *Leucas grandis* *Lippia javanica* *Lippia kituensis* *Maerua decumbens* *Microglossa densiflora* *Nasea lythroides* *Nepeta azurea* *Olea europaea* *Ormocarpum sp* *Phyllanthus fischeri* *Phyllanthus schimperi* *Polygonum setosulum* *Psiadia punctulata* *Teclea nobilis* *Teclea simpliciflora* *Tragia brevidens* *Warbugia ugandensis*	*Scutia myrtina* *Solanum incanum*	

TABLE XVC: NGULIA POTENTIAL TWIG DIAMETER VERSUS BITE DIAMETER

Categories	Wet season	Both seasons	Dry season
Category 1	*Abutilon mauritianum* *Barleria spinosa* *Barleria teitensis* *Erythrococca bongensis* *Hermannia uhligii* *Hibiscus canabinus* *Sericomopsis pallida* *Solanum incanum* *Tephrosia villosa* *Tinnea aethiopica*	*Sericomopsis pallida* *Sida ovata* *Duosperma kilimandscharica*	*Acalypha fruticosum* *Combretum exalatum* *Commelina latifolia* *Croton sp* *Echbolium revolutum* *Helinus integrifolius* *Helinus mystacinus* *Hibiscus micranthus* *Hoslundia opposita* *Indigofera spinosa* *Melhania velutina* *Ruellia megachlamys* *Waitheria indica*
Category 2	*Cadaba farinosa* *Cassia abbreviata* *Catunaregum spinosa* *Combretum exalatum* *Echbolium revolutum* *Erythroclamys spectabilis* *Grewia tembensis* *Premna holstii* *Premna resinosa*	*Bauhinia taitensis* *Ochna inermis* *Boscia coriaceae*	*Acacia brevispica* *Albizia sp* *Cordia monoica* *Grewia villosa*
Category 3	*Acacia brevispica* *Catunaregum spinosa* *Commiphora africana* *Commiphora madagascariensis* *Ehretia teitensis* *Grewia villosa* *Lannea alata* *Melia volkensii* *Solanum renschii* *Tragia ukambensis*	*Acacia tortilis* *Catunaregum spinosa* *Grewia bicolor* *Grewia nematopus* *Melia volkensii*	*Abutilon fruticosa* *Abutilon sp* *Astripomea lyoscyamoides* *Barleria spinosa* *Barleria teitensis* *Boscia angustifolia* *Combretum apiculatum* *Cordia somalensis* *Delonix elata* *Ehretia teitensis* *Grewia tembensis* *Hibiscus canabinus* *Indigofera arrecta* *Ipomea hildebrandtii* *Ocimum americanum* *Premna holstii* *Premna resinosa* *Solanum incanum* *Solanum renschii* *Sterculia africana* *Strychnos decussata* *Tephrosia villosa*

from Ngulia Rhino Sanctuary. For the plants I selected in Aberdares NP, *Rhamnus prinoides* had the lowest GUD (848.3129g) and *Solanum aculeastrum var 1* the highest GUD (185.8916g). Nairobi NP had the lowest GUD values for all plants combined. *Lantana camara* (1085.342g) had the lowest GUD and *Lippia kituensis* the highest GUD (410.4668g). Ngulia Rhino Sanctuary had the highest GUD compared to all the other areas. *Duosperma kilimandscharica* (513.5609g) and *Premna holstii* (490.2663g) had the lowest GUD values and *Solanum incanum* the highest values (52.4102g). The stems weighed significantly more than the leaves for all plants except *Abutilon longicuspe, Rhamnus prinoides, Senna septemtrionalis, Solanum aculeastrum var 1* and *Solanum incanum.*

DISCUSSION

The pattern of bites and bite sizes selected by black rhinos suggest that plant size, morphology and food abundance influence diet choice and amount of browse harvested from depletable food patches. The results from my study indicate that black rhinos treated plant species differently while selecting bite sizes and deciding the number of bites to crop from various food plants. They also responded differently to different habitats (parks). Different environmental conditions give rise to differences in stem or twig morphology and thus their use by herbivores. MacCracken and Van Ballenberghe 1993) found that shrub morphology varied with physical environment of a specific site and that browsing significantly altered shrub morphology. Some plants (e.g *Ochna inermis*) alter their growth as a response to browsing by developing dense branches or fortifying their tissues with lignin that prohibit herbivores from selecting big bites (Shipley et al. 1999).

Figure 10: Mass of browse versus selected mean bite diameter. Estimated food off-take increased non-linearly with increasing bite diameter ($p<0.001$).

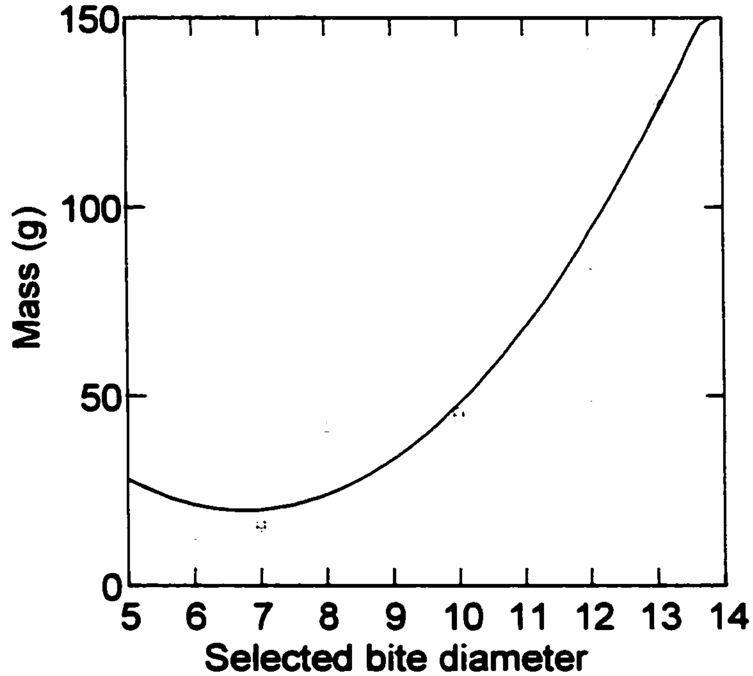

150
100
50
0
Mass (g)
5 6 7 8 9 10 11 12 13 14
Selected bite diameter

TABLE XVI: ESTIMATED OFF-TAKE OF SELECTED FOOD PLANTS

FOODPLANT	Mean Number of bites	Selected Twig diameter(mm)	Mean weight of leaves (g)	Mean weight of stems (g)	Total weight of leaves and stems	Total weight X mean number of bites	Park
Abutilon longicuspe	6.64	10	29.697	14.818	44.515	295.5796	Aberdares
Rhamnus prinoides	6.05	12	69.575	70.642	140.217	848.3129	Aberdares
Senna septemtrionalis	9.57	12	22.685	27.03	49.715	475.7726	Aberdares
Solanum aculeastrum var 2	7.96	12	25.126	40.291	65.417	520.7193	Aberdares
Solanum aculeastrum var 1	6.57	10	12.5	15.794	28.294	185.8916	Aberdares
Lippia kituensis	8.98	10	7.781	37.928	45.709	410.4668	Nairobi
Lantana camara	8.46	13	13.234	115.057	128.291	1085.342	Nairobi
Aspilia mosambicensis	6.74	12	12.819	120.516	133.335	898.6779	Nairobi
Acalypha fruticosum	13	7	2.107	31.634	33.741	438.633	Nairobi
Phyllanthus fischeri	9.5	12	5.139	77.099	82.238	781.261	Nairobi
Solanum incanum	4.86	6	5.702	5.082	10.784	52.41024	Ngulia
Grewia villosa	5.63	7	5.559	10.795	16.354	92.07302	Ngulia
Sericomopsis pallida	12.95	7	3.529	11.888	15.417	199.6502	Ngulia
Premna holstii	12.05	9	12.335	28.351	40.686	490.2663	Ngulia
Duosperma kilimandscharica	12.31	8	7.536	34.183	41.719	513.5609	Ngulia

Black rhinos selected much bigger bites than most large browsing herbivores (giraffes, elephants and elands) in their system. These large bite sizes were generally selected throughout the year and may suggest that black rhinos maintained maximum intake rates by minimizing interruptions to crop bites by selecting big bites. This observation is consistent with other studies on browsers (Shipley and Spalinger 1992, Gross et al.1993). They found that herbivores cropped bigger bites as a way of maximizing food intake while minimizing the time they take to crop new bites. This study comprised plants that varied in size, growth forms and other structural features like fibrousness and plant spinescence and nutritional quality. These differences in plant characteristics may have contributed to differences in mean bite diameters and number of bites cropped from food plants. High levels of fibrous tissue may deter black rhinos from cropping bigger bites especially in more arid areas and during the dry season. I was surprised that prickles of various forms did not deter rhinos from utilizing food plants and cropping large bite sizes. Studies on African ungulates (Cooper and Owen-Smith 1986) showed that hooked thorns were more effective than straight spines at stopping or slowing ungulates from browsing plants. This was not the case with black rhinos. They consumed all *Acacia* and *Solanum* species as well as *Toddalia asiatica* in our study sites. These plants have long straight spines, hooked and some have mixed spines and were consumed in comparable proportions with those that did not have spines. My study concurs with other studies on black rhinos in Africa (Goddard 1968, 1970, Oloo et al 1994, Jourbert and Eloff 1971 and Loutit et al 1987) where they found rhinos feeding on plants with all kinds of prickles.

