MAINTENANCE OF CAPTIVE BLACK RHINOCEROS (*DICEROS BICORNIS*) ON INDIGENOUS BROWSE IN ZIMBABWE: ENERGETICS, NUTRITION AND IMPLICATIONS FOR CONSERVATION

By

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ABSTRACT

Poor nutrition has been implicated as a key factor contributing to the high levels of morbidity and mortality seen in captive black rhinos, *Diceros bicornis*. The translocation of four adult black rhinos to the Intensive Management Centre (IMC) at Sinamatella, Hwange National Park, in January 1995 led to the question of how best to maintain these endangered animals whilst in captivity.

To provide a basis for deciding which indigenous browse species to feed to the captive rhinos at different times of the year, an indirect method of observation was used to gather data on diet composition, feeding preferences and habitat selection of the free-ranging rhinos in the vicinity of the IMC. A feeding preference index for available browse was determined from plant availability and usage data. Feeding preference and digestibility trials were carried out on the captive rhinos to determine whether captive rhinos could be maintained on diets of indigenous cut browse as well as to elucidate the basis of browse preferences. Chemical analyses (crude protein, ash, NDF, ADF, ADL and condensed tannin) of both the browse species fed to the captive rhinos during the feeding and digestibility trials were also determined.

Free-ranging black rhinos were recorded to feed on a total of 113 plant species during the study period of which woody plants were the most important, contributing >90 % to the overall diet in both the wet and early dry seasons. Dietary preferences were, however, noticeably seasonal. During the wet season the free-ranging rhinos foraged in a variety of habitats but during the dry season riverine habitats were highly preferred.

When a wide range of indigenous browse species was provided (12 species), mean daily food intake for the captive rhinos (of known body mass) was 58 kg wet weight (25 kg dry mass). Intake dropped, however, when a limited number of species was on offer. Results from the preference trials indicated that the patterns of browse selection exhibited by the captive animals were as predicted from the studies on the free-ranging population. No correlation, however, could be found between the tissue fractions assayed and browse preferences. Ingestion rates were lower for spinescent species (73 g DM/min) compared to non-spinescent species (116.6 g DM/min).

Mean dry matter digestibilities varied between 28-50 % during the trials, with digestibilities following a pattern of decline as the dry season progressed. Each diet appeared able to provide sufficient crude protein to meet daily requirements but energy appeared to become limiting, dropping below field metabolic requirements during the dry season. Management recommendations are presented for maintaining captive black rhinos on diets of indigenous browse.

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1. INTRODUCTION

1.1 Background to the study

Africa's black rhinoceros, *Diceros bicornis*, is one of the world's most endangered large mammals and like other charismatic species such as the giant panda, *Ailuropoda melanoleuca*, has come to epitomise the global conservation effort of the 1990s. As the primary agent of decline is of human making (Cumming *et al*, 1990), the survival of the species lies at the hand of man; the outcome viewed by many to represent a gauge on which the future survival of the continent's biodiversity can be measured.

In the late 1960s there was an estimated 65000 black rhinos living on the African continent (Cumming *et al.* 1990) but the last three decades have witnessed a 96 % decline in the population to a remaining 2550 individuals by 1994 (Brooks, 1994). Although habitat loss has occurred throughout its former range, it has been commercial poaching, as a result of the demand for rhino horn, that has brought about the catastrophic decline of the population (Cumming *et al.* 1990).

In 1980 Zimbabwe still had a healthy black rhino population, estimated at approximately 3000 animals (DNPWLM, 1993), but by 1984 commercial poaching had commenced along the northern border (Tatham and Taylor, 1989). Despite a major effort in law enforcement (Nduku and Martin, 1991), at least 782 black rhinos were known to have been poached between 1984 and 1990 (Martin, 1991). Recognising the futility of distributing limited conservation efforts over dispersed free-ranging populations, the Department of National Parks and Wild Life Management (DNPWLM) developed a black rhino conservation strategy that incorporated several components (Nduku and Martin, 1991). These included improved law enforcement within specific regions of the Parks and Wild Life Estate (PWLE), the establishment of breeding nuclei on private land and both *in-situ* and *ex-situ* captive breeding programmes. As a result more than 300 black rhinos have been captured, confined to captivity and translocated from areas of high poaching risk to private land, specific areas within the PWLE or overseas programmes since 1986 (Kock *et al.* 1990, Kock, 1993). In addition, an experimental dehorning operation of white rhinos in Hwange National Park was carried out in 1991, but the continued loss of black rhinos, due to poaching, led to a decision to dehorn as many black and white rhinos as possible within Zimbabwe (Kock and Atkinson, 1993). Despite these efforts, by September 1993 the national black rhino population had dropped to less than 300 animals (DNPWLM, 1993).

In recognition of the crisis situation, the DNPWLM adopted the concept of Intensive Protection Zones (IPZs) to safeguard the remaining animals within the PWLE (DNPWLM, 1993). Four areas, including the Sinamatella/Deka Safari Area (Hwange National Park) were selected on the basis of several criteria, namely suitability of habitats, size of the resident population of black rhinos and the possibility of effective patrolling and response. The strategy also included the capture and relocation of outlying animals into IPZs to afford them increased protection as well as improving the viability of the sub-population within the IPZ boundary (DNPWLM, 1992).

The level of management of the rhino population has clearly changed dramatically over the past decade with the surviving animals being more intensively managed than ever before. It is becoming increasingly common practice to confine animals to bomas over extended periods of time prior to their release or shipment to overseas breeding programmes. Despite improvements in capture techniques resulting in negligible direct capture related mortality, there have been a number of problems associated with the confinement of black rhinos to captivity, which greatly affect the health and long term survival of the captive rhinos (Veterinary Unit, 1995). Black rhinos have a poor record for thriving in captivity, often succumbing to disease or death. The main reason for this is that these animals are susceptible to several disease syndromes that appear unique to the species (Miller, 1994). Numerous investigations have been carried out to determine the aetiology of these captive-related diseases (Kock *et al.* 1992; Miller, 1994; Paglia 1994, in press) and whilst no common link has been found, poor nutrition and consequently nutritional stress have been implicated as key factors contributing to the high levels of morbidity and mortality seen in captive black rhino (Kock *et al.* 1992; Miller, 1993; Kock and Morkel, in press; Miller, in press). Inadequate nutritional management during *in-situ* translocation programmes, particularly with regard to the quantity and diversity of browse species presented to captive animals, has also exacerbated the situation, contributing to further mortalities (du Toit, 1994).

In 1994, an Intensive Management Centre (IMC) for black rhinos was constructed within the Sinamatella IPZ to provide a facility to carry out essential research (see section 2.2). Included in the list of research topics was the nutritional management of captive rhinos (Veterinary Unit, 1995). Much of the previous work carried out on black rhino nutrition has focused on either zoo animals fed artificial diets or free-ranging animals. Studies to determine the diet composition of wild black rhinos are clearly essential to establish baseline norms, but if animals are to continue to be confined, for translocation or breeding purposes, research also needs to focus on the nutritional evaluation of indigenous browse diets fed to captive animals.

There is also the need to habituate translocated rhinos to the vegetation at the release site. Nearly all woody plant species contain potentially toxic secondary metabolites, the level of toxicity varying both temporally and spatially (Bryant *et al*, 1991). Learning provides the mechanism necessary for herbivores to maintain nutritional homeostasis in such an environment (Bryant *et al*, 1991). By determining which plant species are important to the free-ranging rhinos at the release site, captive rhinos can be introduced to novel browse species affording them the opportunity to become familiar with these plants and adjust intake levels to avoid intoxication prior to their release.

This study therefore aims to carry out an evaluation of diets fed to captive black rhinos at the Sinamatella IMC and make management recommendations that may assist in improving the future husbandry of these animals whilst in captivity.

1.2 Objectives and questions

The main objectives of this study are:

(1) to determine a rhino feeding preference ranking for available browse species in the area of the Sinamatella IMC;

(2) to utilise this information to determine whether captive rhinos feeding on cut browse exhibit the same feeding preferences as they would under natural conditions;

(3) to elucidate the basis of browse preferences exhibited by captive rhinos;

(4) to provide recommendations for the future management of captive black rhinos maintained on a diet of indigenous cut browse.

To achieve these, the following key questions were posed:

(1) What are the preferred plant species selected by free-ranging (radio-collared) black rhinos living within the study site?

(2) Is there a correlation between the browse preferences of the free-ranging black rhino population and those of the captive rhinos fed on indigenous browse?

(3) What are the intake rates and digestibilities of selected woody browse species fed to captive black rhinos?

(4) What are the mass-specific food requirements of black rhinos fed on freshly cut branches of preferred indigenous browse?

(5) Are there any correlations between browse preferences of captive black rhinos and related levels of the major nutritional constituents and secondary compounds in each browse type?

1.3 Black rhino feeding ecology: an overview.

The black rhinoceros, with a body mass of between 800-1300 kg, is one of Africa's largest browsing mammals (Skinner and Smithers, 1990). Its diet is characterised by an unusually wide variety of plant species, the number of species recorded as food plants varying between areas from 74 for Namibia's desert-dwelling rhinos (Loutit *et al*, 1987) to 191 species for rhinos living in Tanzania's Ngorongoro Crater region (Goddard, 1968).

With the aid of its prehensile upper lip, the black rhino feeds by manoeuvering food into the mouth, biting vegetation off with the premolar teeth and grinding it with massive molars (Skinner and Smithers, 1990). Browsing between heights of about 0.5 and 1.2 metres, with a maximum height of 2 m (Owen-Smith, 1992), rhinos normally select a bite that contains both leaf and twig material (Goddard, 1970; Mukinya, 1977). Depending on plant species, however, rhinos occasionally take either leaf or twig material only and in some cases have been recorded feeding on bark (Oloo *et al* ,1994). In general though, where possible, they are selective feeders, rejecting dry plant material (Goddard, 1968).

1.3.1 *Diet composition*

The contribution of woody plants, herbs, creepers and succulents to the diet vary both seasonally and regionally (Goddard, 1968, 1970; Hall-Martin *et al*, 1982; Loutit *et al*, 1987). Compared to East Africa, herbaceous plants tend to be less plentiful in many of the areas inhabited by black rhinos in southern Africa and in such areas woody plants appear to be relatively more important (Owen-Smith, 1992). Grass is fed on occasionally during the wet season but it constitutes a relatively small proportion of the diet, in some cases only being consumed as part of a mouthful that includes herbs or shrubs (Goddard, 1968: Mukinya, 1970).

In Tsavo East National Park, Kenya, black rhinos are predominantly ground feeders in that they select for herbaceous plants and shrubs and show distinctive preferences for legumes that include the genera *Tephrosia*, and *Caesalpinia* (Goddard, 1970). In the dry season, preferences were shown for green herbs such as *Justicia*, *Vernonia*, *Ipomoea* and *Hibiscus* while species of *Indigofora* were favoured as well as making up a large proportion of the diet, during both wet and dry seasons (Goddard, 1970). Similarly, in Masai Mara National Park, Kenya, rhinos also select for herbs and shrubs showing a marked preference for *Solanum incanum*, *Dichrostachys cinerea* and *Acacia* species (Mukinya, 1977). In contrast to the relatively open habitats of Tsavo, Ngorongoro Crater and Masai Mara, the rhinos inhabiting the dense bushlands of Laikipia Ranch, Kenya, exhibit preferences for woody shrubs and small trees that include various *Acacia* species (Oloo *et al*, 1994). During the wet season, however, several seasonally available plant species of the genus *Indigofora*, *Asparagus* and *Ferula* are favoured.

Woody shrubs are a preferred food source at Addo Elephant National Park, South Africa, but unlike many areas of East Africa herbs are less plentiful and less important (Hall-Martin *et al*, 1982). During dry periods succulent plants with high moisture contents like *Portulacaria* are generally well utilised. The importance, during dry periods, of plants with high moisture contents have also been noted in other areas. For example, in Kaokoland, Namibia, rhinos feed on *Euphorbia virosa* and *Merremia* spp., both of which have very high water contents (Loutit *et al*, 1987). Interestingly, the formidable spines, high tannin content and highly irritating latex of *E. virosa* do not deter rhinos. In fact, rhinos living in this environment are able to use plants that, because of their chemical defences, are unacceptable to most other herbivores.

In Etosha National Park, Namibia, woody plants comprise approximately 90% of the diet throughout the seasonal cycle, the residue being made up of herbs (Joubert and Eloff, 1971). Among the more important woody browse species are the *Acacia* species, *Grewia* species and *Terminalia prunoides*. Annual herbs contributing most to the diet are species of *Blepharis*, *Neorautenia*, *Ipomoea*, and *Hibiscus*. Other species recorded include *Grewia flavenscens*, *Combretum apiculatum*, *Combretum imberbe*, *Colophospermum mopane* and several species of *Commiphora*. As is the case in many regions of sub-Saharan Africa, the diets of black rhinos in the woodlands around Lake Kariba, Zimbabwe, show distinct seasonal changes (Jarman, 1971). Important wet season species such as *Holmskioldia tettensis*, *Combretum celastroides* and *Euphorbia espinosa* being replaced during the dry season by evergreens such as *Diospyros quiloensis* and various *Boscia* species.

1.3.2 *Chemical composition of browse*

The major functional division of all plant material (with regard to large herbivores) is between the cell constituents, composed primarily of sugars and starches (α-1-4- glycosides) and proteins, and the cell wall (or fibre), made up of structural material such as cellulose and hemicellulose (β-1-4-glycosides) and lignin (Van Soest, 1982; Dement and Van Soest, 1985). The cell contents are easily broken down by enzymes present within the mammalian digestive tract but like all other mammals, the black rhino lacks the enzymes capable of splitting long chain carbohydrates such as cellulose and hemicellulose (Van Soest, 1982; Langer, 1984). Instead they rely on enteric microbes to break down this plant material thereby making it available through anaerobic fermentation, the end product being volatile fatty acids (Clemens and Maloiy, 1982).

The non-carbohydrate substance lignin is resistant to digestion in mammals and consequently unavailable as a source of energy (Van Soest, 1982). In addition, it is the main factor responsible for limiting the digestibilities of the structural carbohydrates. Carbohydrates comprise between 50-80 % of the dry matter of forages and are the major source of energy for herbivores but physical encrustation of structural carbohydrates by lignin renders them inaccessible to breakdown. The availability of these potential energy sources are, therefore, variable, depending largely upon the degree of cell wall lignification (McDonald *et al*, 1981; Van Soest, 1982). In most cases, leaf material contains lower levels of lignin than woody material, making it more digestible than twigs or branches. Similarly, young plant tissue is generally less lignified than mature tissue (Van Soest, 1982).

The chemical composition of various rhino browse plants has been determined in Namibia (Joubert and Eloff, 1971; Loutit *et al*, 1987), Kenya (Ghebremeskel *et al*, 1991), South Africa (Hall-Martin *et al*, 1982) and Zimbabwe (Dierenfeld *et al*, in press). Although different methods of chemical analysis preclude direct comparisons between studies, some general trends emerge.

Crude protein levels vary between both browse species and seasons, ranging from 4 to 20 % of dry matter (Dierenfeld, 1995). In South Africa, the highest levels of protein were from samples collected in the spring (11 %) decreasing as the dry season progressed to roughly 9 % (Hall-Martin *et al*, 1982). A similar pattern was observed in Namibia (Joubert and Eloff, 1971). In Zimbabwe, the crude protein contents of samples collected during the dry season ranged from 6 to 21 %, with a mean of approximately 12 % (Dierenfeld *et al*, in press) while in Kenya, plant species collected at the end of the wet season contained between 3.5 and 13 % crude protein (Ghebremeskel *et al*, 1991). Bound protein levels recorded by Dierenfeld *et al* (in press) suggested, however, that the effective available protein of rhino browse was about 2% lower than recorded.

As with crude protein, there is variation between the crude fibre contents of different browse species (4 to 50 %). Mean crude fibre content of browse also varied between areas ranging from 22 to 42 % of dry matter. Only two studies have been undertaken that analyse the total cell wall contents (NDF) or the various fibre fractions, namely cellulose, hemicellulose and lignin of rhino browse. Samples from 26 browse species collected during the dry season in Zimbabwe revealed mean levels of 58 % cell wall, 26 % cellulose and 14 % lignin (Dierenfeld *et al*, in press). Similar mean values of 31 % cellulose and 11 % lignin were reported from 7 browse species collected in South Africa (Hall-Martin *et al*, 1982).

Apart from the variation in protein and fibre content, almost all woody plants contain potentially toxic secondary plant metabolites (Bryant *et al*, 1991). In a study carried out on various southern African browse plants, the highest leaf concentrations of condensed tannins were among species in the Caesalpiniaceae (*Burkea africana*), Anacardiaceae (*Sclerocarya birrea*) and Ebenaceae

(*Euclea* spp.), especially among evergreen species (Owen-Smith, 1993). The *Acacia* species, with the exception of *A. nilotica* and *A. karoo*, showed generally low levels of phenolics while species in the Combretaceae had high levels of total phenolics but low levels of condensed tannins. With tannin levels exceeding 10 % of dry mass, *Combretum hereroense* was, however, an exception.

Although, it has previously been suggested that plants with condensed tannin levels greater than 5 % were rejected by herbivores (Cooper and Owen-Smith, 1985), more recent work carried out on browsing ruminants suggests that the palatability of woody plant foliage to browsing is dependent on the difference between protein content and levels of secondary plant metabolites, represented by condensed tannins (Cooper *et al*, 1988). There is growing evidence, however, that different species of mammalian herbivore are not equally vulnerable to tannins in plants (Provenza *et al*, 1990), and plant species utilised by black rhinos often include browse species such as *Euphorbia* spp., which are ignored by other herbivores because of high tannin contents (Loutit *et al*, 1987).

Interestingly, in Zimbabwe, a number of deaths have occurred among rhinos translocated from the Zambezi Valley (arid-eutrophic savanna) to private conservancies in the Midlands (moist-dystrophic savanna), and these deaths were related to poor nutrition (du Toit, quoted in Owen-Smith *et al*, 1993).Theoretical predictions based on resource availability link the production of secondary metabolites to soil nutrient levels (Bryant *et al*, 1991). Consequently, it is suspected that higher levels of plant toxins in the browse of the nutrient poor soils at the release site may have contributed to these mortalities.