In order to forage efficiently, a forager must keep track of changes that occur in its environment that subsequently affect their foraging decisions. Changes in mean patch sizes and density affect foraging decisions in terms of number of bites and bite diameters selected. Shipley and Spalinger (1992) suggested that bite size may remain constant or even decrease with increasing forage density in some browsers. The results show that mean bite diameters and percent browse generally decreased with increasing food abundance in all areas except in Ngulia Rhino Sanctuary where I observed the opposite effect. This means rhinos adjusted their foraging decisions in response to changes in food abundance by selecting bigger bite diameters and high percent browse in the dry season when food is scarce and in more arid areas (e.g Ngulia) where food resources occur in low densities. Similar results were observed in the moose (Vivas and Saether 1987, Shipley and Spalinger 1995, Shipley et al. 1999) where they selected selected bigger bite diameters as stem density declined.

My results showed that bite diameter was influenced to some extent by plant size. A diet optimization model developed by Shipley et al. (1999) showed that diameter at current annual growth was positively correlated with the twig diameter selected by herbivores. Their model suggested that animals would gain more energy from bites larger than optimal than those bites smaller than optimal. However, the bite size selected by herbivores is limited by plant architecture and the morphology of an animal's mouth. Therefore the bite size that yields the highest net energy intake for the animal may not always be feasibly obtained. Furthermore, for black rhinos, obtaining bigger bites would mean cutting off portions of branches without leaves that may offer little or no nutritional gain. Bite diameters selected by black rhinos leveled off (Figure 12) as basal diameter increased. This may be the point at which it is physically difficult to crop bigger bites because they contain high levels of fiber thus requiring more force to break off twigs. This may imply that cropping bigger bite diameters may increase metabolic costs expended by a forager during a foraging bout or maybe physically impossible above a certain stem diameter.

When potential twig diameter was compared with selected bite diameter, I found that most plants that fell in category 1 were small annuals that were available in the wet season only. Thus they contributed significantly to the wet season diet. Plants that fell in Category 2 and 3 were large woody shrubs and trees that provided large amount of browse. Most plants in Category 3 were highly preferred by black rhinos and occurred in high densities. These plants form staple diets and are important to black rhino conservation and management. Seasonal plant shifts between category 2 and 3 may have resulted from changes in fiber levels. For example, *Abutilon longicuspe, Dovyalis abyssinica* (Aberdares), *Lippia kituensis, Lippia javanica, Olea europaea, Phyllanthus fischeri* (Nairobi), *Grewia villosa* and *Acacia brevispica* (Ngulia) are very woody and may have become even tougher to crop in the dry season as they dried out. There were indications that black rhinos expanded their diet breadth as food became scarce in the dry season. More food plants were added to category 2 in Aberdares and Nairobi in the dry season, whereas in Ngulia, they added new plant species to their diet and selected bigger bite diameters (Table XIIa, XIIb and XIIc) in the dry season. Also, rhinos adjusted their food off-take as food became scarce by selecting bigger bite diameters and high percent browse in the dry season. The results indicate that estimated food off-take significantly increased with increasing bite diameter hence rhinos can adjust food intake using bite diameter.

In conclusion, the analyses showed that decisions made at the bite level have important consequences to browsing herbivores and the plants they eat. These decisions affect the amount of food they consume, their nutritional intake and the trade-offs they face during foraging. These decisions in turn affect their individual fitness and those of their conspecifics and competitors. Understanding the decisions leading to bite size selection by a black rhino and other large herbivores provides a foundation for understanding their nutritional requirements, habitat suitability, and determining the amount of food available in various environments that support them. This information can then provide a basis for deciding the carrying capacities of various Rhino Sanctuaries and designing black rhino conservation areas in Kenya.

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CHAPTER V

DOES FOOD QUALITY INFLUENCE DIET CHOICE AND FOOD PREFERENCE FOR BLACK RHINOCEROS *Diceros bicornis michaeli L.*?

INTRODUCTION

This study is part of a larger study where we investigated factors affecting diet choice and habitat selection for black rhinoceros (*Diceros bicornis L.*). In this study, we examine the role played by nutritional quality of food plants and plant secondary compounds in shaping diet choice and preference. Understanding the diets and nutritional requirements of free-ranging wildlife populations is important for designing proper management programs. But diets consumed emerge from a complex interplay between the animal's nutritional status, perception and distribution and abundance of food.

An animal's daily requirement for nutrients is influenced by body size, physiological condition, activity level, age, health status and other factors (Allen and Oftedal 1988). Animals need to consume food items that supply essential nutrients required for growth. Studies have shown that many animals grow better when fed mixed diets (Rapport 1980, Krebs and Avery 1984, Freeland et al. 1985, Lindroth 1988, Pennings et al. 1993, Bernays et al. 1994). By consuming a mixed diet, a forager obtains a more beneficial mix of nutrients allowing for growth and reproduction (Westoby 1978, Rapport 1980, Dearing and Schall 1992, Pennings et al. 1993).

Mammals exhibit a wide range of morphological, physiological and behavioral adaptations for acquiring and utilizing a diverse array of foods (Allen and Oftedal 1988).

In natural systems, both the temporal and spatial distribution of food resources are typically heterogeneous. Food acquisition involves time and feeding choices. Like other mammals, herbivores require a wide array of nutrients. Herbivores ingest foods that vary widely in nutritional composition. Among hindgut fermentors (e.g equids, rhinoceros and elephant) there can be substantial differences in diet selection in response to variation in digestive function. Some large species such as rhinoceros and elephants are able to retain substantial amounts of fibrous material in colon fermentation system, and have adopted a strategy of consuming great amounts of poorly digestible high-fiber food (Foose 1982, Owen-Smith 1988).

Food is composed of major nutrients such as fat, protein and carbohydrate, and of essential nutrients such as amino acids, fatty acids, minerals and vitamins. The nutritional value of food varies with plant species, plant parts (e.g stem, leaves, flowers and fruit), and these differences may be affected by phenological changes such as maturation of leaves and seasonal effects (Howe and Wesley 1988 and references therein). In most habitats, seasonal variation in food quality and quantity is pronounced (Van Soest 1994). Nutritional quality and quantity of food plants may also vary from one area to another (Boutton 1988, Allen and Oftedal 1988, Van Soest 1994). Such variation may be driven by changes in environmental factors such as rainfall distribution, temperature, and soil type and composition which may influence the nutrient content of plants. Within an ecosystem, the degree of abundance and depletion of different mineral nutrients can have profound effects on plant and animal communities (Bell 1982 and Van Soest 1994).

A plant's chemical makeup includes primary metabolites (e.g nitrogen and carbohydrates) as well as secondary metabolites. Constituents of some plants may serve as feeding deterrents and may be toxic to animals (Feeny 1968, 1970; Rhoades 1979; Provenza et al. 1984; Altmann et al. 1985; Robbins et al. 1987, 1991; Bernays 1981; Smallwood and Peters 1986; Butler 1988; Dearing 1997; Van Soest 1994; Waterman and Mole 1994). Deterrents include lignin, tannins, alkaloids and cyanogenic glycosides. Tannins are widely cited as antinutritive plant secondary compounds (Feeny 1975; Rhoades 1979; Cooper and Owen-Smith 1985; Smallwood and Peters 1986; Butler 1986; Waterman and Mole 1994; Van Soest 1994; Schmidt et al. 1999). Tannins are polyphenolic compounds thought to interfere with the digestibility of nutrients following their ingestion by herbivores (Feeny 1976; Rhoades and Cates 1976). Tannins act within the animal's digestive tract by binding with the substrate to be digested usually proteins (Bernays et al. 1989), and also carbohydrates and lipids (Scalbert 1991).

In this study, I examine the extent to which diet selection by black rhinoceros are influenced by plant nutritional quality and plant secondary compounds, specifically condensed tannins. I carried out nutritional analysis of some selected plant species that are highly preferred by black rhinos and those that are less preferred or uneaten from Salient area of Aberdares National Park, Nairobi National Park and Ngulia Rhino Sanctuary in Tsavo West National Park. These areas occupy different eco-climatic zones, and differ in their annual rainfall amounts and distribution, temperature, soils and plant species composition.

Nutritional analysis included nitrogen, fat content, minerals, crude fiber content and condensed tannins. I analyzed levels of condensed tannin only because previous studies by Cooper and Owen-Smith (1985) on the greater kudu showed that diets of large ruminants are influenced mainly by condensed tannins and not by soluble tannins due to their dependence upon microbial fermentation of plant cell walls for part of their energy needs. Does this apply to the black rhino? I compared nutrient levels and condensed tannin content between highly preferred food plants and less preferred plants. When all else is equal, black rhinos should select and harvest more food from plants that exhibit high nutritional quality and low levels of condensed tannins. Consequently, highly preferred food plants are expected to be highly nutritious with low levels of condensed tannins than the less preferred plants.

STUDY AREA AND METHODS

Plant materials were collected from the Salient area of Aberdares National Park during the dry season (September, 1999), Nairobi National Park during the dry season (October, 1999) and Ngulia Rhino Sanctuary located in Tsavo West National Park during the wet season (December, 1999). During the study period, a total of 82 plants were identified as black rhino food plants in Aberdares, 113 in Nairobi and 51 in Ngulia Rhino Sanctuary.

The Salient is a wet upland forest located in the Northern part of Kenya. It covers an area of $70km^2$ and has an estimated population of 50 black rhinoceros. Soils in this area are of volcanic origin with deep clay soils dominating the lower areas of the Park and granulated sandy soils in the higher areas. This area receives an average of 1000mm of rainfall per year. The vegetation in Salient is characterized by bamboo forest, wet upland forest and scrubland with glades of open grassland.

Nairobi National Park is located 8 km south of Nairobi City. It occupies an area of $114.8km^2$ and supports approximately 60 black rhinoceros. The soils in this area are derived from volcanic rocks of the middle tertiary. Sediments cover the southern part of the Park while black clay soils with calcareous and non-calcareous clays derived from colluvium dominate other parts of the Park. This area receives mean annual rainfall of 900mm. Over 90% of the Park is open grassland with scattered acacia trees and bushland. The rest of the Park is covered by a riverine woodland and bushland, and a forested area.

Ngulia Rhino Sanctuary is an enclosed area within Tsavo West National Park, located in the South-eastern part of Kenya. The Sanctuary occupies 73km^2 with approximately 45 black rhinoceros. Soils in this area developed from recent volcanic rocks and show a wide range in depth, color and drainage condition. Most soils have sandy-clay texture. The average annual rainfall varies from 200-700mm. This is a region of bushed-grassland with scattered acacia and commiphora trees.

I selected four samples from highly preferred plant species and less preferred or uneaten plant species from each study area (Table XVII). Food preferences were determined from work on bite diameters and browsing intensity of black rhinos. I used the patch use behavior of a black rhino at a feeding station (to accept or reject the opportunity to forage) to calculate percent preference. All the sample collection was restricted to black rhino home ranges in all the study sites. For each food plant, I attempted to collect representative samples of what the black rhino eats, paying attention to the plant part selected, and cutting twigs at diameters similar to those browsed by rhinos on the particular plant species. I analyzed material from less preferred plants because they were largely ignored by rhinos even when they occurred in high densities or were overtly avoided. These plants did not exhibit obvious anti-herbivory plant defenses e.g spines that would physically deter many browsers.

TABLE XVII: PLANTS SELECTED FOR NUTRITIONAL ANALYSIS

Park	Plants	Preference level
Aberdares	*Abutilon longicuspe*	Highly preferred
	Senna septembtrionalis	Highly preferred
	Sida rhombifolia	Highly preferred
	Solanum aculeastrum	Highly preferred
	Crotalaria angatiflora	Not eaten
	Vernonia auriculifera	Less preferred
Nairobi	*Acacia kirkii*	Highly preferred
	Acalypha fruticosum	Highly preferred
	Gnidia subchordata	Highly preferred
	Rhus natalensis	Less preferred
	Psidia punctulata	Less preferred
Ngulia Rhino Sanctuary	*Ochna inermis*	Highly preferred
	Acacia tortilis	Highly preferred
	Grewia bicolor	Highly preferred
	Duosperma kilimandscharica	Highly preferred
	Premna resinosa	Less preferred
	Bauhinia taitensis	Less preferred

The samples were transported as soon as they were collected in manila bags to Moi University where they were oven dried at a steady temperature of 60^0C, milled and analyzed at the Chemistry Department. The plant samples were analyzed for total nitrogen, phosphorus, iron, zinc, calcium, magnesium, sodium, potassium, total fat and crude fiber using the standard methods employed in this laboratory (see Okalebo et al. 1993 and A.O.A.C. 1980 for details of methods). Kjedahl method was used to determine percent nitrogen and protein in this laboratory. Percent phosphorus was analyzed using ascorbic acid procedure with no pH adjustment whereas atomic absorption spectrometry was used to determine the mineral concentration in the plant samples. Analysis of fat and non digestible fiber was conducted using the extraction and weighing method. All results were calculated on a dry mass basis.

Samples were analyzed for condensed tannins at the East African Tanning and Extract Company (EATEC) using weight difference method. The source of commercial extracts of tannic acid in this laboratory is the bark and heartwood of wattle tree (*Acacia mollisima*). An aqueous infusion of plant tannins is prepared and the total solids determined by evaporation of aliquot. Tannins are removed by adsorption onto a hide and the comparison of the two figures allows the tannin to non-tannin ratio in the extract to be determined. Because of the practical nature of the study, dry samples were used instead of fresh samples. Condensed tannin concentrations were expressed as a percentage of the dry weight.

RESULTS

The means from nutritional analysis data (nitrogen, fat, crude fiber, mineral elements and condensed tannins) are presented in Table XVIII. I used MANOVA with total nitrogen, phosphorus, iron, zinc, calcium, magnesium, sodium, potassium, fat, crude fiber and condensed tannins as dependent variables and park and preferences as independent variables with plant species nested within park and preferences. This revealed that all the plants contained significantly different levels of nutrients and condensed tannins ($p<0.001$ for fat, phosphorus, iron, calcium, magnesium, sodium and potassium; $p<0.01$ for crude fiber and condensed tannins; $p<0.05$ for zinc) except nitrogen which did not vary significantly between plants after factoring out the effect of parks and black rhino preferences on nitrogen among plants (Table XIX). Levels of nutrients and condensed tannins differed significantly between Parks ($p<0.001$ for nitrogen, sodium and potassium; $p<0.01$ for crude fiber; and $p<0.05$ for phosphorus, iron, zinc, calcium, magnesium, fat and condensed tannins).

Levels of nitrogen from 0.565 to12.425% with higher levels recorded in *Premna resinosa* and *Bauhinia taitensis*. Phosphorus occurred in trace amounts (range: 0.002 to 0.163 ppm) with notable levels in *Abutilon longicuspe, Acacia kirkii, Gnidia subchordata, Rhus natalensis* and *Psidia punctulata.* Iron levels ranged from 0.115 to 87.050 ppm with high in *Rhus natalensis, Gnidia subchordata* and *Acalypha fruticosum.* Zinc levels ranged from 0.065 to10.298 ppm with significantly high levels in *Duosperma kilimandscharica*. The levels of calcium varied greatly (range: 1.175 to 357.525 ppm) with *Acalypha fruticosum* exhibiting extremely high levels. Magnesium levels were generally high among all plants with ranges from 9.713 to 23.120 ppm. Plants from