1.3.3 *Digestive physiology*

Average food intake values recorded for black rhinos in southern Africa range from approximately 28 - 40 kg (wet weight) per day (Emslie and Adcock, 1994a; Maddock *et al*, 1995). In contrast, work carried out on zoo animals fed artificial diets of grass hay and alfalfa hay (lucerne) reported dry matter intakes of 14 and 21 kg (1.1 and 1.6 % of body mass) respectively (Foose, 1982). The lower intake rates of grass hay compared with alfalfa hay may, however, have been due to the unacceptability of dry grass to black rhinos.

The digestive anatomy of the black rhino resembles that of equids (Owen-Smith, 1992). As non-ruminants or hindgut fermenters, black rhinos have a simple stomach and a voluminous and sacculated caecum (Clemens and Maloiy, 1982). Digestion and absorption of soluble carbohydrates, protein and fats takes place in the stomach, before the food residue undergoes fermentation (Langer, 1984; Clemens and Maloiy, 1991). The caecum, containing high concentrations of volatile fatty acids, is the principal site of microbial activity while further fermentation occurs in the colon (Clemens and Maloiy, 1982). Microbial decomposition of food, however, requires a considerable length of time and the pockets and folds in the walls of the hindgut appear to reduce the rate of passage (Langer, 1984).

Mean retention time of ingesta recorded for grass hay and alfalfa hay were 60 and 55 hours, respectively, with corresponding maximum retention times of approximately 84 and 72 hours (Foose, 1982). As a non-ruminant, restriction of large fibrous particles in the gut of the rhino does not occur to the extent seen in ruminants. As a result, fermentation is relatively depressed but compensated for by the faster passage rates, allowing more food to be processed per unit time (Owen-Smith, 1992). Compared to smaller non-ruminants, however, given the same diet, the larger gut capacity of the black rhino would result in increased retention times allowing higher levels of cell wall digestibility.

Using data collected by Hall-Martin *et al* (1982) the dry matter digestibility of diets for free-ranging rhinos was estimated to be approximately 50 % (Dierenfeld *et al*, in press). Using organic matter to determine digestibility (dry matter - ash) zoo animals fed artificial diets of grass hay and alfalfa hay, achieved similar levels of digestion, with apparent digestibility coefficients of 43 and 65 % respectively (Foose, 1982).

1.3.4 *Body size, dietary tolerance and responses to seasonality*

As larger animals have lower specific metabolic requirements and increased gut retention times they can tolerate a wider range of dietary quality (Bell, 1971). Large browsers do select high quality green herbage when available (Owen-Smith, 1992) but their higher absolute energy requirements usually force them to expand their diet to include lower quality, more abundant plant material (Bell, 1971; McNaughton and Georgiadis, 1986; Owen-Smith, 1992). This general pattern appears to hold for the black rhino. In most parts of Africa, the diet of the black rhino is noticeably seasonal. During the wet, growing season, a large proportion of the plant material ingested consists of nutrient rich annual herbs (Goddard, 1970; Mukinya, 1977). As conditions get drier, however, and more favourable foods become less available, they shift to less palatable food items including semi-dried or dried leaves (Mukinya, 1977) and less palatable species such as *Euclea divinorum* (Oloo *et al*, 1994).

Dicotyledonous herbs and woody plants offer relatively higher, and more seasonally constant levels of protein in leaf tissues than grasses (Owen-Smith, 1982), however, deciduous woody plants shed their leaves, whilst many annual herbs and legumes die. As a consequence, black rhinos may be forced to feed on larger quantities of woody and structural material during the dry season compared to the wet. Thus, it is under dry season conditions that the metabolic tolerance of these large bodied animals should be most clearly expressed (Owen-Smith, 1992).

Some species of browsing ungulates appear to respond to changes in dietary quality by engaging in localised seasonal movements that correspond closely with topography. Giraffe, *Giraffa camelopardalis*, in the Serengeti undertake dry season movements across the catenary sequence to exploit the accumulated biomass and sustained production of the riverine woodland, enabling them to maintain a high rate of nutrient and energy intake for most of the year (Pellew, 1984). Similarly, seasonal patterns of habitat use have been observed for black rhinos. In Kenya, this large browser was observed frequenting the tops and sides of gorges in the wet season, whilst concentrating in riverine habitat during the dry season where palatable herbs persisted (Oloo *et al*, 1994). The importance of riverine habitats during dry periods has also been noted in southern Africa (Emslie and Adcock, 1994a). Thus, black rhinos, like other large browsing mammals, appear able to position themselves in a manner that increases their likelihood of encountering nutritious forage (Provenza and Balph, 1990).

1.3.5 *Plant morphology and ingestion rates*

In some regions of Africa, a high proportion of the preferred food plants of black rhinos consist of spinescent species (Joubert and Eloff, 1971; Emslie and Adcock, 1994a). Structural repellents such as thorns, spines or twiggy growth form seem to characterise those woody plants with highly nutritious foliage, such as the African *Acacias* (Owen-Smith, 1982). Compared to non-spinescent species, they typically have higher crude protein levels (Cooper and Owen-Smith,

1986) and relatively reduced chemical defences (Owen-Smith, 1993). Thus, if browsers were not deterred by these physical structures, one would expect browser acceptability of such species to be extremely high. An animal's nutritional balance depends, however, on the rate of food ingestion and on the nutritional value of the vegetation ingested (Owen-Smith, 1992). The rate of food intake is a function of bite size, biting rate, time spent apprehending or manipulating food items and passage rate. Research on medium-sized browsing ungulates (kudu, *Tragelaphus strepsiceros*, impala, *Aepyceros melampus*, and domestic goats) suggests that these structural features modify the relative acceptability of the plant species possessing them - at least to the extent that spinescent species are favoured no more than non-spinescent species (Cooper and Owen-Smith, 1986). As many of the preferred woody browse species fed on by black rhinos are spinescent, it is possible that the prehensile lip and dentition (large molars) allow spinescent plants to be manipulated more effectively than is achieved by medium sized ungulates.

2. STUDY AREA

2.1 Location and history

Hwange National Park, covering an area of 14600 km^2 , lies in the north-west of Zimbabwe (Figure 2.1). Situated in the northern part of Hwange is the Sinamatella sub-region, which together with the neighbouring Deka Safari Area form the northern boundary of the park. Although the Wankie Game Reserve (now Hwange National Park) was established in 1928, the Sinamatella region was not included until the 1950s. Prior to that time, Sinamatella was under intensive cattle ranching (Tafangenyasha, 1990) and it was only in 1952 when the area was proclaimed a game sanctuary that it was incorporated into the present day park (Tafangenyasha and Campbell, 1995). In 1993, an area of 1300 km^2, including the Sinamatella region and part of the adjoining Deka Safari Area, was designated as an Intensive Protection Zone (IPZ) for black rhinos (Figure 2.2).The study area was located within the IPZ boundary, covering an area of approximately 120 km^2, between Dombashuro in the north-west, Salt Springs in the west and the Ngwangwena River crossing in the north-east (see Figure 2.2).

Whilst black rhinos occur naturally in the area and were perceived by former residents during the time of cattle ranching operations to be relatively common (Tafangenyasha and Campbell, 1995), the species had become locally extinct in Hwange National Park and the neighbouring safari area by 1928 (Tatham and Taylor, 1989). Following re-introductions during the 1960s from the Kariba area and Binga District, the population within the park in 1971 was roughly estimated at between 30 and 40 individuals (Kerr and Fothergill, 1971). Surveys carried out in the Sinamatella region and Deka Safari Area in 1982, suggested population estimates of 47 and 37 respectively (Ballance, unpubl., quoted in: Kock and Atkinson, 1993). Between 1984 and 1987, as a result

Figure 2.1 Location of Hwange National Park and Deka Safari Area in Zimbabwe

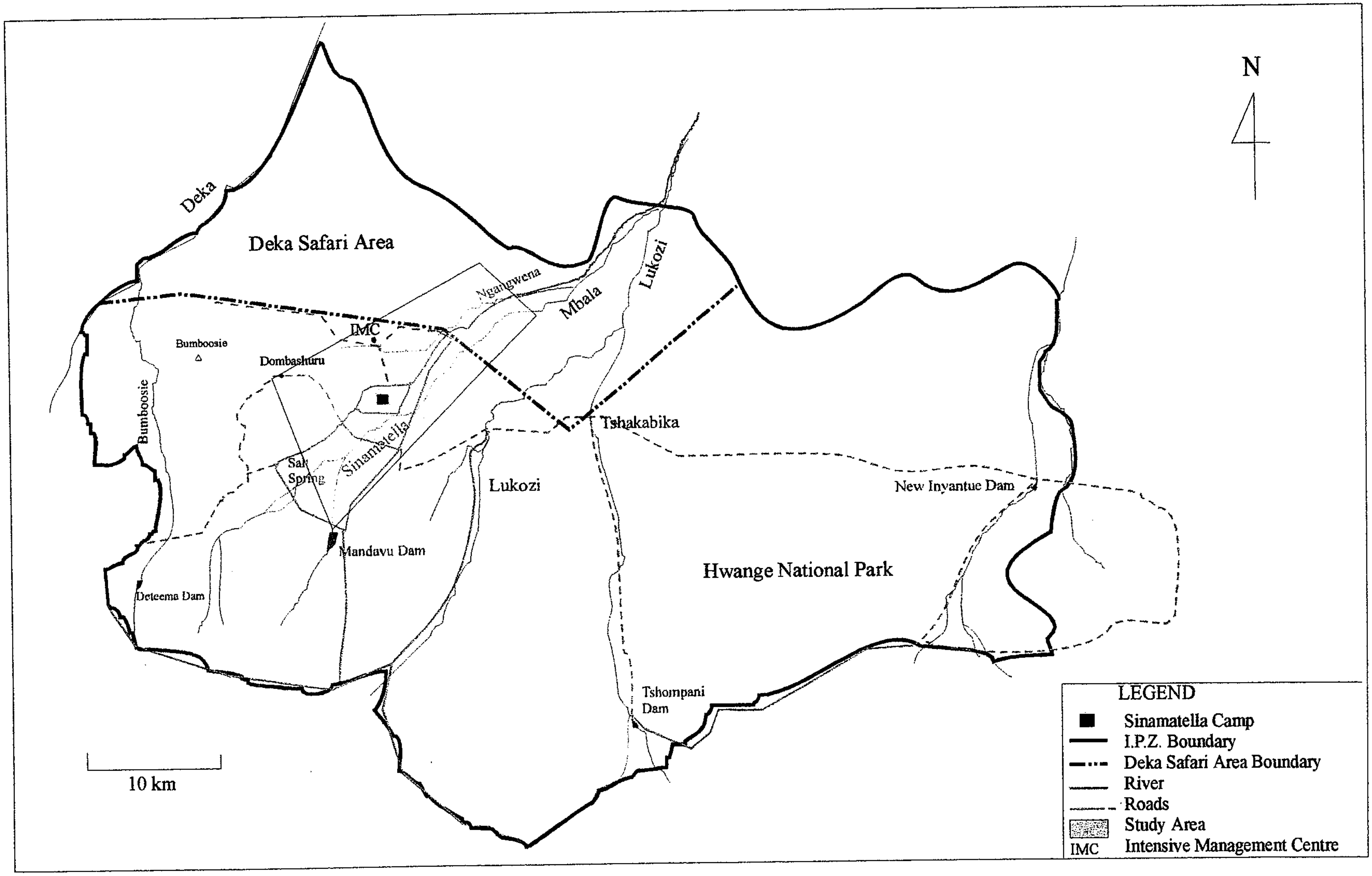


Figure 2.2 Sinamatella Intensive Protection Zone (IPZ) showing the location of the study area

of the increased poaching activity along the northern border of Zimbabwe, an additional 79 black rhinos were translocated from the Zambezi Valley into the park and by 1990, the estimated population within the Hwange/Deka wildlife complex stood at 250 animals (DNPWLM, 1992). Heavy poaching during the early 1990s resulted in the Hwange/Deka population undergoing another decline, to less than 120 animals today (DNPWLM, 1993). Based on estimates of 0.2 rhino/km^2, this wildlife complex should be able to support a black rhino population of approximately 3000 (DNPWLM, 1992). At no time during this century has the population come close to this figure.

2.2 Intensive Management Centre

All work carried out on captive black rhinos took place at the Intensive Management Centre (IMC) for black rhinos which is located close to Sinamatella Camp (see Figure 2.2) and was designed to cater for the short term confinement of translocated rhinos as well as providing a research facility. The layout of the centre was planned as a boma and paddock complex, including interleading gates and overhead walkways (Figure 2.3). Each boma, measuring 10m by 10m, opened into a large adjoining paddock area (Plate 2.1).This allowed for the daily movement of individual animals during cleaning and data collection periods as well as providing an area in which the rhinos could exercise and mud wallow.

2.3 Climate

The Sinamatella area lies within Agro-Ecological Region IV (Vincent and Thomas, 1960) and is characterised by fairly low rainfall and periodic droughts. Three distinct climatic seasons occur during the year; hot and wet (November to March), cool and dry (April to July) and hot and dry (August to October). Consequently, in the majority of years rainfall occurs over a 5 to 6 month

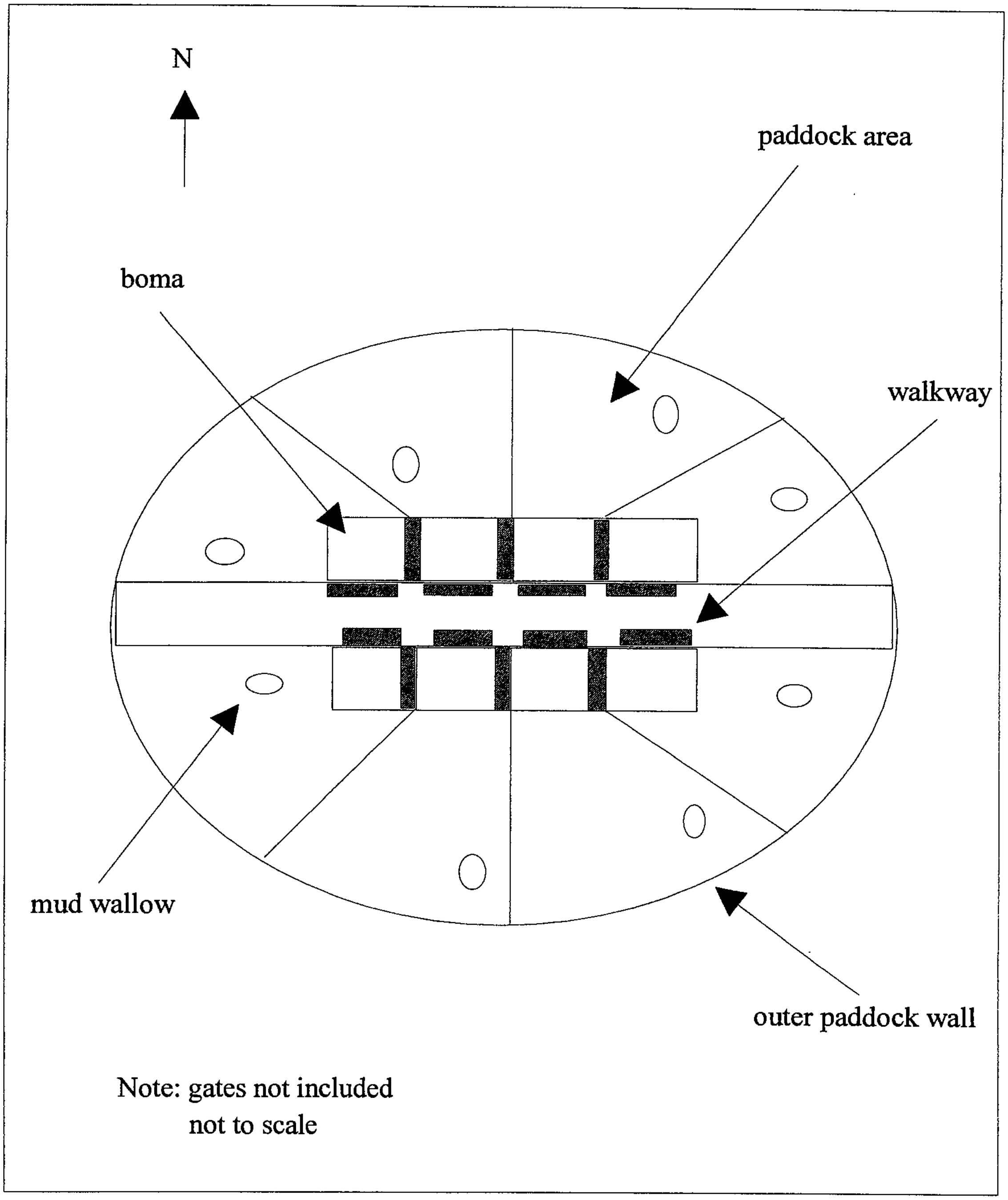


Figure 2.3 Layout of Intensive Management Centre (IMC) for black rhinos at Sinamatella

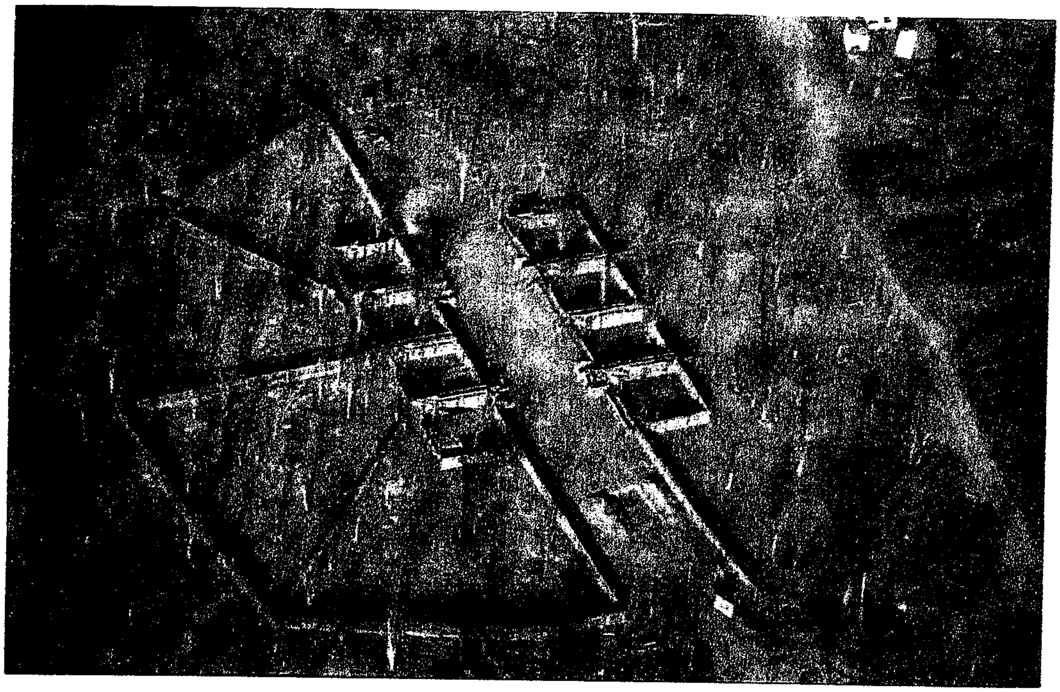


Plate 2.1 Aerial view of IMC, under construction, 1994

period. Mean annual rainfall recorded at Sinamatella Camp (prior to its incorporation into the park until the present) is 587 mm (n=72), varying from 269.5 mm to 1138 mm (Chikonyora, 1994). During the study period Sinamatella experienced less than average rains for the 1994/1995 rainy season, receiving a total of 422 mm. Mean monthly temperatures are recorded at Hwange Main Camp and range from 24 ^{0}C for June and 33 ^{0}C for October (n=40). Main Camp lies on Kalahari sands, however, and generally experiences lower temperatures than Sinamatella.