TABLE XVIII: MEAN (±SEM, N=4) NUTRITIONAL VALUES OF ALL PLANT SPECIES USED IN THE STUDY

Food plants	% N	% Fat	P (ppm)	Fe (ppm)	Zn (ppm)	Ca (ppm)
Abutilon longicuspe	2.058±0.017	2.052±0.010	0.157±0.002	0.115±0.013	1.420±0.026	6.237±0.022
Senna septembtrionalis	2.260±0.018	2.163±0.017	0.002±0.000	4.515±0.013	0.877±0.025	6.215±0.021
Sida rhombifolia	1.715±0.013	0.842±0.017	0.002±0.000	7.385±0.013	1.232±0.017	1.175±0.013
Solanum aculeastrum	1.330±0.008	28.805±0.013	0.008±0.000	3.778±0.031	0.880±0.018	3.032±0.017
Crotalaria angatiflora	3.532±0.013	21.123±0.013	0.008±0.000	5.262±0.022	1.225±0.024	4.735±0.013
Vernonia auriculifera	2.328±0.017	1.180±0.008	0.007±0.000	10.053±0.088	1.230±0.022	5.937±0.010
Acacia kirkii	0.565±0.013	1.275±0.171	0.163±0.080	2.350±0.100	0.065±0.001	85.523±0.010
Acalypha fruticosum	0.967±0.017	0.475±0.021	0.023±0.002	69.505±0.013	0.065±0.002	357.525±0.096
Gnidia subchordata	1.230±0.018	0.353±0.017	0.142±0.001	65.325±0.013	0.812±0.022	57.065±0.013
Rhus natalensis	0.815±0.021	0.875±0.171	0.143±0.002	87.050±0.129	0.042±0.001	75.658±0.017
Psidia punctulata	0.925±0.013	2.545±0.021	0.150±0.018	8.847±0.017	0.235±0.013	47.865±0.013
Ochna inermis	3.660±0.018	0.650±0.018	0.053±0.001	4.415±0.013	1.295±0.001	19.660±0.008
Acacia tortilis	1.650±0.129	0.425±0.013	0.035±0.021	12.258±0.010	1.683±0.002	32.275±0.096
Grewia bicolor	4.958±0.017	0.087±0.052	0.050±0.002	3.055±0.064	3.055±0.064	37.620±0.014
Duosperma kilimandscharica	0.642±0.013	0.825±0.013	0.069±0.001	3.290±0.039	10.298±14.268	26.755±0.013
Premna resinosa	12.425±0.171	1.675±0.017	0.065±0.002	4.170±0.008	1.917±0.001	14.108±0.040
Bauhinia taitensis	9.610±0.022	0.937±0.017	0.105±0.001	3.265±0.013	1.397±0.026	28.915±0.013

TABLE XVIII continued

Food plants	Mg (ppm)	Na (ppm)	K (ppm)	% Fiber	% Tannins
Abutilon longicuspe	15.743±0.155	18.025±0.013	18.140±0.018	28.737±0.013	1.850±0.208
Senna septembtrionalis	14.025±0.013	3.433±0.022	19.053±0.017	29.597±0.022	5.275±0.126
Sida rhombifolia	16.035±0.013	3.645±0.013	7.135±0.013	29.845±0.013	1.825±0.096
Solanum aculeastrum	10.730±0.018	2.610±0.016	13.475±0.171	38.685±0.013	7.175±0.222
Crotalaria angatiflora	12.637±0.010	3.415±0.013	10.815±0.021	38.540±0.022	4.275±0.096
Vernonia auriculifera	13.540±0.014	2.523±0.010	20.957±0.017	37.835±0.024	3.675±0.171
Acacia kirkii	9.713±0.010	8.500±0.183	9.148±0.130	40.048±0.036	0.522±0.003
Acalypha fruticosum	11.840±0.008	7.425±0.171	2.153±0.048	41.668±0.022	6.350±0.129
Gnidia subchordata	17.213±0.005	8.800±0.082	2.898±0.017	9.450±0.129	1.850±0.129
Rhus natalensis	13.358±0.010	7.700±0.183	6.220±0.008	37.750±0.129	9.350±0.129
Psidia punctulata	10.475±0.006	8.625±0.126	8.612±0.010	18.480±0.022	8.000±0.258
Ochna inermis	15.532±0.010	86.500±1.291	58.750±0.957	60.128±27.505	3.875±0.171
Acacia tortilis	14.025±0.013	85.750±0.957	52.750±0.957	45.665±0.026	2.275±0.171
Grewia bicolor	21.327±0.017	88.250±0.957	84.750±0.957	51.817±0.017	2.575±0.171
Duosperma kilimandscharica	23.120±0.008	86.000±0.816	81.000±0.816	61.068±0.010	2.175±0.299
Premna resinosa	17.125±0.013	86.750±0.500	26.250±0.957	73.528±0.998	6.475±0.171
Bauhinia taitensis	17.035±0.013	87.000±0.816	81.000±0.816	53.628±0.017	2.950±0.265

TABLE XIX: F-VALUES FROM MANOVA

Element	Plant	Park	Preference
% Nitrogen	1.52	22.15***	26.27***
% Fat	1281.37***	2.04*	0.13
% Crude fiber	9.34**	11.54**	0.71
Phosphorus (ppm)	28.99***	4.29*	0.17
Iron (ppm)	1220.12***	5.54*	0.01
Zinc (ppm)	1.83*	1.99*	0.36
Calcium (ppm)	31.58***	4.42*	0.95
Magnesium (ppm)	3383.96***	4.61*	0.52
Sodium (ppm)	44.83***	799.04***	0.42
Potassium (ppm)	42.03***	25.24***	0.29
Condensed tannins	13.31**	2.13*	4.72*

Note: $p \leq 0.05$, $^{**}p \leq 0.01$, $^{***}p \leq 0.001$

Ngulia Rhino Sanctuary exhibited the highest concentrations. All plants from Ngulia Rhino Sanctuary contained significantly higher levels of sodium (range: 85.750 to 88.250 ppm), potassium (range: 26.250 to 84.750 ppm) and crude fiber (range: 45.665 to 73.528%) than those from Aberdares (sodium range: 2.523 to 18.025 ppm, potassium range: 7.135 to 20.957 ppm, crude fiber range: 9.450 to 73.528%) and Nairobi (sodium range: 7.425 to 8.800 ppm, potassium range: 2.153 to 9.148 ppm, crude fiber range: 9.450 to 41.668%). Fat levels varied from 0.087 to 28.805% with highest levels recorded in *Solanum aculeastrum* and *Crotalaria angatiflora. Acacia kirkii* contained the lowest levels of condensed tannins (0.522%) whereas *Rhus natalensis* contained the highest (9.350%). Higher levels were also recorded from *Psidia punctulata* (8.000%) and *Solanum aculeastrum* (7.175%).

I used MANOVA to determine differences in nutrition and condensed tannins between highly preferred food plants and less preferred or uneaten plants (Table XIX). Nitrogen levels were significantly lower ($p<0.001$) among highly preferred plants compared to less preferred plants. Condensed tannin were also significantly lower ($p<0.05$) in highly preferred plants compared to less preferred plants. Significant differences were not observed for all the other nutrients.

I observed some strong trends when I compared levels of nutrients and condensed tannins between highly preferred plants and less preferred plants within each study site. The means are tabulated in Table XX.

Aberdares NP: Nitrogen, iron and fiber levels were lower in highly preferred plants than less preferred plants. Sodium levels were higher among preferred plants than less preferred plants. Levels of other nutrients did not differ strongly.

TABLE XX: COMPARISON BETWEEN HIGHLY PREFERRED AND LESS PREFERRED FOOD PLANTS IN SPECIFIC PARKS

Elements	Aberdares		Nairobi		Ngulia	
	High, n=16	Less, n=8	High, n=12	Less, n=8	High, n=16	Less, n=8
N	1.841±0.365	2.930±0.644	0.921±0.286	0.870±0.061	2.728±1.741	11.018±1.509
P	0.042±0.069	0.007±0.001	0.109±0.065	0.146±0.013	0.052±0.015	0.085±0.021
Fe	3.948±2.676	7.657±2.561	45.727±32.085	47.949±41.801	5.754±3.914	3.717±0.484
Zn	1.102±0.242	1.227±0.021	0.314±0.368	0.138±0.104	3.673±7.506	1.657±0.278
Ca	5.421±1.424	5.336±0.643	166.704±141.452	61.761±14.856	29.077±6.876	21.511±7.915
Mg	14.133±2.180	13.089±0.483	12.922±3.296	11.916±1.541	18.501±3.939	17.080±0.050
Na	6.928±6.629	2.969±0.477	8.242±0.632	8.163±0.515	86.625±1.360	86.875±0.641
K	14.451±4.879	15.886±5.421	4.732±3.277	7.416±1.279	69.312±14.268	53.625±29.277
Fat	8.466±12.140	11.151±10.660	0.692±0.445	1.710±0.900	0.497±0.286	1.306±0.395
Crude Fiber	31.716±4.077	38.188±0.377	30.388±15.480	28.115±10.301	54.669±13.927	63.578±10.657
Tannins	4.031±2.375	3.975±0.345	4.000±1.930	8.675±0.746	2.725±0.727	4.713±1.895

Nairobi NP: I observed high levels of calcium, and low levels of potassium, fat and condensed tannins in highly preferred plants. The levels of all the other nutrients did not differ strongly between preferred and less preferred plants.

Ngulia rhino sanctuary: Low levels of nitrogen, phosphorus, fat and condensed tannins were recorded among highly preferred plants compared to less preferred plants. Calcium levels were higher among highly preferred than the less preferred plants. There was no notable difference in iron, zinc, magnesium, sodium, potassium and fiber levels.