The majority of water points and rivers in the area are seasonal, providing water during the rains up until the end of the cool, dry period. Salt Springs is one exception, suppling water throughout the year. The water is saline, however, and frequently avoided. Other springs in the area and pumped water points provide a source of water for the remainder of the year.

2.4 Geomorphology and soils

Sedimentary formations laid down during Karoo times characterise the geology of the Sinamatella area (Watson, 1960). Below the camp, in an area of gently undulating to flat topography, the Madumabisa mudstones are exposed. These mudstones give rise to mainly shallow, fine grained, sandy clay soils (Sweet, 1971). Overlying the Madumabisa mudstones are the younger escarpment grits of the Beaufort Series (Watson, 1960). These are exposed on the ridge tops of the steep sloped escarpments, such as is seen at Sinamatella Camp and along the main access road. The broad ridges are gently undulating to flat and the soils derived from these grits are moderately deep, coarse grained, loamy sands and sandy loams (Sweet, 1971). A narrow tongue of land, in the vicinity of the IMC, is characterised by shallow loamy sands and sandy loams. These are derived from colluvial material off gneisses and sandstone, and overlie Madumabisa mudstones (Sweet, 1971).

To the west of Sinamatella, towards Bumboosie, is a region of very rocky terrain with hilly outcrops of castle kopjes (Rogers, 1993a). Pre-Cambrian era basement complex formations are exposed in this region and the soils derived from it are typically shallow and sandy. The earlier mudstones and sandstones of the Ecca series are exposed in the Sinamatella Salt Springs region. The soils are typically sandy lithosols and the topography rocky and undulating. Sweet (1971) notes, however, that around the immediate vicinity of Salt Springs, owing to the nature of the water itself, the soils are typically highly alkaline and saline.

2.5 Vegetation

The vegetation types in the area are closely associated with the soil types which in turn reflect the underlying geology. An extensive vegetation survey of Hwange National Park carried out by Rogers (1993a, 1994a) identified five major groups of vegetation types comprised of nine different plant communities within the Sinamatella study area. These are named below, according to the dominant or indicator species and underlying geology.

- Woodland thicket types on Karoo sediment, represented in the study area by:
  Combretum - Boscia angustifolia open scrub and thicket on lower Karoo sandstone;
  Colophospermum mopane - Acacia woodland adjacent to riverine vegetation;
  Colophospermum mopane - Commiphora marlothii mixed woodland on scree slopes.
- Mixed bushland, thicket and woodland on Basement Complex formations, represented in the study area by:
  Castle kopje mixed woodland and thicket ;
  Colophospermum mopane - Julbernardia - Combretum wooded bushland;
  Combretum - Diospyros thicket.

- *Colophospermum mopane* woodland and thicket on Gneiss and Madumabisa mudstones.
- *Colophospermum mopane* bushed grassland to woodland on the watershed, on Basalt and Karoo formations.
- Riverine vegetation with *Diospyros mespiliformis* and *Combretum mossambicense* located within *Colophospermum mopane* - *Combretum imberbe* wooded or bushed grassland in seasonally inundated areas.

The above classification of Rogers (1993a, 1994a) was generally adhered to during this study but several modifications were made. At the scale of sampling it was not possible to distinguish between the two communities of *C. mopane* woodland and as a result these were grouped together. Similarly, the species composition in the *Combretum* - *Boscia* thicket and *Combretum* - *Diospyros* thicket were similar enough to warrant classification under a single habitat group. The floristic composition along drainage lines was also more closely associated with the riverine division than its neighbouring habitat type and was consequently grouped within the riverine habitat.

2.6 Other large browsing mammals

There is a wide variety of large browsing mammals (>5 kg) resident within the Sinamatella region (Table 2.1), ranging in body size from the grysbok, *Raphicerus sharpei* (7.5 kg) to the elephant, *Loxodonta africana* (>4500 kg). Whilst some of these mammals may be classified as almost exclusively browsers, others such as the elephant and impala, *Aepyceros melampus*, are considered mixed feeders, the proportion of browse in the diet depending very much on availability and the season of the year (Skinner and Smithers, 1990).

Table 2.1 Large browsing mammals resident within the Sinamatella area

COMMON NAME	SPECIFIC NAME
Black rhinoceros	*Diceros bicornis*
Bushbuck	*Tragelaphus scriptus*
Duiker	*Sylvicapra grimmia*
Eland*	*Taurotragus oryx*
Elephant*	*Loxodonta africana*
Giraffe	*Giraffa camelopardalis*
Grysbok	*Raphicerus sharpei*
Impala*	*Aepyceros melampus*
Klipspringer	*Oreotragus oreotragus*
Kudu	*Tragelaphus strepsiceros*

* mixed feeders (Skinner and Smithers, 1990)

3. DIET COMPOSITION OF FREE RANGING BLACK RHINOCEROS

3.1 Introduction

Feeding studies conducted in Tanzania (Goddard, 1968), Kenya (Goddard, 1970; Mukinya, 1977; Oloo *et al*, 1994), Namibia (Joubert and Eloff, 1971; Loutit *et al*, 1987) and South Africa (Hall-Martin *et al*, 1982; Emslie and Adcock, 1994a), confirm that black rhinos are primarily browsers, feeding on a large variety of woody plants and herbs. Although broad generalisations can be made on feeding preferences, the availability of browse species, and hence preferences, obviously vary from region to region (Loutit *et al*, 1987; Maddock *et al*, 1995).

With Zimbabwe's black rhino population reduced by poaching to less than 300 known individuals, various conservation measures have been undertaken in recent years, including the capture and relocation of animals (DNPWLM, 1993). Although necessary given the present situation, the movement of these animals can be problematic as different areas may have very different floristic compositions and rhinos are often, therefore, confronted with browse species which are unfamiliar to them (Maddock *et al*, 1995). The translocation of black rhinos from areas of high poaching risk into the Sinamatella IPZ resulted in the need to gather information on feeding habits and diet composition of the resident population. This was to provide a basis for deciding which species to feed the captive rhinos as well as determining whether their diet should be altered at different times of the year. Captured animals are routinely confined to captivity prior to release into the surrounding area and it was hoped that this study would aid their nutritional management as well as to allow them the chance to become familiar with any novel browse species in their release areas.

3.2 Methods

3.2.1 *Work schedule and study animals*

In 1994, a total of 35 black rhinos within the Sinamatella IPZ were fitted with radio collars as part of an ongoing monitoring programme. Data were collected on use and availability of browse species for these animals during the months of January and May/June 1995. The observations were classified by habitat type and divided into wet season (January) and early dry season (May/June) periods. Attempts were made to gather data during the early morning and late afternoon, with observations coinciding with periods of foraging. In practice this was not always possible and animals were frequently located late in the morning after they had fed. A total of 85 hours were spent tracking rhinos in January and a further 91 hours during May/June.

As floristic composition and the proportional occurrence of these plants varies between the different habitat types, data collection was limited to those animals living within the area where browse collection for the captive animals would take place (Figure 2.2). A total of six known rhinos (two males, three females, one calf) ranged through this area. One animal (male) had thrown its collar prior to commencing this study and the calf was still too young to include in any field work. Thus, data were collected from a total of four animals in January. During the months preceding the early dry season study, three of the four animals lost their collars and as a result the methods used to locate these rhinos in May/June had to be modified. Four collared black rhinos held at the IMC were released into the surrounding area on 1st May but three of these animals moved a considerable distance from the study area. In order that the data collected be comparable, it was decided that only those animals located within the rough confines of the study area be included in the dry season study. Early dry season data were collected from five animals (two males, three females).

Animals were found using radio telemetry equipment or by chance encounter of fresh spoor. All wet season locations were established by radio tracking. In January, a vehicle was driven along the roads within the study area. When a signal was heard, the direction was followed on foot, to within close proximity of the rhino. At this point, so as not to disturb the animal, the surrounding area was searched until fresh spoor was located. Once found, the foraging path was followed.

Locating feeding rhinos in the early dry season proved to be problematic as three of the original study animals were without collars. Searches were made by driving the same roads used in January and checking for any fresh spoor crossing the road as well as checking water points. If fresh spoor was found, the foraging path was followed. The remaining collared rhinos were located using the same technique as described for January.

3.2.2 *Diet composition and feeding preferences*

Data collected in previous studies to determine diet composition of free-ranging black rhinos have utilised either direct (Goddard, 1968; Mukinya, 1977) or indirect observational techniques (Hall-Martin *et al*, 1982; Emslie and Adcock, 1994a; Oloo *et al*, 1994) or a combination (Loutit *et al*, 1987). Due to similar constraints noted by Oloo *et al.* (1994), particularly dense vegetation cover, direct observation was not possible. Instead a technique of indirect observation similar to those employed by Hall-Martin *et al.* (1982) and Oloo *et al.* (1994) was adopted.

Black rhinos browse in a very distinctive manner, severing twigs at a 30-45 degree angle. By following the foraging path exactly, at a reasonable distance (<1000 m) behind the animal and recording freshly browsed plants only, it was possible to exclude any feeding that may have resulted from other large browsing mammals (see Table 1.1). At each feeding station along the track (Goddard, 1968), the plant species fed on and the number of bites taken were recorded. A bite was considered as any isolated cut twig or branch or where multiple twigs had been cut, then all twigs less than 5 mm in diameter and within a hypothetical circle of 8 cm diameter were counted as one bite (Hall-Martin *et al*, 1982).

Potential problems can arise when trying to determine diet selection based on a comparison of usage and availability data (Johnson, 1980; Peek, 1986). If availability data are collected separately to plant utilisation, availability is determined by the observer and not the animal. Similarly, species recorded as present may not necessarily be available to the animal if the foliage is above the animals maximum browsing height. Feeding preference indices can also obscure the importance of certain browse species because items common in the diet and of relatively high occurrence could be ranked lower than rarer dietary items (Peek, 1986). Thus, an important or principal food plant, being consumed in relatively large quantities irrespective of its availability or proportional abundance, may have a low preference ranking (Petrides, 1975). To overcome some of these problems, availability was recorded along the foraging path of the animal at the same time as food utilisation data were collected.

At every fifth feeding station along the foraging path, the browsed plant along with all species present within a 5 m radius of that plant, were recorded (du Toit, 1993). Plants with foliage above the reach of the rhino (defined as >2m) were excluded. If the fifth feeding station occurred within the previous availability circle, only plant usage data were collected. The proportional usage (proportion of bites taken) for a given plant species (P_b) was calculated for each habitat type, by dividing the number of bites taken from that species by the total numbers of bites taken from all species in that habitat. The proportional availability of each plant species in the foraging path

(P_{fp}) was calculated as $P_{fp} = n_i / N$, where n_i is the number of times the *i*th species occurred in all the availability circles for that habitat type, and $N = \sum n_i$. A feeding preference index (FPI) was determined using the formula, $FPI = P_b / P_{fp}$ (du Toit, 1993). FPI values were calculated only for species that were recorded at least five times in each habitat. Wet and dry season FPI values were compared using Spearman rank correlation coefficients to test for seasonal variation in browse species selection patterns within each habitat. As data were gathered from the same animals in the confines of the relatively small study area and the animals did not limit their daily foraging path to one habitat type, data for all habitat types were also combined to give a composite data set for each season. FPI values were then recalculated for each season as were Spearman rank correlation coefficients. Species were arbitrarily categorised according to their FPI values into the following preference groups: "high", $FPI \geq 2.00$; "medium", $0.74<FPI<2$; "low", $0.1<FPI<0.75$; "ignored", $FPI=0$.

Dietary diversity of the foraging paths followed in various habitats during wet and dry seasons as well as for the overall seasonal diet was calculated using the Shannon Index, H'.

3.2.3 Habitat selection

Habitat selection was determined using the information collected during radio tracking and chance encounters of rhinos. The position of the animal at the time of first contact as well as the time and habitat type were recorded and locations for each habitat type and season were totalled to give an estimate of rhino occurrence within each habitat for each season. From vegetation maps of the area, the total area of each habitat type was determined, allowing an estimate of proportional availability to be made. Goodness-of-fit tests (χ^2) were used to determine if the observed values of habitat use were significantly different to expected from proportional habitat area for each season. In addition, the length of each foraging path followed was measured from a 1: 50 000 map and the number of bites per 100 m used as an estimate of the profitability of feeding in each habitat type for each season.

3.3 Results

3.3.1 *Diet composition*

During the wet and early dry season periods, a total of 113 plant species was recorded as having been browsed by black rhinos in the Sinamatella area. Graphical representation of the relationship between plant species utilisation and the number of foraging paths followed gives an indication as to whether the sample size is adequate to identify all the plant species fed on (Hall-Martin *et al*, 1982). Plots of the data collected during this study (Figure 3.1) show that the curves do not reach a plateau, indicating that several other species are probably utilised. As the rate of increase of the curves had begun to decline towards the tail end, the contribution to the overall diet of any additional species is, however, likely to be small. Thus, it is reasonable to assume that all the important species were included.

Woody plants, including trees and shrubs, were the most important dietary items throughout the study, accounting for approximately 93% of all wet season bites and 95% of the dry season bites (Figure 3.2). Species of herbaceous plants made up 2.9 % of the diet in January and 5.3 % in May/June, the rise in consumption primarily as a result of the increased utilisation of *Solanum incanum* and the species of *Sida*. Climbers (3.7 %) and grass (0.7 %) accounted for the remainder of the wet season diet. It should be noted, however, that when feeding on herbs the rhinos occasionally uprooted the whole plant. A portion, including roots and some stem, was invariably discarded further along the foraging path. Whilst this made identification of each food item

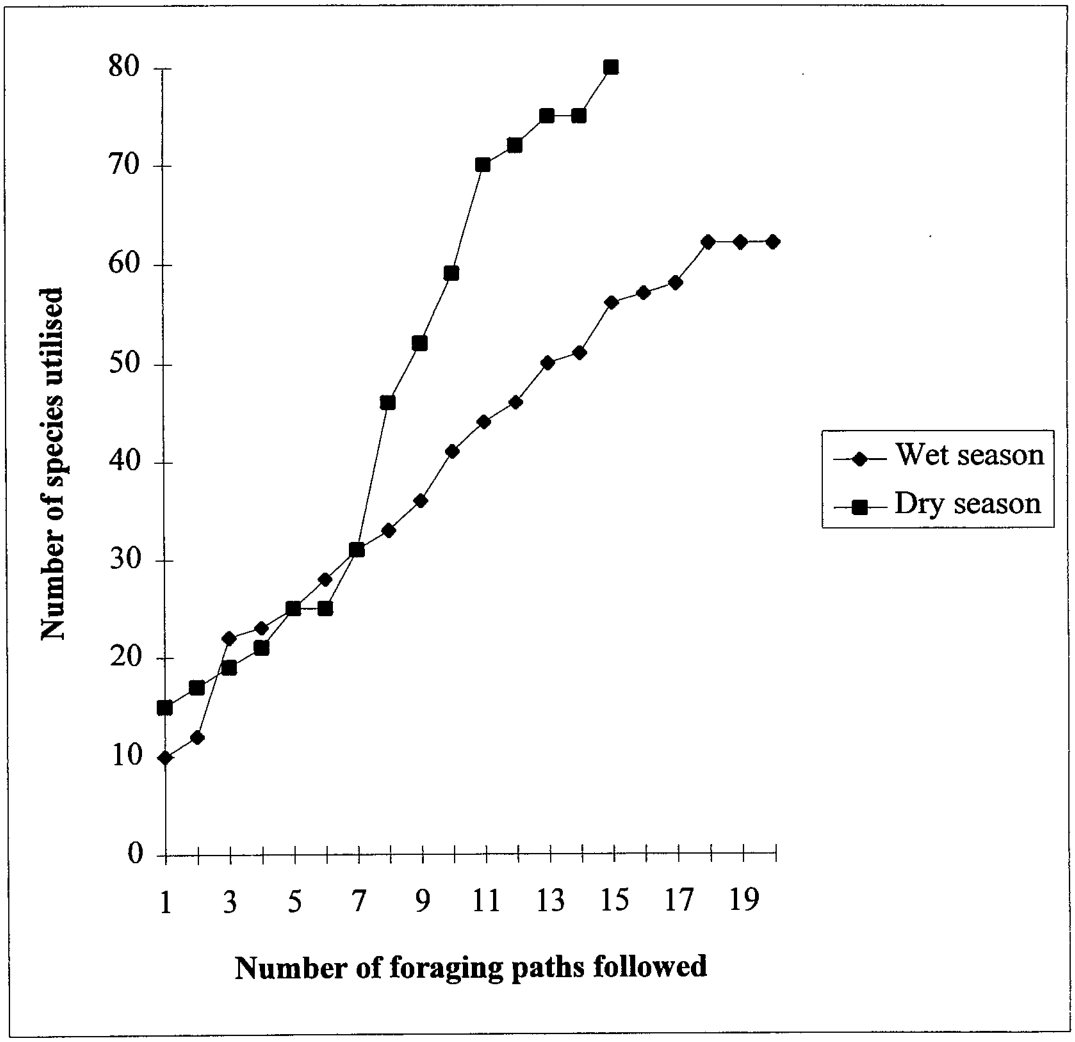
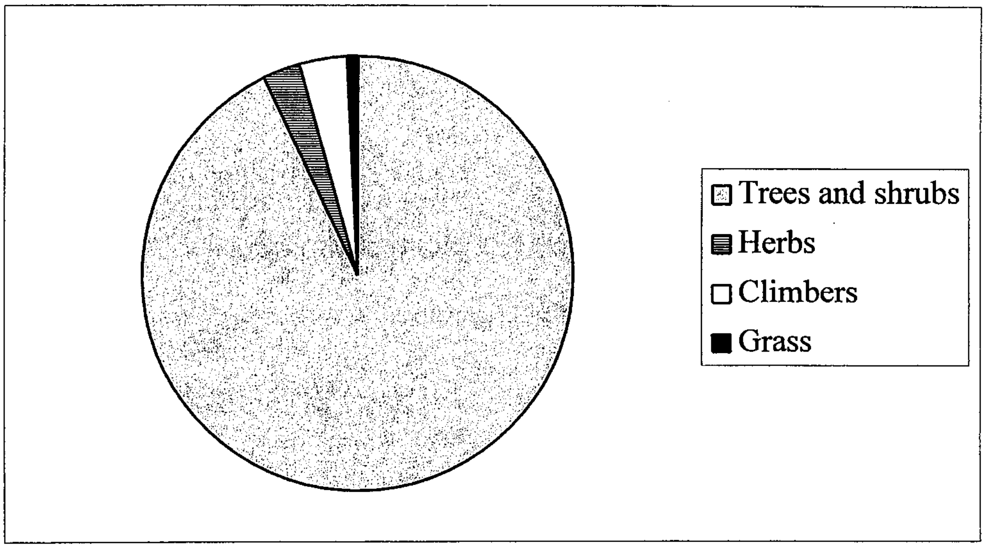