DISCUSSION

Essential nutrients required for healthy animal growth and development include water, energy, minerals and amino acids usually considered as crude protein (Van Soest 1994). My study suggests that of all the nutrients analyzed, nitrogen and condensed tannin concentrations influence diet choice and food preference by black rhinos. Although nutritional requirements for wild animals have not been fully investigated, there seems to be threshold levels of nutrients and plant toxins upon which a given food plant is highly preferred or less preferred and in some instances avoided. Belovsky (1978) suggested that when there are dietery thresholds to nutrient consumption, than only one or a small number of nutrients will be limiting. Foragers maybe viewed as attempting to maximize energy intake while reducing the intake of any one plant secondary compound (Freeland and Janzen 1978) and thus may select food items that give a balance mix of nutrients (Crawley 1983). The fact that black rhinos utilize different plant species in varying proportions and nutrients might suggest that generalist herbivores have this opportunity to mix diets.

Diet choice by non-ruminant herbivores should be closely related to positive nutritional factors such as nitrogen (usually expressed in crude protein content) and total non-structural carbohydrates than to negative factors such as phenolic and alkaloids (Bergeron and Jodoin 1989). Food availability is also an important factor in diet choice and utilization and the black rhino is expected to select widely available food plants of high quality. However, my observations are not fully consistent with this prediction. Black rhinos behaved somewhat differently with respect to nitrogen levels. They showed high preference for plants that contained less nitrogen. This unexpected result may be explained by their selection of plants low in condensed tannins and other phenolics and alkaloids. Previous studies on black rhinos have shown that plants with high levels of crude protein have correspondingly high levels of phenolic compounds such as tannins (Provenza and Malechek 1984) and alkaloids (Muya and Oguge 2000). The findings from my study are in agreement with previous studies that showed that due to their inability to benefit from bacterial degradation of toxins, Perissodactyls favor utilization of plant species low in condensed tannins and other plant secondary compounds (Freeland and Janzen 1978). The rejection of plants that contain high condensed tannin levels is presumably an evolved response to negative effects tannins have on food digestibility (Rhoades 1979, Provenza et al. 1991).

Black rhinos selected plants with high crude fiber content unless such plants were associated with higher levels of nitrogen as was the case in Aberdares (Table XX) where the less preferred plants had significantly high crude fiber and nitrogen levels. For both fore-gut and hind-gut fermentors, energy and protein requirements per unit weight diminish with increasing size, so that large herbivores can survive on lower quality food

(Bell 1971, Janis 1976). Hind-gut fermentors are known to adequately obtain optimum nutrients from plant material with high fiber content (Janis 1976) as long as the browse material is widely distributed (Bell 1982). This strategy employed by many perissodactyls places rhinos at the lowest level of requirement in a food quality continuum. High dietery diversity maybe necessary for intake of essential nutrients particularly of full complement of amino acids (Gartland et al. 1980).

Animals require minerals for synthesis of structural materials, as constituents of fluids and tissues, and as components of enzymatic machinery (Underwood 1981). Twenty two mineral elements are believed to be essential for higher forms of life (Underwood 1981) and of these seven are major (calcium, phosphorus, sodium, chloride, potassium, magnesium and sulphur). The rest are trace minerals that are found in animal tissues in trace amounts. Important trace minerals include iron, zinc, copper, manganese, selenium and cobalt. Many elements required only at low levels by plants are necessary to animals in more substantial amounts. Conversely, plants have higher needs for some elements than animals (Van Soest 1994). Of the elements I analyzed, iron, calcium, phosphorus, sodium and potassium significantly influenced diet choice and food preference for black rhinos in specific areas.

In Aberdares, black rhinos preferred plants that contained low iron levels and high sodium levels (Table XX). Excess amounts of iron in black rhino diets accumulate in the liver and may cause hemolytic anemia (Smith et al. 1995). Low levels of sodium cause deficiencies and animals may show cravings for salt. This in fact may be the case in Aberdares where black rhinos walk long distances to salt licks. High levels of sodium cause toxicity especially in arid areas where water is scarce. Black rhinos preferred plants that contained high levels of calcium and low levels of phosphorus in Ngulia and only high calcium levels in Nairobi (Table XX). These elements are required in large amounts and in appropriate ratios during both growth and lactation (Van Soest 1994). Imbalances in the ratio of calcium and phosphorus can lead to poor absorption and exacerbate deficiencies of both minerals. Preferred dietary levels are expressed as a desired range of 1:1 to 2:1 in the Ca:P ratio (Van Soest). I observed differences in potassium levels between highly preferred and less preferred plants in Nairobi only. This was surprising since potassium is required in trace quantities and Nairobi had much lower levels than Aberdares and Ngulia (Table XX). This result may suggest that whenever black rhinos have a choice between high and low potassium levels, they select those food plants that offer low levels.

This study provides preliminary data on the nutritional quality of black rhino's food plants. Much work remains to be done, however. Nutritional analyses have not been carried out for a number of food plants, and analysis of other components in the diet such as vitamins, other minerals and plant secondary compounds. Vitamin E analysis is particularly important because its deficiency maybe a factor in haemolytic anemia that is an important cause of mortality in captive black rhinos (Miller et al. 1986; Dierenfeld et al. 1988; Ghembremeskel et al. 1988). There is also need to determine the seasonal variation of nutrients in black rhino food plants. This study was conducted in one season and did not address the effect of season on plant chemical composition. Studies in savanna ecosystems (Boutton et al. 1988) have shown that seasonal changes occur in the concentrations of nitrogen, phosphorus, potassium and calcium. These changes appear to be related to seasonal moisture inputs which make conditions favorable for plant growth and nutrient uptake. More nutritional studies will lead to a wide array of practical improvements in black rhino management and conservation both in the wild and captivity.

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CHAPTER VI

APPLYING OPTIMAL FORAGING APPROACH TO BLACK RHINO (*Diceros bicornis*) CONSERVATION AND MANAGEMENT

CONSERVATION STATUS OF BLACK RHINO

The black rhino, like all the other Rhinocerotidae, is endangered across its range despite legislation taken to protect it (Hamilton and King 1969; Hillman and Martin 1979; Hillman 1980; Western and Sindiyo 1972; Western 1982, Western and Vigne, 1985; Cummings et al. 1990). This species which once occupied most of sub-sahara Africa and numbered into the hundreds has experienced a catastrophic decline both in numbers and extent of its range. Numbers dropped from an estimated 65000 animals in 1960s to approximately 3800 in 1987 (Ashley et al. 1990). This represents 95% decline in two decades. In Kenya the black rhino population dropped in numbers from an estimated 20,000 animals in 1970 to under 500 in the early 1980's (KRCP 1993).

As with all endangered species, loss of habitat has been an important but not the major cause of rhino's decline. The greatest problem is over-exploitation through illegal hunting (poaching) for the horn (Martin 1979; 1983). The main use of the rhino horn is in Chinese traditional medicine, in which it is used to reduce fever associated with serious illness, and as an aphrodisiac. The horn is also used in the Middle East to make dagger handles that confer social status. Unfortunately, the rhino is still in grave danger because the price of the horn has risen accordingly as it becomes rare and harder to find. The rhino has been referred to as a good example of a species that is disappearing much more rapidly than its habitat.

Efforts to rehabilitate black rhino populations have centered on anti-poaching campaigns and legislation as well as introductions of laws that prohibit trade of the rhino's horn. The black rhino is listed in appendix I of CITES (Convention on International Trade in Endangered Species of wild fauna and flora). IUCN (International Union for the Conservation of Nature and Natural Resources - The World Conservation Union) has created a Species Survival Commission Specialist Groups that deal with the conservation needs of endangered species like the rhino (IUCN 1982). Zoos have introduced captive breeding programs for rhinos and other endangered species. They have also initiated and funded research and educational activities that address rhino's management needs and raise awareness of its plight.

Pioneering conservation strategies in Kenya included translocation of rhinos from areas of low rhino density and unprotected areas to small protected Rhino Sanctuaries within their former range. There has increased security for black rhinos within Sanctuaries which usually have electric fences. As a result of these efforts, the black rhino population is stable and an increasing throughout much of Africa. In Kenya, the current black rhino population is estimated at 650 animals (Rhino Conservation Program 2000), this total number being fragmented across 19 populations. The annual growth rate is approximately 5%. As adequate numbers of black rhinos breed up in these Sanctuaries, the surplus rhinos will be translocated to selected larger areas of their former range. In the past, black rhinos have been re-introduced into areas based on previous history of high density of black rhinos, rainfall data, low poaching risks and areas with no known disease or other health risks.

Critical measures have to be implemented to ensure the successful management of black rhino populations in Sanctuaries, including those managed for maximum sustained breeding output and avoidance of overpopulation. These include developing viable security measures to protect rhinos and eliminate poaching, designing effective population and ecological monitoring programs and encouraging management driven research on all important aspects such as genetics, diseases, diet and nutrition and habitat interactions. Conservation activities in Kenya have included detailed census and identification of black rhinos in order to determine population parameters such as annual population performance, recruitment rate, age structure, and densities of rhinos in each area. Population dynamics of other grazing and browsing herbivores, as well as predator species in Rhino Sanctuaries are routinely assessed.

Long-term vegetation monitoring has been conducted in some Rhino Sanctuaries. This entails routine ground photography from fixed points at the end of wet and dry seasons, and use of beacons to mark long-term transects. Ground monitoring techniques (quadrats, line and belt transects, point centered quarter - PCQ) have been used to identify and determine browse abundance and availability to black rhinos. Although these are valid techniques, they are time consuming and costly. They also yield little information because data collection methods are not consistent from year to year. Therefore it is difficult to analyze and compare information statistically and the resulting data set often go unutilized. This shortcoming can be minimized by designing standardized techniques and selecting representative plots that can be sampled effectively. Ecological indicators can be chosen (Noss 1990a) since it is difficult to measure biodiversity in totality. For monitoring vegetation, indicators that collectively represent multiple levels of organization (populations, species, communities, ecosystems and landscapes) should be selected.

The health status of black rhino populations is critical in management of rhinos in Sanctuaries. Disease resistance and monitoring in Kenya are being done in collaboration with regional research institutions (International Center for Insect Physiology – ICIPE, International Laboratory for Research on Animal Disease – ILRAD, and Kenya Trypanosomiasis Research Institute – KETRI) (Rhino Conservation Program 2000). Information from these studies is used to establish the feasibility of translocating black rhinos from upland areas of Kenya, free from tsetse fly and trypanosomiasis, to lowland tsetse fly invested areas. Endo-parasite loads of translocated rhinos are monitored by Kenya Wildlife Service Veterinary Department. Proper nutritional status is crucial to maintaining and propagating black rhino populations. Nutritional studies are lacking in most of the rhino conservation areas. There is need to analyze the chemical composition of black rhino food plants because it influences diet choice and habitat suitability. Some areas (for example Lake Nakuru National Park (Jonyo 1987)) suffer from deficiencies of certain minerals in the soil and browse. Mineral studies are needed to determine the potential impact of these deficiencies on the health and breeding of rhinos in these areas.

To avoid the accumulation of data from various research projects, appropriate computer databases need to be established. To be most useful, information from long-term monitoring and research must be coordinated, accessible, and applicable. Databases not only provide important facilities for storage and manipulation of data over long periods of time, they also facilitate a wider usage of the information acquired from long term studies and minimize duplication of research effort. Proper dissemination of information (publications, seminars and conferences) is also important as it increases awareness.

As data becomes available, the value of computer modeling and projections of future performance of black rhino populations increases. Scientists have developed Population Viability Analysis (PVA) models (Harris et al. 1987; Menges 1990; Shaffer 1990; Kinnaird and O'brien 1991; Lacy and Kreeger 1992; Possingham et al. 1993; Hamilton and Moller 1995; Gilpin 1996) that estimate the Minimum Viable Population (MVP) for any given species in any given habitat that has a 99% chance of remaining extant for a thousand years (Shaffer 1981). These models take into consideration demographic, environmental, and genetic stochasticity, and natural catastrophes. Conservation biologists and wildlife managers can use PVA to aid in management of black rhino and to determine carrying capacities for Rhino Sanctuaries. PVA models are information hungry models that require currently available data and theory both of which contain some degree of uncertainty and inaccuracy.

USING OPTIMAL FORAGING APPROACH TO ASSESS PATCH USE BEHAVIOR IN BLACK RHINO

I applied an optimal foraging approach to assess patch use behavior in black rhinoceros. This approach improves over previous techniques because it integrates aspects of foraging ecology of black rhino that influence diet choice and habitat selection. I applied this approach by measuring forage availability, bite diameters, and browsing intensity of black rhinos in three Rhino Sanctuaries in Kenya, comparing behaviors in both wet and dry season. Mean bite diameters and number of bites was used as an index of food patch utilization. We considered individual food plants (trees and shrubs) as food patches (Astrom et al. 1990)

The study was conducted in three black rhino conservation areas in Kenya. The Salient area of Aberdares National Park (upland forest), Nairobi National Park (mesic savanna), and Ngulia Rhino Sanctuary (dry wooded savanna) in Tsavo West National Park. These areas represent the range of all potential habitats for black rhinos in Kenya. They are important black rhino conservation areas and support significant numbers of black rhinos. The overall abundance of food and the plant species browsed by black rhinos differs in these areas. The Salient covers an area of 70 km^2 and has an estimated population of 50 black rhinos. Nairobi NP occupies an area of 114.8km^2 and supported 60 black rhinos at the time of the study. Ngulia Rhino Sanctuary occupies an area of 73 km^2 and at the time of the study there were approximately 45 rhinos.

Feeding surveys were conducted in the wet season (Aberdares: October-November 1998, Nairobi: July-August 1998, Ngulia: December 1999), and dry season (Aberdares: August-September 1999, Nairobi: October-November 1999, Ngulia: September 1998). Of all the plants we sampled, 57% are browsed by black rhinos in Aberdares, 65% in Nairobi and 70% in Ngulia. In Aberdares, 82 food plants were identified as black rhino food plants in the wet season and 54 in the dry season. In Nairobi, 43 food plants were identified in the wet season and 68 in the dry season. We recorded 37 food plants from Ngulia Rhino Sanctuary in the wet season and 51 in the dry season.

This study revealed that black rhinos approached each food plant differently. Mean bites and bite diameters differed significantly between food plants and between study sites. I observed some seasonal variation in the number of bites and bite sizes selected by rhinos. In Aberdares, season had a significant effect on mean number of bites and percent browse, and no effect on mean bite diameter. Mean number of bites was higher in the wet season and percent utilization was higher in the dry season. Only mean bite diameter showed a strong plant-season interaction. In Nairobi NP, season had a strong effect on mean number of bites and mean bite diameter. There was a strong plant-season interaction on all variables. I recorded more and bigger bites in the wet season than in the dry season. Percent utilization was higher in the dry season. In Ngulia, there was a strong effect of season mean bite diameter. Black rhinos selected bigger bite diameters during the dry season. There was no significant difference in mean number of bites and percent utilization between seasons. Strong plant-season interactions were observed for all variables except percent utilization.

By assessing patch use behavior, I was able to quantify food preferences and diet choice. Black rhino's decision to eat or reject a food plant upon encounter can be used to compute percent preference. I used this technique to rank preferences for all the identified food plants. Quantifying preferences provides a basis for determining food quality by carrying out chemical analyses of black rhino diets. The nutritional value and levels of plant secondary compounds can be determined for highly preferred plants and results compared with those of less preferred plants in the system. By doing this, we can determine the chemical composition in their diets and use the information to formulate diets for captive rhinos. I conducted preliminary nutritional studies on two categories of selected black rhino food plants, those that were highly preferred and those less preferred. The plant samples were analyzed for percent nitrogen, fat, crude fiber, phosphorus, iron, zinc, calcium, magnesium, sodium, potassium and condensed tannins. Interestingly, the results suggest that black rhinos prefer food plants which contain low levels of nitrogen and condensed tannins.

Mean bite diameter can provide an indication of how black rhinos utilized various food plants given their availabilities. This can be done by comparing potential or available twig diameter on a plant species basis with the actual mean bite diameter selected by black rhinos. This provides a way of determining the critical food plants in black rhino conservation areas. In this study, I grouped food plants into three categories depending on their potential or available twig diameters and the actual mean bite diameters. I chose a mean bite diameter of 5.5mm (the median value for mean bite diameter) to be the dividing line between small and large bite diameter. The first category are food plants with small (<5.5mm) actual mean bite diameter due to their small twig size. These plants, high quality at low quantity, may be valuable to rhinos but do not offer much off-take due to their small stature. The second category are food plants with large (>5.5mm) potential twig diameter and small actual mean bite diameter. These plants, high quantity at low quality, may not be particularly valuable to black rhinos and may be fed on less in the presence of preferred plants. The third category are food plants that have a large (>5.5mm) potential twig diameter and large actual mean bite diameter. These are high quality-high quantity plants and are critical because they are both preferred by black rhinos and offer large amounts of browse material.

Bites and mean bite diameter data can be used to estimate the amount of food harvested by black rhinos from each plant species. Representative sprigs can be cut at bite diameters selected by black rhinos, dried and weighed to determine the contribution of each food plant to the black rhino's diet. Such estimations can be carried out on preferred and critical food plants. I collected sprigs from plants of the same species that were browsed by black rhinos. Sprigs were cut off at the biggest bite diameter selected from the particular plant species by black rhinos. The results indicate that estimated food off-take significantly increased with increasing bite diameter hence rhinos can adjust food intake by varying the number of bites and mean bite diameter.