Figure 3.1 **Cumulative relationships between the number of food plants found to be utilised and the number of foraging paths followed in the wet and dry seasons**

A. Wet season



B. Dry season

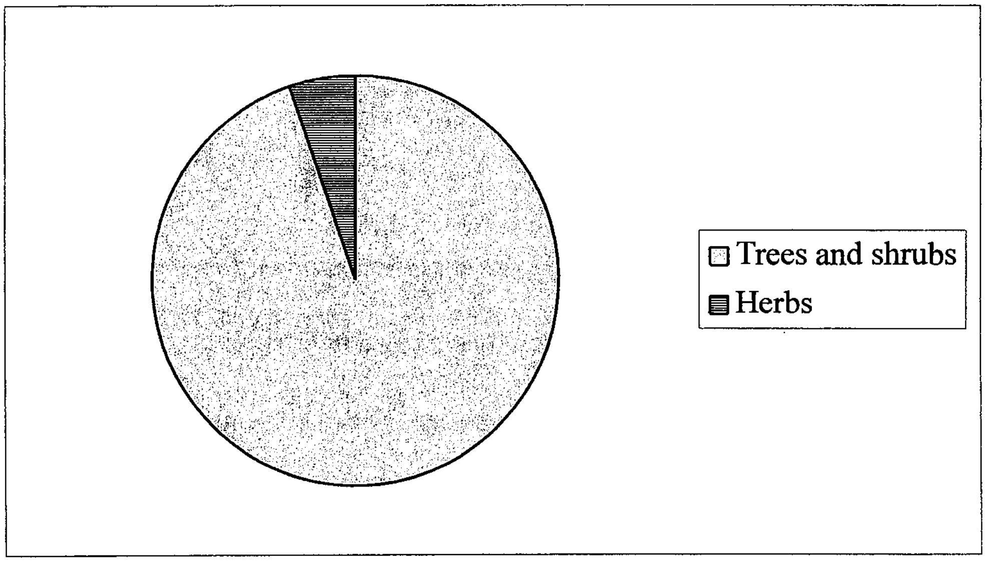


Figure 3.2 Proportional contribution of various plant classes to the total diet of free-ranging black rhinos in the wet and dry seasons

possible, the indirect method of observation may have resulted in an under-estimation of the total number of bites taken from herbaceous plants. All records of grazing were from very new green stems of *Panicum maximum*. Documentation of grazing records during the wet season was made possible by following the foraging path exactly as well as concurrent surveillance of the foreground for signs of disturbance. No sign of grazing took place during the dry period and although it would have been harder to detect, it is unlikely given that the grasses had dried out.

From plant availability transects, 156 species were identified, indicating that approximately 72% of the potentially available species were utilised. In the wet season, a large proportion of the diet consisted of a few highly preferred species (Figure 3.3). For example, the top 10 ranking species (Table 3.1) account for >70% of the total diet (number of bites). During the early dry season the highly preferred species (Table 3.1) also contributed significantly to the overall diet, the top 10 species making up 53% of the total number of bites (Figure 3.3) although several species of lower preference ranking were equally important (Table 3.1).

Despite the total number of bites recorded in both seasons being similar (2247 in the wet and 2063 in the early dry) the dietary richness for January (62 species) was lower than that for May/June (80 species). Although the difference is not significant, the slopes of cumulative sums of food plants utilised in each season (Figure 3.1) indicate an increased dietary richness in the early dry season. Likewise, the dietary diversity of the overall diet (all habitats), calculated using the Shannon Index, although not significant, was greater during the early dry period than during the wet season (Table 3.2). As indicated in Figure 3.3, the rhinos tended to concentrate their feeding on several highly preferred species during the wet season, with plants such as *Elephantorrhiza goetzei* and *Commiphora mossambicensis* accounting for approximately 20%

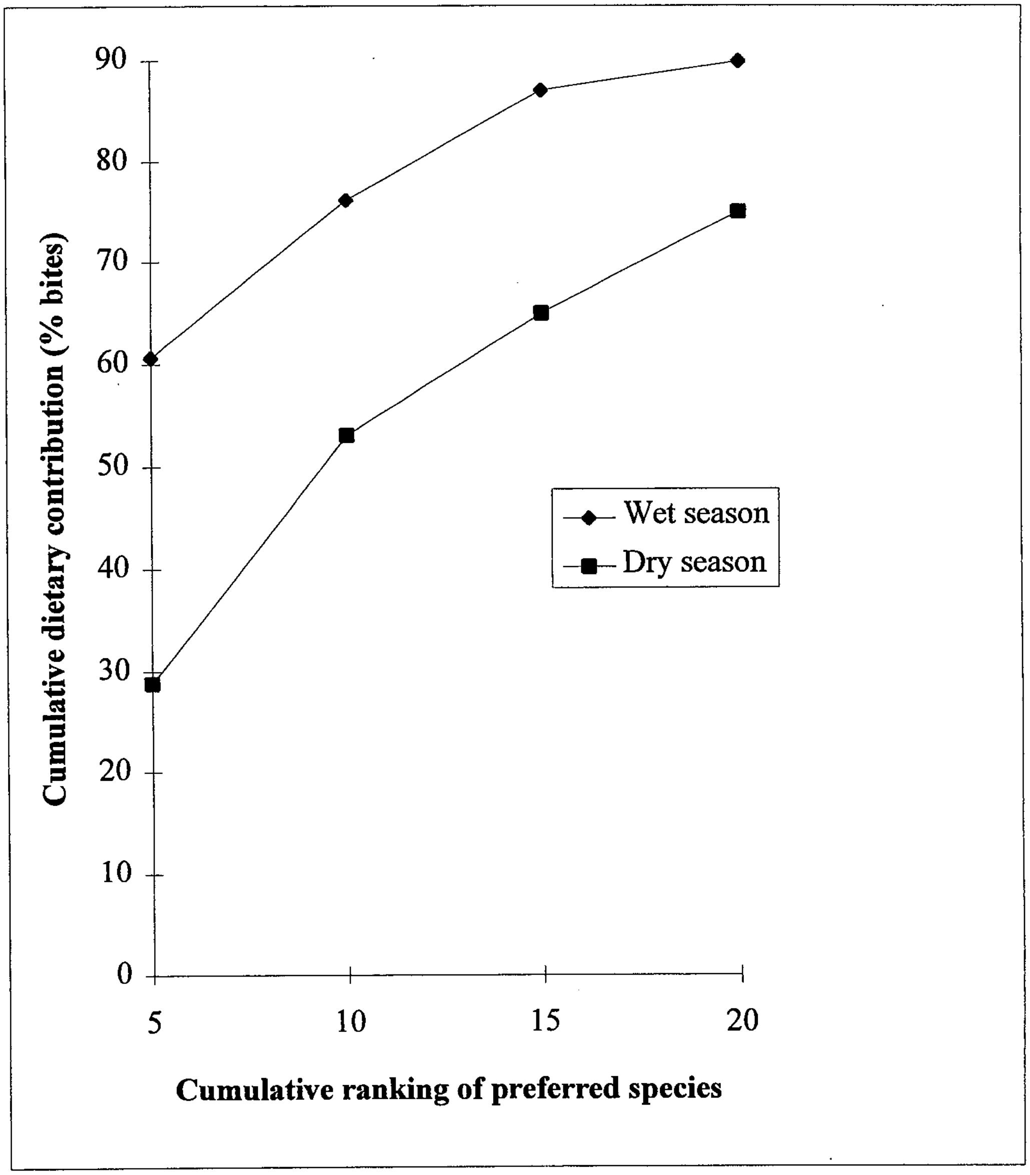


Figure 3.3 **The cumulative contribution of most preferred plant species to the total diet of free-ranging black rhinos in the wet and dry seasons**

Table 3.1 **Feeding preference index (FPI) values of available browse species in the wet and/or dry seasons and their contribution to the overall diet of black rhinos living within the Sinamatella study site. Species common to both seasons are ranked according to their averaged rank of FPI values**

	WET SEASON		DRY SEASON	
Browse species available	% contribution to diet (P_b)	FPI	% contribution to diet (P_b)	FPI
Diplorynchus condylocarpon	5.74	3.02	5.62	2.48
Pterocarpus rotundifolius	6.63	2.20	6.35	2.12
Carphalea pubescens	0.62	0.45	4.31	4.79
Vitex petersiana	0.31	0.62	2.72	4.52
Dalbergia melanoxylon	13.22	2.54	1.31	0.69
Combretum zeyheri	3.87	1.68	2.08	0.91
Grewia monticola	1.96	0.85	1.84	1.09
Combretum apiculatum	3.65	0.76	3.78	1.08
Canthium glaucum	1.47	1.13	0.49	0.54
Catunaregum spinosa	0.13	0.10	9.26	4.63
Diospyros quiloensis	0.58	0.19	13.38	2.97
Commiphora mossambicensis	15.40	2.57	0.05	0.03
Combretum celastroides	1.65	1.37	0.39	0.28
Duosperma crenatum	0.94	0.43	3.01	0.88
Dichrostachys cinerea	0.53	0.45	1.41	0.61
Flueggea virosa	0.05	0.05	10.28	3.11
Acacia nilotica	0.13	0.09	0.92	2.30
Grewia flavescens	0.05	0.06	3.10	1.55
Bauhinia petersiana	0.58	0.45	0.82	0.46
Elephantorrhiza goetzei	19.63	5.61	0	0
Asparagus africana	1.47	0.70	0.05	0.04
Terminalia prunoides	0.31	0.39	0.24	0.49
Solanum incanum	0.05	0.11	1.31	0.65
Commiphora pyracanthoides	3.03	1.01	0	0
Colophospermum mopane	0.36	0.05	2.23	0.50
Jasminum stenlobum	0.05	0.05	0.68	0.46
Markhamia accuminata	0.22	0.32	0	0

Table 3.1 (cont.)

	WET SEASON		DRY SEASON	
Browse species available	% contribution to diet (P_b)	FPI	% contribution to diet (P_b)	FPI
Ipomoea shupangensis	0.36	0.30	0	0
Gardenia resiniflua	0.22	0.2	0	0
Combretum hereoense	0	0	0.15	0.13
Euclea divinorum	0	0	0.19	0.08
Terminalia sericea	0	0	0.05	0.03
Ipomoea shirabensis	2.98	1.49	-	-
Commiphora africana	5.52	1.17	-	-
Commiphora karibensis	0.80	0.80	-	-
Sclerocarya birrea	0.53	0.68	-	-
Acacia nigrescens	0.76	0.50	-	-
Stylochilon puberulus	0.40	0.45	-	-
Tephrosia villosia	0.18	0.36	-	-
Lannea stuhlmanni	0.18	0.30	-	-
Schrebera trichoclada	0.13	0.16	-	-
Chlorophytum blepharophy	0.09	0.15	-	-
Terminalia randii	0.09	0.11	-	-
Terminalia stuhlmanni	0.09	0.04	-	-
Acacia karoo	-	-	2.23	5.57
Acacia luederitzii	-	-	2.28	2.85
Maytenus senegalensis	-	-	1.07	2.67
Sida cornifolia	-	-	1.89	2.36
Hibiscus ssp.	-	-	2.57	1.98
Barleria kirkia	-	-	0.49	1.62
Strychnos potatorum	-	-	1.41	1.56
Sida alba	-	-	0.82	1.37
Strychnos cocculoides	-	-	0.49	1.21
Xeroderris stuhlmanni	-	-	0.29	0.97
Ziziphus abyssinica	-	-	0.34	0.85
Plumbago zeylanica	-	-	0.44	0.73
Rhus lucens	-	-	0.29	0.42

Table 3.1 (cont.)

	WET SEASON		DRY SEASON	
Browse species available	% contribution to diet (P_b)	FPI	% contribution to diet (P_b)	FPI
Cassia abreviata	-	-	0.24	0.40
Lonchocarpus cappasa	-	-	0.34	0.38
Boscia angustifolia	-	-	0.15	0.36
Bauhinia tomentosa	-	-	0.53	0.35
Hippocratea indica	-	-	0.44	0.29
Combretum collinum	-	-	0.24	0.27
Freisodielsia obovata	-	-	0.49	0.27
Vangueria infausta	-	-	0.10	0.24
Hoslundia opposita	-	-	0.05	0.16
Combretum mossambicense	-	-	0.19	0.13
Cappasis tomentosa	-	-	0.10	0.11
Thamnosma rhodesica	-	-	0.10	0.09
Boscia albintrunca	-	-	0.05	0.08
Achyranthes aspera	-	-	0.05	0.06
Asystegia gangentica	-	-	0.05	0.04

Note: "0" = available but not eaten in that season; "-" = not recorded as available in that season

Table 3.2 **Dietary diversity (mean Shannon Index, H′, ±SE) of foraging paths followed in various habitat types during wet and/or dry seasons and for the overall diet in wet and dry seasons**

Habitat type	Wet season	Dry season
Castle kopje	0.77 ± 0.09	0.81 ± 0.03
Combretum thicket/woodland	0.67 ± 0.13	0.66 ± 0.09
Riverine thicket/drainage line	0.91 ± 0.14	0.90 ± 0.08
C. mopane woodland	0.85 ± 0.10	0.32 ± 0.05
Ecotone: castle kopje and *Julbernardia* woodland	0.72 ± 0.07	-
Overall diet (all habitats combined)	1.29	1.54

Note: "-" = no data collected in habitat during that season

Table 3.3 **Black rhino habitat selection in wet and dry seasons in the Sinamatella study area**

		Wet season		Dry season	
Habitat	% of area	No. of sightings	% utilisation	No. of sightings	% utilisation
C. mopane / *Acacia* woodland	18	0	0	2	9.5
C. mopane / *Commiphora* woodland	2	0	0	0	0
Castle kopje	13	4	20	5	24
Combretum / *Julbernardia* woodland	10	4	20	0	0
Combretum woodland / thicket	16	4	20	5	24
C. mopane woodland	34	6	30	2	9.5
Riverine/ drainage line	7	2	10	7	33
Total sightings		20		21	

and 15% respectively of all bites. By way of contrast, the early dry period diet comprised of a more even distribution, with bites being distributed more uniformly between different plant types.

3.3.2 *Browse preferences*

Food preference rankings for each habitat type and season (Appendix A) are combined in Table 3.1 to give the overall preference rankings for the wet and early dry seasons. The importance, or proportional utilisation of each species, expressed as a percentage of the total number of bites recorded for each habitat (Appendix A) and as a total for each season (Table 3.1), is also presented.

Within any particular habitat type there was no inter-seasonal correlation between the preference ranking of browse species. This was also the case for the combined-habitat data set. That there was no correlation between seasonal preference rankings suggests that these animals display a complete shift in diet selection patterns through the seasonal cycle. This was exemplified by woody species such as *Elephantorrhiza goetzei* and *Commiphora mossambicensis,* which were consistently highly favoured during the wet season, as well as forming a large proportion of the overall diet. Despite their continued availability, selection changed dramatically during the early dry period as these plants became ignored contributing <0.05 % to the total dry season diet. In contrast, low preference plants in the wet season, such as *Flueggea virosa, Diospyros quiloensis* and *Catunaregum spinosa*, became highly preferred and important dietary items as the dry season progressed. During the early dry period there was an increase in the utilisation of spinescent species, particularly the *Acacias*, as well as evergreen species such as *Euclea divinorum*, *Maytenus senegalensis*, *Strychnos cocculoides*, *Strychnos potatorum* and *Boscia* species.

Several additional plant species were also fed on occasionally by rhinos but were recorded less than five times per season in availability circles (Appendix C) while other species were recorded at least five times in availability circles during the study but were completely ignored by the rhinos (Appendix D).

3.3.3 *Habitat selection*

The rhinos at Sinamatella foraged in a variety of habitats, notably Castle kopje, *Combretum* thicket and woodland, *Colophospermum mopane* - *Julbernardia* woodland, riverine thicket/drainage lines and *C. mopane* woodland. From observations of feeding records, a noticeable shift in the amount of time spent feeding in these different habitats appeared to take place between the two seasons. Very few foraging records were made in the *C. mopane* woodland during the dry season despite the fact that the rhinos frequently moved through this habitat to water. By way of contrast, a proportionately larger number of foraging records were collected for the riverine habitat during the dry season compared to January.