Feeding survey and data from vegetation sampling plots can be used to determine suitable habitats for black rhino. A mean habitat suitability index can be derived by dividing the sum of the utilization indices for each food plant represented in the sampling plots by the total number of plants in the plot. The variance explains the extent to which a rhino can be selective at the habitat level. The variance also gives an indication of how variable habitats are and their distribution in a given area. The mean habitat suitability indices from our study suggest that Ngulia sanctuary is the most suitable habitat for the black rhino followed by Nairobi, and Aberdares as the least suitable. This index should be incorporated to routine vegetation monitoring programs as a means of continuously assessing habitat quality.

EXPLORING BLACK RHINO'S BITE SIZE AND PATCH USE BEHAVIOR AS AN INDICATOR FOR ENVIRONMENTAL CHANGE

Behavioral indicators can be used to translate the animal's experiences and responses into meaningful assessments of their ecology. Traditional programs rely on long term ecological monitoring that emphasize repeated vegetation sampling and animal censuses. At best, these are trailing indicators of environmental quality; by the time these metrics suggest a problem, the problem has already occurred. While these data may indicate whether management has succeeded, such data are poor indicators of future problems, and may give incorrect assessments of current and future population viability and habitat quality. Behavior, in contrast, can provide early indicators and can afford a quick, seamless integration of monitoring, assessment and appraisal of success.

Black rhino's bite size and patch use behavior can provide insights into habitat suitability and changes in suitability. Changes may include fluctuation in food, competition, human activity, predators or other factors that have management and conservation implications. Previous studies have shown that black rhinos forage selectively with strong preferences for certain food plants. Habitat changes can be determined by monitoring bite sizes and intensity of browse for highly preferred food plants. Bigger bites and higher browse intensity can indicate preferences. Also, bigger bites and high browsing intensity environment wide can indicate declining habitat quality due to a decrease in overall food availability, increased competition and higher predation risk. Similar environmental changes can be detected through changes in patch use behavior such as opportunistic versus selective behavior.

Monitoring bite sizes and intensity of browse for highly preferred food plants can form a baseline to observe habitat changes. In the case of black rhino, these measures can provide an inexpensive and less time consuming way of obtaining information which can be used by managers to make decisions regarding animal translocations, expansion of sanctuaries and habitat improvements. My study provides baseline information that can be used to design long-term ecological programs.

The techniques employed in this study are not complex and can be communicated and understood easily by park managers, rangers and conservation biologists. These techniques can be integrated into management plans and incorporated into routine ecological monitoring activities. Collection of data can be achieved using simple devices such as a caliper and tape measure. Information can be gathered by rangers while patrolling Rhino Sanctuaries on foot and can later be entered in rhino databases along with population dynamics data. Park managers and rangers can be trained on data collection methods and provided with the necessary tools.

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APPENDIX: BLACK RHINO FOODPLANTS FROM ABERDARES, NAIROBI AND NGULIA RHINO SANCTUARY

A. Black rhino food plants from Salient, Aberdares National Park

Plant name	Family name	Plant name	Family name
Abutilon longicuspe	Malvaceae	*Pentas lanceolata*	Rubiaceae
Abutilon mauritianum	Malvaceae	*Phytolacca dodecandra*	Phytolaccaceae
Achyranthes aspera	Amaranthaceae	*Pluchia ovalis*	Compositae
Achyrospermum schimperi	Labiatae	*Rhamnus prinoides*	Rhamnaceae
Asparagus africanus	Asparagaceae	*Rhamnus staddo*	Rhamnaceae
Blepharis maderaspatensis	Acanthaceae	*Rhus natalensis*	Anacardiaceae
Calodendrum capense	Rutaceae	*Rytigynia uhligii*	Rubiaceae
Clausena anisata	Rutaceae	*Scutia myrtina*	Rhamnaceae
Clerodendrum johnstonii	Verbenaceae	*Senecio syringifolius*	Compositae
Clutia abyssinica	Euphorbiaceae	*Senna septemtrionalis*	Caesalpiniaceae
Commelina africana	Commelinaceae	*Senna didymobotrya*	Caesaipiniaceae
Conyza bonariensis	Compositae	*Sida cordifolia*	Malvaceae
Conyza newii	Compositae	*Sida rhombifolia*	Malvaceae
Crassocephalum sp	Compositae	*Sida schimperana*	Malvaceae
Crotalaria incana	Papilionaceae	*Sida tenuicarpa*	Malvaceae
Croton macrostachyus	Euphorbeaceae	*Solanecio angulatus*	Compositae
Dovyalis abyssinica	Flacourtiaceae	*Solanum aculeastrum var 1*	Solanaceae
Ehretia cymosa	Boraginaceae	*Solanum aculeastrum var 2*	Solanaceae
Erythrococca bongensis	Euphorbeaceae	*Solanum incanum*	Solanaceae
Euclea divinorum	Ebenaceae	*Solanum mauense*	Solanaceae
Euphorbia schimperana	Euphorbiaceae	*Solanum nigrum*	Solanaceae
Hibiscus callyphylus	Malvaceae	*Solanum sp*	Solanaceae
Hibiscus fuscus	Malvaceae	*Sp A*	not identified
Hibiscus vitifolius	Malvaceae	*Teclea nobilis*	Rutaceae
Hyoestes forskahlii	Acanthaceae	*Teclea simplicifolia*	Rutaceae
Hypoestes aristata	Acanthaceae	*Tephrosia sp*	Papilionaceae
Hyppoestes verticillaris	Acanthaceae	*Toddalia asiatica*	Rutaceae
Indigofera arrecta	Papilionaceae	*Triumfetta sp*	Tiliaceae
Juniperus procera	Cypressaceae	*Urtica massaica*	Urticaceae
Lantana trifolia	Verbenaceae	*Vangueria infausta*	Rubiaceae
Leonotis mollissima	Labiatae	*Vernonia auriculifera*	Compositae
Leucas deflexa	Labiatae	*Vernonia galamensis*	Compositae
Leucas grandis	Labiatae	*Vernonia sp*	Compositae
Leucas urticifolia	Labiatae	*Vernonia ssp galamensis*	Compositae
Maytenus senegalensis	Celastraceae		
Nuxia congesta	Loganiaceae		
Ocimum gratissimum	Labiatae		
Olea europaea	Oleaceae		
Pavonia patens	Malvaceae		
Pavonia urens	Malvaceae		

B. Black rhino food plants from Nairobi National Park

Plant name	Family name	Plant name	Family name
Abutilon mauritianum	Malvaceae	*Euphorbia bongensis*	Euphorbiaceae
Acacia brevispica	Mimosaceae	*Fuerstia africana*	Labiatae
Acacia drebanolobium	Mimosaceae	*Gnidia subcordata*	Thymeleaceae
Acacia elatior	Mimosaceae	*Gomphorcarpus semilunatus*	Asclepiadaceae
Acacia etbaica	Mimosaceae	*Gomphorcarpus stenophylus*	Asclepiadaceae
Acacia gerrardii	Mimosaceae	*Grewia bicolor*	Tiliaceae
Acacia kirkii	Mimosaceae	*Grewia similis*	Tiliaceae
Acacia melifera	Mimosaceae	*Grewia tembensis*	Tiliaceae
Acacia seyal	Mimosaceae	*Gutenbergia cordeifolia*	Compositae
Acacia stuhlmannii	Mimosaceae	*Heliotropium steudneri*	Boraginaceae
Acacia xanthophloea	Mimosaceae	*Hermannia uhligii*	Sterculiaceae
Acalypha fruticosum	Euphorbiaceae	*Hibiscus aponeurus*	Malvaceae
Achyranthes aspera	Amaranthaceae	*Hibiscus calyphylus*	Malvaceae
Aeschynomene schimperi	Papilionaceae	*Hibiscus flavifolius*	Malvaceae
Ageratum conyzoides	Compositae	*Hibiscus fuscus*	Malvaceae
Albizia amarus	Mimosaceae	*Hypoestes triflora*	Acanthaceae
Allophylus rubifolius	Sapindaceae	*Hypoestes verticillaris*	Acanthaceae
Asparagus africana	Smilacaceae	*Indigofera arrecta*	Papilionaceae
Asparagus flagellaris	Smilacaceae	*Indigofera schimperi*	Papilionaceae
Aspilia mosambicensis	Compositae	*Indigofera swaziensis*	Papilionaceae
Aspilia pluriseta	Compositae	*Indigofera volkensii*	Papilionaceae
Astrpomea kyoscyamoides	Convolvulaceae	*Jasminium abyssinica*	Oleaceae
Balanites aegyptiaca	Balanitaceae	*Justicia anagalloides*	Acanthaceae
Barleria erathemoides	Acanthaceae	*Justicia flava*	Acanthaceae
Becium obovatum	Labiatae	*Kalanchoe sp*	Crassulaceae
Bidens pilosa	Compositae	*Lantana camara*	Verbenaceae
Brachaelena sp	Compositae	*Lantana trifolia*	Verbenaceae
Calpurnea aurea	Papilionaceae	*Lawsonia inermis*	Lythraceae
Capparis tomentosa	Capparaceae	*Leonotis ocymifolia*	Labiatae
Carissa edulis	Apocynaceae	*Leucas glabrata*	Labiatae
Cissus quadrangularis	Euphorbiaceae	*Leucas grandis*	Labiatae
Clerodendrum myricoides	Verbenaceae	*Lippia javanica*	Verbenaceae
Commelina benghalensis	Commelinaceae	*Lippia kituensis*	Verbenaceae
Commiphora schimperi	Burseraceae	*Lycium europaeum*	Solanaceae
Conyza stricta	Compositae	*Maerua decumbens*	Capparaceae
Conyza sumatrensis	Compositae	*Maytenus heterophylla*	Celastraceae
Cordia monoica	Boraginaceae	*Maytenus senegalensis*	Celastraceae
Crotalaria brevidens	Papilionaceae	*Microglossa densiflora*	Compositae
Crotalaria keniensis	Papilionaceae	*Monechma debile*	Acanthaceae
Croton dichogamous	Euphorbiaceae	*Nasea lythroides*	Lythraceae
Cussonia sp	Araliaceae	*Nepeta azurea*	Labiatae
Cyprus renschii	Cyperaceae	*Nicotiana glauca*	Solanaceae

Nairobi food plants continued

Plant name	Family name	Plant name	Family name
Dombeya burgessiae	Sterculiaceae	*Ochna holstii*	Ochnaceae
Dombeya burgessiae	Sterculiaceae	*Ocimum gratissimum*	Labiatae
Dovyalis caffia	Flacourtiaceae	*Ocimum kituensis*	Labiatae
Elaedendron buchananii	Celastraceae	*Olea europaea*	Oleaceae
Englerastrum scandens	Compositae	*Ormocarpum kirkii*	Papilionaceae
Euclea divinorum	Ebenaceae	*Ormocarpum sp*	Papilionaceae
Pavonia patens	Malvaceae	*Sida rhombifolia*	Malvaceae
Pavonia urens	Malvaceae	*Sida tenuicarpa*	Malvaceae
Phyllanthus fischeri	Euphorbiaceae	*Solanum incanum*	Solanaceae
Phyllanthus schimperi	Euphorbiaceae	*Sphaeranthus suaveolens*	Compositae
Plectranthus caninus	Labiatae	*Tagetes minuta*	Compositae
Polygonum setosulum	Polygonaceae	*Teclea nobilis*	Rutaceae
Psiadia punctulata	Compositae	*Teclea simpliciflora*	Rutaceae
Pupalia lappacea	Amaranthaceae	*Tephrosia hildebrandtii*	Papilionaceae
Rhamnus staddo	Rhamnaceae	*Tragia brevidens*	Euphorbiaceae
Rhus natalensis	Anacardiaceae	*Triumfetta rhomboides*	Sterculiaceae
Rhus terminervus	Anacardiaceae	*Turraea mombassana*	Meliaceae
Rhynchosia minima	Papilionaceae	*Verbena bonariensis*	Verbenaceae
Sarcostemma viminale	Asclepiadaceae	*Vernonia lasiopus*	Compositae
Schrebera alata	Oleaceae	*Waitheria indica*	Sterculiaceae
Scutia myrtina	Rhamnaceae	*Warbugia ugandensis*	Canellaceae
Sida ovata	Malvaceae	*Ziziphus mucronata*	Rhamnaceae

C. Black rhino food plants from Ngulia Rhino Sanctuary

Plant name	Family name	Plant name	Family name
Abutilon fruticosa	Malvaceae	*Premna holstii*	Verbenaceae
Abutilon mauritianum	Malvaceae	*Premna resinosa*	Verbenaceae
Abutilon sp	Malvaceae	*Ruellia megachlamys*	Acanthaceae
Acacia brevispica	Mimosaceae	*Sericomopsis hildebrandtii*	Amaranthaceae
Acacia tortilis	Mimosaceae	*Sericomopsis pallida*	Amaranthaceae
Acalypha fruticosum	Euphorbiaceae	*Sida ovata*	Malvaceae
Albizia sp	Mimosaceae	*Solanum incanum*	Solanaceae
Astripomea lyoscyamoides	Convolvulaceae	*Solanum renschii*	Solanaceae
Barleria spinosa	Acanthaceae	*Sterculia africana*	Sterculaceae
Barleria teitensis	Acanthaceae	*Strychnos decussata*	Loganiaceae
Bauhinia taitensis	Caesalpinaceae	*Tephrosia villosa*	Papilionaceae
Boscia angustifolia	Capparaceae	*Tinnea aethiopica*	Labiatae
Boscia coriaceae	Capparaceae	*Tragia ukambensis*	Euphorbiaceae
Cadaba farinosa	Capparaceae	*Waitheria indica*	Sterculaceae
Cassia abbreviata	Caesalpinaceae	*Lannea alata*	Anacardiaceae
Catunaregum spinosa	Rubiaceae	*Melhania velutina*	Sterculaceae
Combretum apiculatum	Combretaceae	*Melia volkensii*	Meliaceae
Combretum exalatum	Combretaceae	*Ochna inermis*	Ochaceae
Commelina latifolia	Commelinaceae	*Ocimum americanum*	Labiatae
Commiphora africana	Burseraceae	*Premna holstii*	Verbenaceae
Commiphora madagascariensis	Burseraceae	*Premna resinosa*	Verbenaceae
Cordia monoica	Boraginaceae	*Ruellia megachlamys*	Acanthaceae
Cordia somalensis	Boraginaceae	*Sericomopsis hildebrandtii*	Amaranthaceae
Croton sp	Euphorbiaceae	*Sericomopsis pallida*	Amaranthaceae
Delonix elata	Caesalpinaceae	*Sida ovata*	Malvaceae
Duosperma kilimandscharica	Acanthaceae	*Solanum incanum*	Solanaceae
Echbolium revolutum	Acanthaceae	*Solanum renschii*	Solanaceae
Ehretia teitensis	Boraginaceae	*Sterculia africana*	Sterculaceae
Erythroclamys spectabilis	Labiatae	*Strychnos decussata*	Loganiaceae
Erythrococca bongensis	Euphorbiaceae	*Tephrosia villosa*	Papilionaceae
Grewia bicolor	Tiliaceae	*Tinnea aethiopica*	Labiatae
Grewia nematopus	Tiliaceae	*Tragia ukambensis*	Euphorbiaceae
Grewia tembensis	Tiliaceae		
Grewia villosa	Tiliaceae		
Helinus integrifolius	Rhamnaceae		
Helinus mystacinus	Rhamnaceae		
Hermannia uhligii	Sterculaceae		
Hibiscus canabinus	Malvaceae		
Hibiscus micranthus	Malvaceae		
Hoslundia opposita	Labiatae		
Indigofera arrecta	Papilionaceae		
Indigofera spinosa	Papilionaceae		
Ipomea hildebrandtii	Convolvulaceae		

VITA

ALINA J. KIPCHUMBA

Educational Background:

Major: Ecology (Conservation biology)

B.S. Range Management: 1991
University of Nairobi, Nairobi. Kenya.

Ph. D. Biological Sciences (Ecology and evolution): 2002
University of Illinois at Chicago, Chicago, Illinois. USA

Honors and Awards:

Grant from MacArthur Foundation to attend Advanced Training in Tropical Biodiversity Conservation (ATP) at the Field Museum, Chicago. Fall, 1994.

Grant from Rockfeller Foundation, African dissertation internship Awards, to conduct research in Kenya (1998-1999).

Grant from Chicago Zoological Society to travel to Kenya to conduct research (1998).

Grant from Lincoln Park Zoological Society to conduct research in Kenya (1999).

Grant from Chicago Training Consortium to present paper at the African Rhino Specialist Group meeting in Tanzania (2000).

Grant from the University of Illinois at Chicago, Biology Department and graduate school to present paper at the International Theriological Conference in South Africa (2001).

Award for excellence in teaching from the Department of Biological Sciences, University of Illinois at Chicago. March 2002.

Professional societies:

Society for Biological Conservation

African Rhino Specialist Group