Analysis of habitat selection revealed that the observed pattern of rhino distribution during the wet season was not significantly different to that expected from proportional habitat area ($\chi^2 = 7.3$, df = 6, NS). In contrast, however, during the early dry period their distribution differed significantly to that expected ($\chi^2 = 30.6$, df = 6, $p<0.05$), primarily as a result of the increased utilisation of riverine habitats (Table 3.3). The proportion of bites per 100 m (Figure 3.4) corroborates this. Whereas many species of plant had begun shedding their leaves from April onwards, the vegetation within riverine areas retained its foliage. That rhinos appeared to consume more browse per unit distance in riparian areas is probably as a result of less time spent searching for edible items. Thus, it was clearly more profitable for the rhinos to reduce the

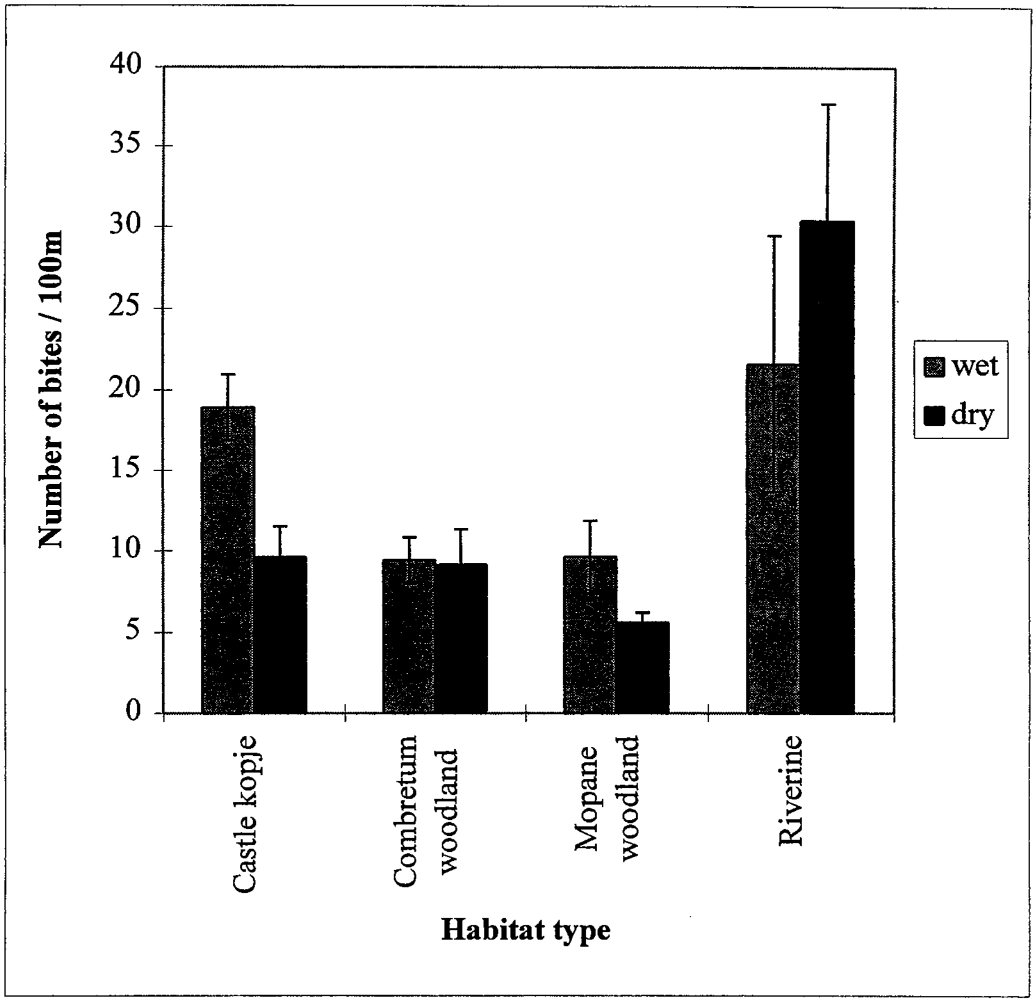


Figure 3.4 **Seasonal variation (wet vs. dry seasons) in the mean (+/- SE) number of bites taken by black rhinos per 100 m of foraging path in each available habitat type**

duration of time spent foraging in the castle kopje and *C. mopane* woodland habitats during the dry season and increase their foraging time in the riverine habitat.

3.4 Discussion

The high dietary richness exhibited by black rhinos at Sinamatella is in accordance with the findings of studies carried out in other regions of sub-Saharan Africa (Goddard, 1968, 1970; Mukinya, 1977; Loutit *et al*, 1987). Oloo *et al.* (1994), however, comment on the fact that all the lists of food plants utilised by black rhinos in previous studies are probably incomplete. As it was not possible, given time constraints, to carry out any observations during the critical late-dry period, and additional browse species were still being recorded with each additional foraging path followed when the study ended, the same is almost certainly true of this study. As already noted, however, it is probable that the most important species have been included.

Seasonal differences in habitat utilisation for other large browsers have been attributed to changes in the distribution of the food resource (Pellew, 1981). Similarly, the black rhinos at Sinamatella appear to position themselves such that they are able to encounter nutritious forage at different times of the year. During the wet season, when there is an abundance of available vegetation, they tend to utilise a variety of different habitats in which to feed. In contrast, during the dry season habitat selection becomes more apparent, as in other regions of Africa (Oloo *et al*, 1994; Emslie and Adcock, 1994a), with riverine habitats being utilised significantly more than expected, providing important resource patches during this critical time of the year. In fact, the continued utilisation of herbaceous plants recorded in the early dry season is primarily as a result of the persistence of green herbs in riverine habitat.

Visual observation indicated that the study animals browse between a height of 0.2 and 1.5 m, with the majority of bites taken including both leaf and some twig material. On rare occasions only the leaves would be eaten, this being most commonly noted in the wet season when feeding on *Colophospermum mopane*. During the early dry season, however, proportionately more *C. mopane* was consumed compared to the wet season (Table 3.1) and bites including both leaf and twig material were taken. Although rhinos will use their horns to break off branches, thereby gaining access to otherwise unavailable browse (Joubert and Eloff, 1971), on one occasion, during which direct observation was possible, an adult female was observed using her body to "walk" up a 3 m high *Commiphora mossambicensis* tree. With her forelimbs off the ground, she used her weight to push the tree over and then proceeded to feed.

The black rhinos at Sinamatella selected from a wide variety of species but it was apparent that dietary preferences and/or the importance of certain plant species depended largely on the season. They were selective for a few highly preferred species during the wet period, but during the dry season, as many species die back or shed their leaves, the rhinos were unable to be as selective in the majority of habitats and several of the important dietary species comprised of medium preference plants which were proportionately more abundant than higher ranking species. Two browse species, however, namely *Diplorynchus condylocarpon* and *Pterocarpus rotundifolius*, were highly preferred as well as contributing significantly to the diet (> 5 %) during both seasons. Interestingly, *P. rotundifolius*, was generally ignored by black rhinos in other areas of Zimbabwe (Goode, pers. comm.).

As drier conditions prevail, an increase in the contribution of evergreen species to the overall seasonal diet occurred and species such as *Maytenus senegalensis*, *Strychnos cocculoides* and

Strychnos potatorum became highly preferred. Many of these species were not recorded as available during the wet season but they are most commonly encountered in riverine habitats. The very limited use of this habitat type during wet conditions may explain the apparent differences in availability. During the dry period, increased utilisation of spinescent browse species, particularly various *Acacia* species, *Catunaregum spinosa, Dichrostachys cinerea* and *Ziziphus abyssinica* also occurred and it is suspected that both the evergreen and spinescent *Acacia* species may become increasingly more important during the critical late-dry period. Herbaceous plants were fed on by the black rhinos at Sinamatella but this plant category did not contribute a large proportion to the overall diet in either season. As previously acknowledged, it is possible that the contribution to the diet of these plants may well have been underestimated (section 3.3.1), but, the availability of herbaceous species is dependent on seasonal rainfall. With Sinamatella experiencing below average rainfall during the study period, it is possible that the proportional utilisation of this group of species was lower than normal.

Comparison of rhino browse preferences at Sinamatella with the palatability classification of woody plant species outlined by Owen-Smith and Cooper (1987) for browsing ruminants reveal many similarities. Genera of palatable deciduous non-spinescent species including *Vitex*, *Combretum* and *Diospyros* were also favoured by the black rhinos at different times of the year, as were spinescent species of *Acacias*. In addition, *Peltophorum* and *Euclea*, classified as unpalatable for browsing ruminants, were either ignored completely by the rhinos or eaten sparingly during the dry season. Some differences were noted, however, particularly with regard to *Grewia monticola*. Although considered unpalatable to browsing ruminants, this browse species was a preferred food item at Sinamatella and contributed approximately 2 % to the overall rhino diet in both seasons.

4. FEEDING TRIALS ON CAPTIVE BLACK RHINOCEROS

4.1 Introduction

The poor survival record of black rhinos in captivity has been associated either directly or indirectly with poor nutrition (Kock *et al*, 1992; Miller, 1993; Blumer, in press) and the capture and translocation of four black rhinos to the IMC at Sinamatella led to the obvious question of how best to maintain these endangered animals whilst in captivity. Given that diets of cut browse are desirable, the aim of this study, therefore, was to gather information that would provide a protocol for maintaining black rhinos on a diet of indigenous browse. To achieve this the daily intake requirements of indigenous browse had to be determined but, there was a need for this data to be derived from animals of known body size as it would allow adjustments to be made in the future when dealing with other captive black rhinos. Secondly, having collected data on the feeding preferences of the resident free-ranging population, it was also necessary to ascertain whether field preferences persisted in captivity and finally whether feeding preferences were related to intake rates. It was hoped that the information gathered would help to improve the future management of captive black rhino at Sinamatella and allow broad recommendations to be made regarding the management of captive rhinos in other areas of Zimbabwe.

Studies carried out in South Africa have reported average daily food intake (wet weight) by captive black rhinos to be in the region of 28-30 kg (Emslie and Adcock, 1993b; Hillman, 1982; quoted in Maddock *et al*, 1995) and have led to management recommendations that captive black rhinos should receive approximately 30 kg of fresh browse per day (Emslie and Adcock, 1993b). More recently a short-term study carried out in the Eastern Cape, indicated an average intake of 41 kg (wet weight) of thorny browse per day and suggestions were made that whilst housed in bomas black rhinos should receive at least 40-45 kg/day (Maddock *et al*, 1995). Alternatively, analysis of food consumption by captive adult black rhinos in East Africa reported daily dry matter intakes of about 30 kg (Ghebremeskel *et al*, 1991) whilst rhinos maintained on artificial diets in zoo studies ate approximately 14 kg and 21 kg (dry mass) per day of grass and alfalfa hay (lucerne) respectively (Foose, 1982). In view of the large variation in reported daily intake levels and the differences in plant availability and preferences exhibited by free-ranging rhinos between different regions (Loutit *et al*, 1987; Maddock *et al*, 1995) it was necessary to conduct further investigations into the feeding habits of the captive rhinos at Sinamatella.

4.2 Methods

Four black rhinoceros (two males, two females) living on the periphery of the Sinamatella IPZ were captured and translocated to the IMC in mid-January 1995. As outlying animals, these rhinos were difficult to protect, and it was on this basis that the animals were recommended for uplift to the IMC. On arrival, the rhinos were housed in individual bomas. After an initial three week settling-in period, each animal was allowed access into a corresponding paddock area (Figure 2.3). Aggressive behaviour between individuals along the adjoining paddock walls culminated in the decision to stagger the times each animal had access to its paddock (animals confined to bomas 1 and 3 were allowed into the paddocks at any one time, followed by animals in numbers 2 and 4). Because of this, feeding trials could only be conducted on two animals at any one time. Animals were paired, therefore, (1 with 3 and 2 with 4) throughout the trials. Immediately prior to commencing a trial, animals were confined to their respective paddock area whilst the bomas were cleaned, ensuring all food residues were removed.

4.2.1 *Total daily food intake*

Trials were carried out during February 1995. A list of palatable browse species was compiled, based on observations from the wet season free-ranging study (section 3.2). From this list, animals were presented with a selection of at least twelve species per feed, comprising of no less than three "high preference" and six "medium preference" species (Table 3.1). Animals received two feeds per day and, based on visual observation, in amounts exceeding that eaten prior to the trial. Water was available *ad libitum*, but consumption could not be measured as animals frequently chose to drink from the mud wallows in the paddocks.

Freshly cut browse was sorted according to species into roughly 10 kg bundles and tied with 8 gauge wire. All browse was weighed to the nearest 100 g on a Salter 25 kg balance, before being secured to the inside wall of the boma. At the same time, representative bundles of each species were weighed and hung in an unoccupied boma to measure evaporative water loss. Animals had access to at least 150 kg of browse for approximately 7 ½ hours in the morning and 13 ½ hours overnight. Before the next feed the rhinos were moved to the adjoining paddocks, allowing the food residue to be sorted into species type, collected and weighed. Each trial lasted 24 hours and was repeated three times for each animal.

After correcting for water loss, total daily intakes (wet weight) were calculated. To convert wet weight intake to dry matter intake, two 50 g samples, representing analogue bites (including leaves and twigs), of each species were collected from the cut browse. The twigs, which had been chopped into 2 cm long fragments, and leaves were then oven dried at 60 ^{0}C until constant weight. A dry matter correction factor for each species was obtained by dividing the initial wet weight (50 g) by the weight after drying for each sample and obtaining the mean. The wet weight consumed for each species was divided by the corresponding mean dry weight correction factor and total 24 hour dry matter intake was thus calculated. One week prior to commencing the trials, each rhino was immobilised and body measurements were taken to calculate body mass (Freeman and King, 1969). Daily dry matter intake was then determined as a proportion of body mass. During the browse preference trials (section 4.2.2), the evening feed was also weighed on three randomly selected days to determine total daily intake during the trial.

As not all of the cut browse was edible (branches up to 10 cm diameter), measurements were taken to determine the average amount of potentially edible browse per bundle for various species. After making up bundles of browse of exactly 10 kg, secateurs were used to remove all the browse deemed edible (representative of rhino browsing, including leaf and some twig material). Bundles were then reweighed and the difference between the initial and final weight used to calculate the percentage of potentially edible browse.

4.2.2 *Browse preferences*

"Cafeteria" trials were carried out during February and March, 1995. Due to time constraints only five browse species were selected for the trial. The particular species used were chosen as they appeared relatively easy to collect and fell into either a high preference (*Diplorynchus condylocarpon, Commiphora mosambiscensis*), medium preference (*Combretum zeyheri, Diospyros quiloensis*) or low preference (*Scherbera trichoclada*) category, based on qualitative observations made both during the free-ranging wet season study (section 3.3) and the boma confinement period.

It was suspected that browse intake would decrease due to the restricted diets, and it was decided *a priori* that these trials only be carried out during the morning feed and on alternate pairs of rhinos every day. Each of the five plant species were paired with each other, giving ten combinations, and random selection used to determine the order of the trials. Every morning, alternate pairs of animals were given a choice of 70 kg of each trial species. At the end of the morning feed all plant residues were collected and reweighed. Evaporative water loss was measured as for the previous trial. The amount of browse consumed (wet weight) for each species was converted to a percentage of the total amount ingested (both species combined) during the morning trial. Each species was allotted a positive (+) sign if it was consumed in greater amounts than the second species and a negative (-) sign if *vice versa*. At the end of the trials the sign scores for each species were counted. If the rhinos exhibited no preferences, the number of positive and negative signs should occur with equal frequency but if clear preferences emerged, preferred species would be expected to have a greater number of positive signs than lower preference species. Species were ranked, therefore, from the highest positive score to the lowest. The preference ranks of these species when fed to the captive animals were compared to the relative preference rankings recorded for the same species when browsed by the free-ranging rhinos (section 3.3.2).

4.2.3 *Bite rates and ingestion rates*

Observations were made to determine browse intake rates by black rhinos for a variety of plant species, including both spinescent and non-spinescent species. Immediately prior to each trial, a freshly cut branch was weighed to the nearest 100 g and secured to the inside wall of the boma. During each trial, the total time spent feeding on the branch was recorded using a stop watch. At the same time the number of bites taken were counted. A bite was considered as those actions resulting in a twig and/or leaves being severed from the branch. Recording commenced as the animal took its first bite and continued until the animal stopped feeding. Feeding was assumed to have finished if the animal walked away from the branch or stopped feeding for more than 30 seconds (Cooper and Owen-Smith, 1986). Feeding was terminated prematurely by withdrawing the branch on any occasion where over 30 % of the foliage had been removed. Upon removal, the branch was reweighed to determine the mass of plant material consumed.

Samples of each species were oven dried (section 4.2.1) and consumption rates calculated on a dry mass basis. The mean bite size (g), biting rate (bites/min) and ingestion rate (g/min) were determined (Cooper and Owen-Smith, 1986) for each browse species.

4.3 Results

4.3.1 *Total daily food intake*

Intake was greater for the evening feed than the morning feed (Table 4.1), probably as a result of the longer time period that the food was on offer. Individual mean daily food intake ranged from 22.8 kg dry mass (51.9 kg wet weight) to 26.0 kg (64.8 kg wet weight), varying from 2.8 - 4.2 % of body mass (dry mass intake/live mass) over all trials.

The amount of potentially edible browse per 10 kg bundle varied according to species type from 14 % for *Commiphora mossambicensis* to 40% for *Combretum zeyheri*. As a large selection of palatable species were on offer at any one time, hopefully reducing any negative effects associated with the build up of secondary plant metabolites, and an average of 22 % of the total mass of browse presented was consumed, it is probable that the amount of available browse exceeded requirements. Thus, since intake was *ad libitum*, daily intake values are likely to be an accurate refection of potential daily intake levels for captive rhinos at Sinamatella.

Table 4.1 **Mean daily food intake for captive black rhinos fed a mixed diet of woody browse species**

A. Wet weight

Rhino	morning intake* (kg)	evening intake* (kg)	total 24 hour intake (kg)	24 hour intake (kg) / kg livemass
01 (♂)	23.6	31.6	55.2	0.06
02 (♀)	25.5	26.4	51.9	0.10
03 (♀)	24.5	34.8	59.3	0.07
04 (♂)	30.5	34.3	64.8	0.08
Mean	26.0	31.8	57.8	0.08

B. Dry weight

Rhino	morning intake* (kg)	evening intake* (kg)	total 24 hour intake (kg)	24 hour intake (kg) / kg livemass
01 (♂)	10.7	12.7	23.4	0.03
02 (♀)	10.6	12.2	22.8	0.04
03 (♀)	11.3	15.9	27.2	0.03
04 (♂)	12.6	13.4	26.0	0.03
Mean	11.3	13.6	24.9	0.03

* browse on offer for 7 ½ hours during the morning feed and 13 ½ hours during the evening feed

4.3.2 *Browse preferences*

During the “cafeteria” trials clear preferences emerged between the different species on offer. *Diplorynchus condylocarpon* was consistently favoured above all other species, representing the largest intake levels (wet weight) obtained (Table 4.2) as well as the highest score value during the trials (Table 4.3). *Commiphora mossambicensis*, another highly preferred species of the free-ranging population (see Table 3.1), was also eaten in larger proportions when paired with the remaining three species (Table 4.2). *Combretum zeyheri* was consumed in slightly larger amounts than *Diospyros quiloensis*.

Although only five browse species were tested, the patterns of browse selection exhibited by the captive rhinos during the wet season were as predicted from studies on the free-ranging population, with species of lower preference rankings being taken in smaller proportions than the highly preferred species (Table 4.2). From visual observations made during normal daily feeding, however, some differences did exist. For example, *Dalbergia melanoxylon*, a highly preferred and important species of the free ranging rhinos, was generally ignored by the captive animals.

For the three randomly selected trial days, during which both morning and evening browse intake were measured, browse consumption during the morning trials ($\bar{x}$ =13.2 kg wet weight; SE = 1.51) was significantly lower than that achieved during morning feeds when a large variety of browse species was on offer (Table 4.1). Intake levels increased dramatically after the morning trial so that although total 24 hour intake levels were lower ($\bar{x}$ = 46.8 kg wet weight; SE = 1.60) than those recorded during the multiple species trial, the difference was insignificant. Thus, the amount of browse consumed during the evening feed appeared sufficient to compensate for the reduction seen during the earlier feed. That voluntary intake levels decreased markedly when the

Table 4.2 Percentage contribution of each trial species to the total amount consumed (wet weight) during morning feeding trials (time: 0730-1500 hours)

Rhino	Browse species 1	Browse species 2	Total mass consumed (kg)	Ratio of species 1 : species 2 (%)
1	*Diplorynchus condylocarpon*	*Commiphora mossambicensis*	26.5	65:35
2			16.0	82:18
3			27.2	67:33
4			22.5	67:33
1	*Diplorynchus condylocarpon*	*Combretum zeyheri*	27.1	62:38
2			15.8	87:13
3			20.4	84:16
4			16.0	98:2
1	*Diplorynchus condylocarpon*	*Diospyros quiloensis*	14.1	91:9
2			16.0	88:12
3			20.7	90:10
4			11.4	86:14
1	*Diplorynchus condylocarpon*	*Schrebera trichoclada*	37.3	82:18
2			14.4	96:4
3			24.3	80:20
4			17.2	83:17
1	*Commiphora mossambicensis*	*Combretum zeyheri*	14.7	58:42
2			15.3	58:42
3			18.6	59:41
4			17.8	61:39
1	*Commiphora mossambicensis*	*Diospyros quiloensis*	14.8	64:36
2			12.0	57:43
3			21.2	66:34
4			16.6	58:42
1	*Commiphora mossambicensis*	*Schrebera trichoclada*	8.8	64:36
2			6.7	94:6
3			9.2	67:33
4			15.1	58:42

Table 4.2 (cont.)

Rhino	Browse species 1	Browse species 2	Total mass consumed (kg)	Ratio of species 1: species 2 (%)
1	*Combretum zeyheri*	*Diospyros quiloensis*	13.9	51:49
2			8.3	55:45
3			20.8	57:43
4			10.8	60:40
1	*Combretum zeyheri*	*Schrebera trichoclada*	20.0	74:26
2			6.0	70:30
3			9.7	72:28
4			9.2	64:36
1	*Diospyros quiloensis*	*Schrebera trichoclada*	14.4	61:39
2			7.5	88:12
3			13.6	57:43
4			10.2	73:28

Table 4.3 Comparison between browse species preferences exhibited by captive black rhinos and those of the free-ranging population during the wet season

Browse species	Sign score	Captive study rank	Free-ranging study rank
Diplorynchus condylocarpon	+16	1	1
Commiphora mossambicensis	+12	2	2
Combretum zeyheri	+ 8	3	3
Diospyros quiloensis	+ 4	4	4
Schrebera trichoclada	−16	5	5

number of species on offer was reduced suggests that there is almost certainly a limit to the amount of any one species that these animals can ingest over a relatively short time period.

4.3.3 *Bite rates and bite sizes*

The relationship between bite rate and bite size (Figure 4.1), illustrates that whilst feeding on non-spinescent species, rhinos were able to increase their biting rate when bite size was reduced, and as a result maintain high rates of ingestion for a variety of species (Table 4.4). This was not, however, the case for spinescent plants. When feeding on spinescent species the rhinos tended to spend a longer time period selecting as well as orientating each potential food item in the mouth. Frequently they would reject a branch and move on to another. This would continue until they apparently found a suitable mouthful, at which point a bite would be taken. Although a limited number of spinescent species were tested, the results indicate that spinescence is effective in reducing rhino ingestion rates.

4.4 Discussion

With the exception of an East African study, the levels of daily food intake achieved by captive black rhinos at Sinamatella are much greater than previously reported. The observation that food intake declined significantly when a limited number of species was on offer (e.g. during the preference trials), may play a significant role in explaining these differences. Freeland and Janzen (1974) proposed that in order to reduce the effects of toxic plant compounds, mammalian herbivores should diversify their diets to keep each toxin below a particular limit. In fact, browsing herbivores usually reduce intake of a food to a level that enables them to avoid intoxification (Bryant *et al*, 1991). Although free-ranging rhinos feed on a very wide selection

Table 4.4 Black rhino bite rates and ingestion rates for a variety of spinescent and non-spinescent browse species

Browse species	Mean bite size (g DM/bite)	Mean bite rate (bites/min)	Mean ingestion rate (g DM/min)
Non-spinescent			
Combretum zeyheri	39.9	3.6	141.1
Commiphora mossambicensis	11.5	6.8	77.3
Diospyros quiloensis	32.8	5.3	183.3
Diplorynchus condylocarpon	35.1	3.1	108.0
Elephantorrhiza goetzei	36.9	2.7	108.9
Flueggea virosa	27.9	3.5	94.2
Grewia monticola	33.5	3.2	104.4
Schrebera trichoclada	23.5	3.9	90.9
Vitex petersiana	33.8	3.5	140.9
Mean	30.5	4.0	116.6
Spinescent			
Dalbergia melanoxylon	27.3	4.1	71.3
Dichrostachys cinerea	15.1	3.8	52.3
Strychnos madagascariensis	17.4	3.6	95.5
Mean	19.9	3.8	73.0

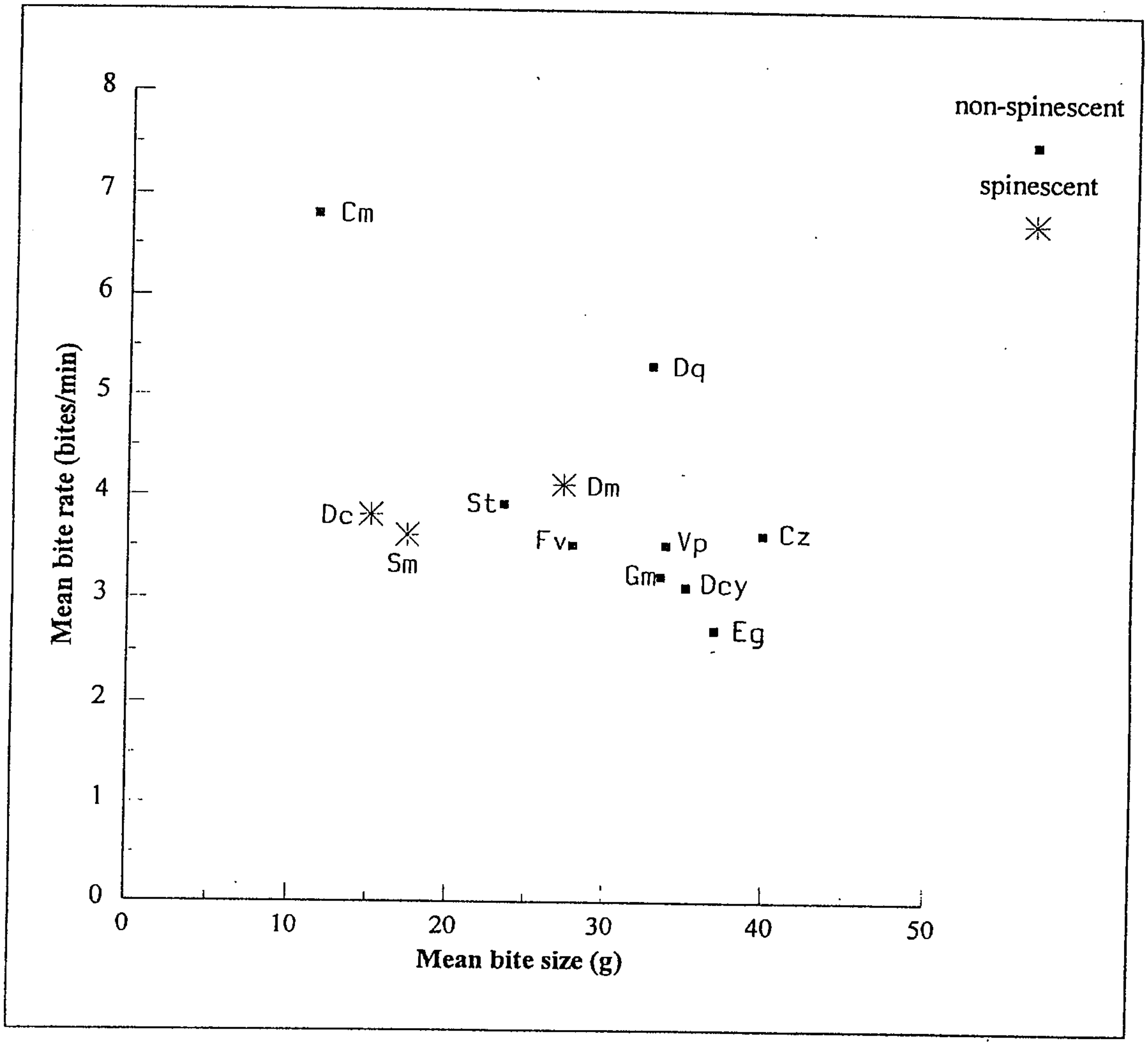


Figure 4.1 Relationship between bite rate (bites/min) and bite size (g dry mass) for spinescent and non-spinescent browse species

Note: Cz, *Combretum zeyheri*; Cm, *Commiphora mossambicensis*; Dm, *Dalbergia melanoxylon*; Dc, *Dichrostachys cinerea*; Dq, *Diospyros quiloensis*; Dcy, *Diplorynchus condylocarpon*; Eg, *Elephantorrhiza goetzei*; Fv, *Flueggea virosa*; Gm, *Grewia monticola*; St, *Schrebera trichoclada*; Sm, *Strychnos madagascariensis*; Vp, *Vitex petersiana* of plant species (Goddard, 1968; Mukinya, 1977; Loutit *et al*, 1987; Hall-Martin *et al*, 1982; Oloo *et al*, 1994), many of which are rejected by other herbivores because of their high levels of secondary plant metabolites (Joubert and Eloff, 1971; Loutit *et al*, 1987), captive rhinos are frequently presented with a limited selection of browse species (in some cases as few as two or three species per day) and their diet supplemented with lucerne. During the trials carried out by Maddock *et al.* (1995) animals were presented with four species at any one time, but at Sinamatella each rhino received at least 12 species per feed, with a minimum of 14 species during any one 24 hour period. The discrepancy noted between daily food consumption is, therefore, quite likely due to the fact that, as Emslie and Adcock (1993a) point out, there is a limit to the amount of any one species that a rhino can eat at any one time.

A limited sample of browse species were tested during the preference trials but the results indicate that the captive rhinos exhibit similar preferences to those shown by the free-ranging population. That rhinos tended to ignore *Dalbergia melanoxylon* may be a reflection of the size class on offer as opposed to the particular species. When collecting browse for the captive rhinos, branches were generally cut from trees ranging in height from 2-4 m. Visual observations made during the free-ranging study, however, indicate that the majority of bites taken from *D. melanoxylon* were from plants <0.5 m in height. Plant spinescence is known to reduce the acceptability of a plant to some browsing mammals (Cooper and Owen-Smith, 1986) and although *D. melanoxylon* is spinescent, at this small size the spines are still relatively young and soft. Thus, larger *D. melanoxylon* may not be as acceptable as the smaller size classes, even to the free-ranging rhinos.

Spinescent species were not included in the preference trials but when fed to the rhinos in the bomas they appeared to be of moderate to low acceptability compared to the majority of non-spinescent species. In fact, during routine daily feeding in the wet season, all the *Acacia* species offered were completely ignored. The reduced ingestion rates seen when rhinos fed on the spinescent species suggests that when palatable non-spinescent browse was available it was more profitable to feed on that. A high proportion of the preferred food plants of black rhinos in certain areas of southern Africa, however, consist of spinescent species (Joubert and Eloff, 1971). Interestingly, as the dry season progressed at Sinamatella, there was a noticeable increase in the utilization of thorny species, particularly *Acacias*, by the free-ranging rhinos (section 3.3.2, Table 3.1). These species typically have higher crude protein levels compared to non-spinescent species and relatively reduced chemical defences (Cooper and Owen-Smith, 1986). As an animal's nutritional balance depends on the rate of food ingestion and on the nutritional value of ingested material (Owen-Smith, 1992), it would appear that as many of the non-spinescent species began shedding their leaves, it became more profitable, despite reduced ingestion rates, to feed on the nutrient rich leaves of the spinescent species.

As black rhinos are currently endangered it is imperative that captive animals be provided with diets as similar as possible to their natural ones. This, therefore, includes a wide array of plants, ranging from woody browse to herbs to creepers. Cutting browse invariably results in wastage as only a small fraction of each branch is potential rhino food. If a wide selection of species is presented but actual browse material is limited, captive rhinos will feed on twigs as large as 2 cm in diameter (pers. obs.). Clearly, the free-ranging animals did not feed on such large twigs. Thus, a far greater amount of cut browse should be presented at each feed, allowing the animals to feed selectively on leaf and some twig material.

5. DIGESTIBILITY AND CHEMISTRY OF BLACK RHINOCEROS DIETS

5.1 Introduction

Strategies for the conservation of black rhinos in Zimbabwe rely heavily on the management option of confining these large mammals to holding facilities (bomas) during *in-situ* translocation programmes (DNPWLM, 1992; du Toit, 1994). As nearly all woody browse contains potentially toxic substances, it would appear advantageous if captive black rhinos were maintained on diets as close to their natural ones to hopefully reduce or avoid the chances of post release intoxication from the ingestion of unfamiliar woody plants (Bryant *et al*, 1991). In captive situations, however, these animals are completely dependant on man to provide them with an adequate and balanced diet. If black rhinos are to be successfully held captive *in-situ*, it is necessary, therefore, to determine whether their nutritional requirements (including both protein and energy) can be met on a diet of indigenous cut browse.

Whilst it is accepted that the nutritional value of food ingested must be adequate to satisfy metabolic requirements, there has been much deliberation regarding which of the nutrients is of greater importance for herbivores at critical times of the year (Bryant *et al*, 1980; Owen-Smith and Novellie, 1982; Owen-Smith and Cooper, 1989). In the past, it has been assumed that protein is the most critical limiting nutrient for African ungulates (Bell, 1971) but as Owen-Smith (1982) points out, although the crude protein content of woody plant foliage does decline marginally during dry periods, in general, it remains relatively high throughout the seasonal cycle. In contrast, the biomass of available browse declines markedly as dry conditions prevail. Thus, the problem facing browsers during the critical dry period, is not one of declining food quality but of a dramatic reduction in availability. It is suggested that for large browsing ruminants, energy rather than protein is most likely to be the limiting nutrient during critical times of the year (Bryant *et al*, 1980; Owen-Smith and Novellie, 1982; Owen-Smith and Cooper, 1989).

Free-ranging rhinos appear to respond to declining food availability during dry periods in two ways. When feeding in habitats where the quantity of available forage is limiting, they will include a larger proportion of lower quality browse in the diet, such as twig or semi-dry leaf material (Mukinya, 1977). In addition, they spend a large proportion of their time foraging in riverine habitats, where the sustained production of plant material provides larger quantities of nutrient rich dietary components during critical times of the year (Emslie and Adcock, 1994a; Oloo *et al*, 1994). The primary aim of this study, therefore, was to determine whether captive black rhinos could meet their maintenance requirements on a diet of indigenous cut browse. In doing so, the study would also provide baseline information on the digestibility of browse diets fed to captive rhinos.

As with other herbivores, it is evident that black rhinos do not forage at random, but are highly selective for certain plant species at different times of the year (Loutit *et al*, 1987; Provenza and Balph, 1990; Oloo *et al*, 1994). Although the nutritional quality of leaves and twigs can influence diet choice, there is growing evidence that chemical and structural defences are the major determinants of browse palatability (Coley *et al*, 1985). For browsing ruminants in southern Africa, preliminary findings suggested that woody species containing more than 5 % condensed tannins in their leaves were generally low in acceptability (Cooper and Owen-Smith, 1985). A relatively new idea, however, indicates that browsing ruminants may respond to a relative balance between nutrient levels and secondary plant metabolites (Cooper *et al*, 1988). For example, a reliable distinction between palatable and unpalatable woody species could be determined by subtracting half the condensed tannin content from the crude protein content in the leaves (Cooper *et al*, 1988; Owen-Smith, 1993). By carrying out browse preference trials coupled with chemical analyses, this study will also, therefore, attempt to determine the basis for browse preferences exhibited by the captive rhinos at Sinamatella.

5.2 Methods

5.2.1 *Apparent digestibility*

Digestibility trials were conducted on the four captive rhinos (section 4.2) between 30 March and 20 April and repeated between 3 and 25 May 1995. Results from the feeding preference trials (section 4.3.2) revealed that food intake levels decreased significantly when only two browse species were available. As the animals' health was of paramount concern and each trial would last for five days, it was decided that the digestibility trials should include several species. Species for inclusion in the study were chosen according to the factors outlined in Chapter 4, section 4.2.2.

Using two different test diets, a medium and a high preference diet, the aim of the study was to carry out replicate trials on each animal for each diet to determine whether there were any significant differences between digestibilities. In practice, the leaf phenology of some of the trial species changed so much in the period between the initial and replicate trials, as did the acceptability shown by the rhinos towards certain browse species, that each trial had to be regarded as a different diet. Thus species that initially fell into the medium preference category were arbitrarily classified as diets 1 and 3, whilst the species categorised from initial observations as high preference were classified as diets 2 and 4.

Throughout all the trials, animals received 200 kg of freshly cut browse per feed. Diets 1 and 3 comprised 40 kg *Diospyros quiloensis, Combretum zeyheri, Grewia monticola, Vitex petersiana and Strychnos madagasceriensis*, whilst diets 2 and 4 were made up of 40 kg *Diplorhynchus condylocarpon, Commiphora mossambicensis, Cassia abbreviata and Elephantorrhiza goetzei,* 30 kg *Dalbergia melanoxylon* and 10 kg *Pterocarpus rotundifolius*. Diets 2 and 4 were composed slightly differently due to two reasons, both logistical and animal based in nature. Although *D. melanoxylon* was consistently a preferred wet season browse in the field, visual observations in captivity indicated it was often ignored completely. *Pterocarpus rotundifolius* occurred as a shrub and it proved impossible to collect enough of this plant before each feed to make up a required 40 kg per animal quota. As a result, a compromise had to be made where by a reduced amount of *P. rotundifolius* was given and the difference made up with *D. melanoxylon.*

Each digestion trial lasted for 5 days, during which time the total intake of browse was measured on a daily basis. Evaporative water loss was determined as for the previous trials (section 4.2.1). Samples, analogous to actual bites (including twigs and leaves), of each species were oven dried at 60 ^{0}C until constant weight, allowing total daily consumption to be given as dry matter. Samples of each browse type were also collected at each feed and frozen for chemical analysis. These samples were then pooled for each species at the end of the trial and chemical analyses were performed on the pooled samples.

Previous digestibility trials carried out on black rhinos fed a diet of alfalfa hay (lucerne) showed mean retention time of ingesta to be about 50 hours with a maximum retention time of 72 hours (Foose, 1982). Owing to the rarity of the black rhino and its susceptibility to several disease syndromes in captivity of unknown cause (Miller, 1994), the use of chemical marker dyes to determine passage rates was ruled out. Instead, digestibility trials were carried out assuming a maximum retention time of 72 hours; ie days 1-3 of each trial.

Total faecal output was collected and weighed during days 4 and 5 of each trial. After weighing, a sample was collected from each individual dung pile and frozen for later analysis. As it was not always possible to collect the dung immediately after the animal had defecated, the moisture content of each sample would obviously vary. In order that dry matter of the faeces be accurately determined a second sample of each faecal output was collected and oven dried at 60 ^{0}C to constant weight. The correction factor determined for each dung pile was used to convert the faecal output to dry matter and mean 24 hour faecal output (kg DM) was used in the calculation of digestibility coefficients. The apparent digestibility of dry matter (DM) was calculated on a 24 hour basis using the following formula:

$$\text{Digestibility Coefficient (DC)} = \frac{\text{dry matter ingested} - \text{dry matter defecated}}{\text{dry matter ingested}}$$

A two-way Analysis of Variance was carried out to test for any significant differences between the digestibilities of individual animals and diets. If the differences were significant, the means of the digestibility coefficients for each animal and/or diet were subsequently compared using Duncan's Multiple Range Test to determine which pairs differed.

5.2.2 *Chemical analysis*

Chemical analysis was carried out on plant samples collected during the browse preference trials (section 4.2.2) as well as on pooled plant and faecal samples collected during the digestibility trials (section 5.2.1). Faecal samples were combined on a proportion basis so that the relative amount contributed by each individual dung pile to the overall amount collected over 48 hour periods was expressed in the composite sample.

Each sample was oven dried to constant weight at 60 ^{0}C before being ground in a Wiley mill through a 2 mm screen. The following analyses were then performed on these samples using the techniques outlined by the AOAC (1990):

a) dry matter (DM) content, determined by further drying to constant weight at 100 ^{0}C (DM calculated using the difference in weight between 60 and 100 ^{0}C);

b) nitrogen content, determined using the Kjeldahl method. Crude protein (CP) values were obtained by multiplying the nitrogen value by a factor of 6.25;

c) total ash content, determined as the residue after heating 1 g samples at 450 ^{0}C overnight in a muffle furnace;

d) total organic matter (OM) content, calculated by subtracting the ash content from dry matter content;

e) cell wall constituents, determined using detergent tests (Goering and Van Soest, 1970). These were:

    i) total cell wall contents, determined by Neutral Detergent Fibre (NDF) test;

    ii) lignocellulose fraction, determined by Acid Detergent Fibre (ADF) test;

    iii) hemicellulose, calculated as the difference between NDF and ADF;

    iv) lignin, calculated as the difference between the fraction remaining after treatment of ADF with potassium permanganate and 72 % sulphuric acid and the residue left after combustion;

    v) cellulose, calculated as the difference between ADF and ADL.

In addition, freeze dried pooled plant samples were analysed at Matopos Research Station to determine their condensed tannin (CT) content. This was carried out using the vanillin - HCl method with catechin as a standard (Broadhurst and Jones, 1978). Absorbance readings were taken at 550 nm. Using Spearmans Rank Correlation, the rank orders of browse preferences exhibited by the captive rhinos (section 4.3.2) were compared with both those of CT content and CP- ½CT values (Cooper *et al*, 1988) to determine if there was any correlation between preferences and secondary plant metabolites, represented by CTs. Likewise, the rank orders of CT and CP- ½CT (mean CP values for browse species used in digestibility trials 1 and 2) were compared with the ranks of browse preferences exhibited by the free-ranging rhinos in the wet season (section 3.3.2).

Apparent digestibility coefficients (DCs) for the various plant tissue fractions during each trial were also calculated for each rhino. The amount of each tissue fraction ingested was determined for each browse species in each trial and the total amount ingested per trial calculated by addition. The amount of each tissue fraction defecated was calculated by multiplying the fraction in the faeces by the total DM of faeces for that trial. The formula to determine total dry matter apparent digestibility (see section 5.2.1) was then applied, replacing dry matter ingested and defecated with mean daily amount of each tissue fraction ingested and defecated. DC values were analysed using a two-way Analysis of Variance followed by Duncan's Multiple Range Test to determine precisely which diets and/or animals differed significantly.

To determine whether the rhinos were able to meet their daily protein requirements, estimates of the protein extracted from the diets (g/24 hours) by the rhinos was calculated (CP ingested - CP defecated) and compared to their estimated requirements. Daily protein requirements (g/24 hours) were calculated for each rhino according to its estimated body mass (see Appendix D) using the standard relationship used by Foose (1982):

$$\text{Protein requirements} = 0.912\ M^{0.75}$$

where mass (M) is measured in kg. As noted by Foose (1982), these estimated values represent endogenous requirements (determined from nitrogen excretion in the urine) but losses of protein due to digestive and metabolic processes elevate actual protein requirements above this "basal" level. Daily requirements are likely, therefore, to be 2 to 3 times greater (Foose, 1982). To determine whether the diets provided sufficient protein to meet daily requirements, the ratios of extraction to requirements were calculated for 2x and 3x "basal" levels.

5.2.3 *Predicted digestibility*

Research carried out on cattle fed a variety of tropical browse species suggests that the summative equations of Goering and Van Soest (1970) can be used to predict the digestibilities of these forages (Conklin, 1994). In this study, therefore, the values for the different fibre fractions of the browse species used in the preference trials and the digestibility trials were incorporated into the following equation (Goering and Van Soest, 1970):

$$\text{Digestibility} = 98\ (1 - \text{NDF}) + \text{NDF}\ (180.8 - 96.6 \log_{10} ((\text{Lk} / \text{ADF})\ 100))$$

where Lk is the lignin value determined from the permanganate test. Using Spearmans Rank Correlation, the rank orders of the predicted digestibilities for the feeding preference trial species (section 4.3.2) were then compared to their preference rankings to determine whether there was any correlation. In addition, the predicted digestibilities for the test diets used in the digestibility trials (section 5.2.1) were also compared to the apparent dry matter digestibilities obtained.

5.2.4 *Energetics*

Assuming a standard gross energy value for rhino browse of 16.3 MJ/kg dry matter and 16.0 MJ/kg for dung (Loutit *et al*, 1987), estimates of the digestible energy (DE) obtained by the rhinos per 24 hour period during each of the trials were determined using the following formula:

$$\mathrm{DE} = (\mathrm{DM\ ingested} \times 16.3) - (\mathrm{DM\ defecated} \times 16.0)$$

Basal energy requirements refer strictly to the fasting metabolism of an animal (Van Soest, 1982; Owen-Smith, 1992) and previous studies (Foose, 1982) have estimated rhino energy requirements as multiples (1.5 and 2) of basal metabolic rate (BMR). Field metabolic rate (FMR), however, is a more accurate estimate of the total energy costs required by a wild animal during the course of a day, incorporating the energy needed for maintenance, basal metabolism, thermoregulation and activity (Nagy, 1987; 1994). As the rhinos in this study were active, each rhino's energy requirement (FMR) per day (MJ/24 hours) was calculated according to its estimated body mass (see Appendix D) using the following formula (Nagy, 1994):

$$\mathrm{FMR} = [4.63\ \mathrm{M}^{0.762}] / 1000$$

where mass (M) is measured in g and the constant 1000 is used to convert kJ to MJ. For means of comparison, maintenance requirements were also estimated as 1.5 BMR (MJ/ 24 hours) using the following formula (Kleiber, 1975):

$$\mathrm{BMR} = (70\ \mathrm{M}^{0.75})\ 4.184 / 1000$$

where mass (M) is measured in kg and the constant (4.184/1000) is used to convert kcal to MJ. Using the horse as a model, metabolisable energy (ME), was estimated as 90 % of DE where approximately 3 % is lost through methane gas production and 7 % in the urine (Blaxter, 1989).

As FMR is an estimate of the total energy costs during a 24 hour period (Nagy, 1994), ratios of ME to FMR were then determined to compare the extent to which captive rhinos would be able to meet their field metabolic energy needs on the diets offered. To assess the quality of the diets purely in terms of maintenance energy requirements, 75 % metabolic efficiency was assumed (from equid studies; Blaxter, 1971) and so 0.75 ME was compared (as the maintenance energy supply) against 1.5 BMR (as the maintenance energy requirement).

5.3 Results

5.3.1 *Chemical analysis*

Analyses of rank orders by Spearman rank correlation showed there to be no significant correlation ($P>0.05$) between browse preference ranks of the captive rhinos and related levels of the major tissue fractions (Table 5.1). Correlation coefficients (r_s) were: CP, $r_s = 0.075$; NDF, $r_s = 0.2$; ADF, $r_s = 0.125$; ADL, $r_s = 0.1$. These results suggest that no single tissue fraction assayed governed the selection patterns displayed by these animals for the five browse species tested. Likewise, there was no correlation between captive browse preferences and levels of secondary plant metabolites (Table 5.2), represented by CT content ($r_s = -0.38$) and CP- ½ CT ($r_s = -0.30$).

Additional correlation analysis of both the CT contents and CP- ½ CT values of plants browsed by the captive rhinos during the digestibility trials with their free-ranging browse preferences suggested that there was also no evidence of any correlation ($r_s = 0.22$ and 0.134, respectively).

During the digestibility trials, although the crude protein levels measured for a few of the browse species remained fairly constant between trials, for the majority of species crude protein levels were slightly lower in the latter two trials (Table 5.3). Additionally, fibre content appeared to

Table 5.1 **Tissue fractions (mean % DM ± SE) of various browse species fed to captive black rhinos in the wet season**

Browse species	Sample size	Ash	CP	NDF	ADF	ADL
Diplorynchus condylocarpon	7	4.75 ± 0.27	12.8 ± 0.85	53 ± 2.06	39 ± 3.10	11 ± 1.01
Commiphora mossambicensis	8	6.74 ± 0.54	12.8 ± 0.75	50 ± 1.41	40 ± 1.14	15 ± 0.81
Combretum zeyheri	7	5.08 ± 0.40	14.5 ± 0.94	40 ± 1.99	30 ± 1.34	8 ± 1.06
Diospyros quiloensis	9	3.99 ± 0.18	16.7 ± 0.91	52 ± 1.46	32 ± 1.76	9 ± 0.69
Schrebera trichoclada	8	4.08 ± 0.54	12.1 ± 0.62	51 ± 1.30	39 ± 1.03	12 ± 0.90
Elephantorrhiza goetzei *	3	5.02 ± 0.37	23.4 ± 2.98	37 ± 1.20	25 ± 1.15	9 ± 0.66
Pterocarpus rotundifolius *	1	6.50	19.1	57	41	9

* not included in feeding preference trials

Table 5.2 **Absorbance readings (A_{550}) and condensed tannin content (% DM) of browse species fed to captive black rhinos during the feeding preference and digestibility trials**

Browse species	Date of collection	Absorbance reading	CT content
Diplorynchus condylocarpon	March 1995	0.568	5.7
Commiphora mossambicensis		0.424	4.2
Combretum zeyheri		0.138	1.4
Diospyros quiloensis		0.184	1.8
Schrebera trichoclada		0.074	0.7
Elephantorrhiza goetzei		0.234	2.3
Pterocarpus rotundifolius		0.323	3.2
Diospyros quiloensis	April 1995	0.212	2.1
Combretum zeyheri		0.090	0.9
Grewia monticola		0.043	0.4
Vitex petersiana		0.072	0.7
Strychnos madagascariensis		0.034	0.3
Elephantorrhiza goetzei		0.127	1.3
Diplorynchus condylocarpon		0.076	0.8
Commiphora mossambicensis		0.047	0.5
Pterocarpus rotundifolius		0.153	1.5
Dalbergia melanoxylon		0.073	0.7
Cassia abreviata		0.080	0.8
Diospyros quiloensis	May 1995	0.168	1.7
Combretum zeyheri		0.087	0.9
Grewia monticola		0.077	0.8
Vitex petersiana		0.020	0.2
Strychnos madagascariensis		0.022	0.2
Elephantorrhiza goetzei		0.063	0.6
Diplorynchus condylocarpon		0.116	1.2
Commiphora mossambicensis		0.064	0.6
Pterocarpus rotundifolius		0.072	0.7
Dalbergia melanoxylon		0.118	1.2
Cassia abreviata		0.136	1.4

Table 5.3 **Tissue fractions (% DM) of pooled samples of browse species fed to black rhinos during the digestibility trials**

Browse species	Ash	CP	NDF	ADF	ADL
Trial 1 (Rhinos 1 and 3)					
Diospyros quiloensis	3.06	14.9	55	33	11
Combretum zeyheri	4.38	11.1	35	31	6
Grewia monticola	8.49	13.0	60	39	10
Vitex petersiana	4.38	6.8	60	44	10
Strychnos madagascariensis	3.14	10.2	62	54	12
Trial 2 (Rhinos 1 and 3)					
Elephantorrhiza goetzei	6.01	15.1	36	33	9
Diplorynchus condylocarpon	4.65	7.1	62	44	7
Commiphora mossambicensis	8.02	7.5	45	37	11
Pterocarpus rotundifolius	6.83	12.4	58	42	9
Dalbergia melanoxylon	6.82	14.2	64	36	9
Cassia abreviata	7.26	8.3	50	43	10
Trial 1 (Rhinos 2 and 4)					
Diospyros quiloensis	3.95	10.3	58	44	12
Combretum zeyheri	5.29	10.7	44	37	10
Grewia monticola	8.09	10.0	60	35	11
Vitex petersiana	4.93	7.6	55	44	11
Strychnos madagascariensis	4.60	10.2	61	44	10
Trial 2 (Rhinos 2 and 4)					
Elephantorrhiza goetzei	3.10	17.7	42	37	10
Diplorynchus condylocarpon	4.68	10.1	63	52	10
Commiphora mossambicensis	8.02	7.6	56	41	11
Pterocarpus rotundifolius	6.14	13.9	51	37	8
Dalbergia melanoxylon	4.68	10.1	63	53	10
Cassia abreviata	5.56	13.5	56	37	8

Table 5.3 (cont.)

Browse species	Ash	CP	NDF	ADF	ADL
Trial 3 (Rhinos 1 and 3)					
Diospyros quiloensis	4.55	8.8	61	47	12
Combretum zeyheri	4.34	8.2	45	32	10
Grewia monticola	9.33	12.2	59	42	11
Vitex petersiana	4.72	5.5	58	49	13
Stychnos madagascariensis	4.42	7.2	67	46	10
Trial 4 (Rhinos 1 and 3)					
Elephantorrhiza goetzei	4.41	9.0	67	64	10
Diplorynchus condylocarpon	5.22	7.9	61	52	8
Commiphora mossambicensis	5.13	10.5	76	62	11
Pterocarpus rotundifolius	6.19	9.1	54	47	9
Dalbergia melanoxylon	4.39	11.5	68	53	11
Cassia abreviata	9.87	7.8	55	35	9
Trial 3 (Rhinos 2 and 4)					
Diospyros quiloensis	5.17	7.1	64	44	10
Combretum zeyheri	4.96	9.3	44	42	9
Grewia monticola	8.77	13.8	67	54	13
Vitex petersiana	4.46	5.4	69	64	15
Strychnos madagascariensis	4.14	11.9	70	58	12
Trial 4 (Rhinos 2 and 4)					
Elephantorrhiza goetzei	4.43	7.8	71	56	11
Diplorynchus condylocarpon	6.36	7.0	56	45	9
Commiphora mossambicensis	5.51	10.9	74	63	9
Pterocarpus rotundifolius	5.47	7.5	56	46	10
Dalbergia melanoxylon	5.67	10.8	69	50	12
Cassia abreviata	8.76	7.8	54	51	12

Table 5.4 **Tissue fractions (% DM) of composite dung samples collected during digestibility trials**

Rhino number	Ash	CP	NDF	ADF	ADL
Trial 1					
1 (♂)	10.50	7.3	66	50	12
2 (♀)	11.72	8.5	64	51	14
3 (♀)	9.95	6.5	70	50	11
4 (♂)	23.23	6.1	71	58	12
Mean	13.85	7.1	68	52	12
Trial 2					
1 (♂)	11.92	5.9	74	51	13
2 (♀)	12.45	9.3	66	48	16
3 (♀)	16.36	5.8	71	59	16
4 (♂)	11.63	5.9	76	51	13
Mean	13.09	6.7	72	52	15
Trial 3					
1 (♂)	13.85	3.5	68	65	15
2 (♀)	12.23	6.7	71	63	9
3 (♀)	10.37	5.2	75	65	12
4 (♂)	7.51	4.4	73	64	13
Mean	10.99	5.0	72	64	12
Trial 4					
1 (♂)	11.39	4.9	72	60	19
2 (♀)	12.81	5.3	72	58	10
3 (♀)	9.15	4.1	75	58	17
4 (♂)	11.15	4.6	72	47	13
Mean	11.13	4.7	73	56	15

increase with age with many of the browse species showing marginally higher levels of cell wall contents (represented by NDF) during trials 3 and 4. A high ash content was recorded in the faecal sample collected for rhino 4 in the first trial (Table 5.4). Both during and immediately after defecating black rhinos frequently scrape the deposited dung with their hind legs. Although every attempt was made during collections to separate any soil from the dung, the high ash content may be a result of contamination with soil.

5.3.2 *Apparent digestibility*

During the digestibility trials the levels of voluntary food intake on the first day of each trial appeared to be influenced to a large extent by the previous days diet, decreasing when a wide selection of pre-trial plants were replaced with five species in trials 1 and 3 and increasing when animals were changed from these five species on to the six browse species on offer during trials 2 and 4. Daily ingestion levels also dropped on the fifth day of each trial regardless of the category of trial. As the maximum retention time of ingesta was assumed to be in the region of 72 hours (Foose, 1982), all the food ingested on the first day would almost certainly have been excreted before faecal collection took place. Similarly, it was highly improbable that any of the fifth days' food would have been excreted during the faecal collection period. It was decided, therefore, that DCs would be calculated using the mean daily dry matter intake of browse during days 2 to 4 inclusive. This would reduce any of the variation seen at the beginning and end of each trial.

The DC values for the various tissue fractions of the different diets (Appendix E) were used in the two-way ANOVAs and least significant range tests (Tables 5.5 and 5.6). The digestibility of the various tissue fractions is discussed below.

Table 5.5 **Results of two-way ANOVA on digestibility coefficients for various tissue fractions**

	Source of variation	
Tissue fraction	F value for diet	F value for animal
Dry matter	8.45 (p= 0.006) **	0.74 (p= 0.555)
Crude protein	5.75 (p= 0.018) **	7.80 (p= 0.007) **
Organic matter	8.45 (p= 0.006) **	1.14 (p= 0.385)
Total cell wall	5.26 (p= 0.023) **	1.24 (p= 0.350)
Lignocellulose	2.93 (p= 0.092)	2.33 (p= 0.143)
Cellulose	2.36 (p= 0.139)	1.14 (p= 0.385)
Hemicellulose	7.91 (p= 0.007) **	0.41 (p= 0.748)
Lignin	9.79 (p= 0.003) **	3.11 (p= 0.081)

Note: For all tests, tabulated $F_{(3,9)\,0.05} = 3.86$; ** indicates significant difference

Table 5.6 **Mean digestibility coefficients (±SE) of tissue fractions assayed for each diet, indicating which diets differ according to the results of Duncan's Multiple Range Tests at a 5% significance level**

	Tissue fractions					
Diet	DM	CP	OM	Cell wall	Hemicellulose	Lignin
1	0.50 ± 0.03	0.67 ± 0.03	0.54 ± 0.04	0.37 ± 0.05	0.47 ± 0.10	0.39 ± 0.04
	(A)	(A)	(A)	(A)	(A)	(A)
2	0.42 ± 0.03	0.68 ± 0.02	0.48 ± 0.02	0.18 ± 0.06	0.15 ± 0.09	0.13 ± 0.05
	(A ; B)	(A)	(A)	(B)	(B)	(B)
3	0.39 ± 0.05	0.68 ± 0.05	0.45 ± 0.04	0.24 ± 0.05	0.61 ± 0.08	0.35 ± 0.08
	(B)	(A)	(A)	(A; B)	(A)	(A)
4	0.28 ± 0.02	0.58 ± 0.03	0.33 ± 0.02	0.11 ± 0.02	0.07 ± 0.07	0.09 ± 0.07
	(C)	(B)	(B)	(B)	(B)	(B)

Note: Lignocellulose and cellulose not included as there was no significant difference between diets. For each tissue fraction, letters in brackets indicate which diets differ significantly- diets with the same letter in brackets are not significantly different from each other

i. dry matter

Although the actual levels of digestion attained by individual rhinos on any particular diet appeared to vary, with the exception of diet 3, exclusion of either the highest or lowest digestibility coefficient resulted in a very small change to the overall mean value for that trial. In fact, with the exception of crude protein, the ANOVA test indicated no evidence that variation in digestibility coefficients was due to animal differences.

Mean dry matter digestion during the first trial was greater than that achieved during the second although the difference was insignificant. Mean digestibilities for both repeat sets of trials (diets 3 and 4) were significantly lower than those shown by the rhinos during the corresponding initial set of trials, suggesting that extraction of energy from the diets decreased substantially as the wet season came to an end. Digestibility during trial diet 4 was also significantly lower than that achieved on diet 3. This dramatic fall in digestion coincided with visual observati[illegible] substantially marked we drop in the preferences shown by the rhinos for many of these species. Of note, *Elephantorrhiza goetzei* and *Dalbergia melanoxylon* were generally ignored during the final trials. At this time, *E. goetzei* had lost the majority of its leaves and the crude protein content, although on a par with the other browse species on offer, had declined noticeably from trial 2. As no noticeable change in tissue contents occurred for *D. melanoxylon*, it is likely that another and/or combination of factors accounted for the change in palatability.

ii. protein

Although the levels of dry matter digestion achieved during all of the trials were fairly low, the rhinos were able to extract a larger proportion of crude protein from each diet, the level of digestion varying between means of 58 and 68 % of crude protein between trials. Differences in digestibility coefficients of crude protein were insignificant between trials 1, 2 and 3 but dropped significantly during the final trial. Variation in the extraction of crude protein between animals was due to rhino 2, a young adult female. This particular animal was unable to match the digestibility coefficients of the other three animals and as a result consistently extracted a lower proportion of crude protein from each diet. As it was clearly impossible (given the nature of a black rhino) to confine these animals to metabolism cages or attach faecal collection bags, the faeces were frequently contaminated with urine. Actual crude protein digestibilities are likely, therefore, to be slightly higher than reported.

With extraction to requirement ratios far greater than 1, all the rhinos appeared able to meet their protein requirements on all of the diets (Table 5.7). In accordance with the CP DCs, compared to the first three diets, diet 4 provided the lowest amount of protein, but even this appeared in excess of maintenance requirements.

iii. organic matter

The mean digestibility of organic matter for each trial was approximately 5 % greater than the corresponding mean dry matter digestibilities. As the animals were housed in an outside facility and dry matter digestibility was determined by total collection, it is likely that the discrepancy was partly due to soil contamination in the faeces. It was not always possible to remove all the soil particles attached to the outside of each dung ball during total collections, but every effort was made to collect uncontaminated samples (samples from inside each dung ball) for chemical analysis. Consequently, the organic matter digestibilities are likely to be a more accurate reflection of the digestibilities achieved by the captive rhinos, but even these may be a slight underestimation as all the rhinos were observed to undertake geophagia, particularly when in the vicinity of the mud wallows. Although the same general patterns of digestion were noted for organic matter and dry matter, differences in digestibility coefficients of organic matter were insignificant during trials 1, 2 and 3 but dropped significantly during the final trial.

iv. fibre fractions

The differences between the mean digestion of the cell wall fraction by the rhinos were insignificant for diets 1 and 3. Interestingly, although higher levels of cell wall digestion were attained during diets 1 and 3 (0.37 and 0.24, respectively) compared to diets 2 and 4 (0.18 and 0.11, respectively), the variation in digestibility between diets 2, 3 and 4 were insignificant.

Differences in the levels of digestibility attained by the rhinos on different diets for both the lignocellulose (0.14 - 0.34) and cellulose (0.09 - 0.31) fractions were insignificant. In contrast differences (significant) did occur with respect to the extraction of hemicellulose, the most noticeable being between the means of diets 3 and 4. Differences in hemicellulose digestion on diets 1 and 3 were insignificant as were those for diets 2 and 4. In large non-ruminants, the digestion of hemicellulose is generally in higher proportions to that of cellulose (Van Soest, 1982). Although, the same general pattern was observed for diets 1 and 3, the opposite was true of diets 2 and 4, with relatively more cellulose than hemicellulose digestion taking place (see Appendix E). The pattern of lignin digestion followed that of hemicellulose, with significantly higher digestibilities being achieved on diets 1 and 3 compared to diets 2 and 4.

5.3.3 *Predicted digestibilities*

Analysis of rank orders showed there to be no correlation between the browse preference ranks of the captive rhinos and rank orders of predicted digestibilities ($r_s = -0.1$, $p > 0.05$). Similarly, the

Table 5.7 Requirements and extraction of protein (g/24 hours) from test diets fed to captive black rhinos

Rhino	Basal requirement	Extraction	Extraction / requirement 2x basal	3x basal
Diet 1				
1 (♂)	149.7	1740	5.82	3.88
2 (♀)	102	1050	5.15	3.43
3 (♀)	145	1930	6.67	4.44
4 (♂)	136.7	1856	6.77	4.53
Mean	133.4	1644	6.10	4.07
Diet 2				
1 (♂)	149.7	1603	5.36	3.57
2 (♀)	102	1590	7.79	5.20
3 (♀)	145	1589	5.48	3.65
4 (♂)	136.7	1792	6.54	4.37
Mean	133.4	1644	6.29	4.20
Diet 3				
1 (♂)	149.7	1520	5.08	3.39
2 (♀)	102	1057	5.18	3.45
3 (♀)	145	1458	5.03	3.35
4 (♂)	136.7	1852	6.76	4.52
Mean	133.4	1472	5.51	3.68
Diet 4				
1 (♂)	149.7	1159	3.87	2.58
2 (♀)	102	702	3.44	2.29
3 (♀)	145	1145	3.95	2.63
4 (♂)	136.7	807	2.95	1.97
Mean	133.4	953	3.55	2.37

mean (±SE) predicted digestibilities for each of the four test diets used in the digestibility trials (69.4±1.67, 71.2±2.59, 68.1±0.97 and 74.0±1.34, respectively) showed no evidence of correlation with the apparent dry matter digestibilities attained (r_s= -0.18, p>0.05). Interestingly, there is a weak correlation between the ranks of preferences exhibited by the free-ranging rhinos during the wet season for browse species included in digestibility trials 1 and 2 and the ranks of predicted digestibilities (r_s=0.596, p<0.05), although no such correlation exists for trials 3 and 4.

5.3.4 *Energetics*

With extraction to requirement ratios greater than one (Table 5.8), the amount of energy extracted from diet 1 was sufficient for both the field and maintenance metabolic requirements. In contrast diet 4 was clearly marginal and it appeared unable to provide adequate energy for field metabolic requirements. The mean extraction of energy from diets 2 and 3 were close to that of field metabolic requirements and above that required for maintenance.

5.4 Discussion

Whilst some research suggests that the acceptability of woody foliage to browsers is dependent on the difference between nutrient contents, represented by protein, and secondary plant metabolites, represented by condensed tannins (Cooper *et al*, 1988), no such correlation existed between the browse preferences of either the captive or free-ranging rhinos at Sinamatella. Previous research has, however, stated that a 5 % threshold of CT content in the leaves determined browse acceptability (Cooper and Owen-Smith, 1985). Differences in the analytical methods used to determine tannin contents do result in very different values and tannin levels may appear 50 % greater in freeze dried samples compared to samples oven dried at 60 ^{0}C

Table 5.8 **Field metabolic requirements (FMR), basal requirements (BMR) and extraction of digestible (DE) and metabolisable (ME) energy (MJ/ 24 hours) from test diets fed to captive black rhinos**

						Extraction / Requirement	
Rhino	FMR	BMR	DE	ME	0.75 ME	ME / FMR	0.75 ME/1.5 BMR
Diet 1							
1 (♂)	159.5	48	184.3	165.9	124.4	1.04	1.73
2 (♀)	108	33	155.1	139.6	104.7	1.29	2.12
3 (♀)	154	47	172.4	155.2	116.4	1.01	1.65
4 (♂)	146	44	235.0	211.5	158.6	1.45	2.40
Mean	142	43	186.7	168.1	126.0	1.20	1.98
Diet 2							
1 (♂)	159.5	48	137.0	123.3	92.5	0.77	1.28
2 (♀)	108	33	164.5	148.1	111.1	1.37	2.24
3 (♀)	154	47	137.6	123.8	92.9	0.80	1.32
4 (♂)	146	44	136.5	122.9	92.2	0.84	1.40
Mean	142	43	143.9	129.5	97.2	0.95	1.56
Diet 3							
1 (♂)	159.5	48	129.3	116.4	87.3	0.73	1.21
2 (♀)	108	33	99.4	89.5	67.1	0.83	1.36
3 (♀)	154	47	173.2	155.9	116.9	1.01	1.66
4 (♂)	146	44	201.9	181.7	136.3	1.25	2.07
Mean	142	43	151.0	135.9	101.9	0.96	1.58
Diet 4							
1 (♂)	159.5	48	122.6	110.3	82.7	0.69	1.15
2 (♀)	108	33	76.0	68.4	51.3	0.63	1.04
3 (♀)	154	47	88.9	80.1	60.1	0.52	0.85
4 (♂)	146	44	94.9	85.4	64.1	0.59	0.97
Mean	142	43	95.6	86.1	64.6	0.61	1.00

(Owen-Smith, 1993). Hence a threshold condensed tannin level of 5 % (oven dried) may be equivalent to a concentration of 10 % in this study (freeze dried). The CT content for browse species in this study were generally low and even those with higher CT contents fell well below 10 %. In fact, only one sample (*D. condylocarpon*, March) had a value higher than 5 %. Thus, the rhinos did appear to be feeding on species with low CT contents. Analysis was, however, carried out on pooled samples that included both leaf and twig material, whereas previous studies have included leaf material only (Cooper and Owen-Smith, 1985; Owen-Smith, 1993).

As all of the browse species used in the correlations were accepted in varying amounts by either the captive and free-ranging rhinos, and no chemical analyses were carried out on browse species known to be completely ignored, it is possible that the acceptability of browse to rhinos may be determined at a very gross scale by the difference between nutrients and secondary metabolites. It should be noted, however, that only condensed tannins were assayed for and other secondary metabolites such as alkaloids may play an important role in plant defence (Bryant *et al*, 1991). Recent work has also shown that some ungulates reject plant species despite low phenolic contents, suggesting the presence of yet unknown chemical deterrents (Owen-Smith, 1993). Without conducting further preference trials, coupled with chemical analyses, it is impossible, therefore, to conclude that any single chemical constituent or combination of constituents governs browse selection patterns, but the indications are that it is more likely to be a combination of factors that may include other secondary compounds not assayed.

The dry matter DCs attained by the rhino during the first set of trials compare favourably with estimated digestibilities of approximately 50 % for free-ranging black rhinos (Hall-Martin *et al*, 1982). In fact, as Dierenfeld (1995) points out, the high digestibilities (65 %) met by zoo rhinos fed diets of alfalfa hay (Foose, 1982) indicate that this artificial diet may be too digestible for these large browsing mammals.

Within any particular trial, digestion by the rhinos of the various fibre fractions was extremely variable. Both cellulose and hemicellulose are, however, calculated by the difference between other fibre fractions. These fractions are themselves approximate values, being estimated from the recovery of certain components (Van Soest, 1982). As each fraction is subject to error, the calculation of cellulose and hemicellulose by difference may consequently increase the error. Despite the variation, mean cellulose digestion was generally low on all diets, and as Foose (1982) points out, black rhinos appear to depend little on digestion of fibre for its nutrients but instead rely on their ability to process large volumes of material (i.e. maximising passage rate).

Given that lignin has long been regarded as theoretically indigestible and consequently used as an internal indicator for the estimation of digestibility (McDonald *et al*, 1981; Van Soest, 1982), it is unlikely that the high DCs for lignin seen during some of the trials are accurate. The determination of lignin content is, however, a relatively crude procedure, and like the estimation of hemicellulose and cellulose suffers from systematic errors. Van Soest (1982) mentions the problems associated with digestibility coefficients determined from measurements of lignin in the food and faeces, the main one being the recovery of lignin from the faeces. The permanganate oxidation reaction used to recover lignin from the rhino dung is dependent on time, but the procedure is fixed at a standardised time of 90 min. Thus, it is probable that the high DCs resulted from the incomplete recovery of lignin from the dung. Consequently, methods involving the use of lignin as an internal indicator of digestibility could not have been used during these trials.

In this study, the predicted digestibilities, calculated from the summative equations, bear no correlation to the apparent digestibilities and several explanations are possible. Firstly, the summative equations of Goering and Van Soest (1970) were originally developed for ruminants fed on temperate forages and then applied to cattle in tropical rangelands (Conklin, 1994). Although, the black rhino is a browser, it is a large non-ruminant with the majority of fermentation taking place in the enlarged hindgut (Clemens and Maloiy, 1982). With more rapid passage rates of ingesta, and consequently lower digestion of cell wall constituents than in ruminants of similar size, hindgut fermenters rely on a higher intake of food per unit time to meet their nutrient requirements (Foose, 1982; van Hoven and Boomker, 1985). As these two groups of herbivores rely on very different digestive strategies it is apparent that the equations do not accurately predict digestibilities for black rhinos.

Conklin (1994) compared the predicted digestibilities to *in vitro* digestibilities, whereas the digestibilities obtained for the rhinos were *in vivo* apparent digestibilities. Furthermore, the *in vitro* digestibilities of twig material were predicted very poorly by the summative equation (Conklin, 1994). Being a megaherbivore rhinos usually include lower quality, more abundant plant material in their diets than smaller browsing mammals do (Bell, 1971; McNaughton and Georgiadis, 1986). Consequently, in this study, a mixture of both leaf and twig material, analogous to bites taken, were analysed and the high proportion of twig material in the samples may partly explain the lack of correlation.

As is the case for other large browsing mammals (Bryant *et al*, 1980; Owen-Smith and Cooper, 1989), protein does not appear to be a limiting nutrient for captive rhinos fed on indigenous cut browse. In fact, even during the transition between the wet and dry season, exemplified by the final diet, although each rhino experienced a drop in the amount of protein it was able to extract from the browse on offer, extraction of protein still remained well above that required for maintenance. Woody plants, however, contain secondary metabolites, such as tannins, which precipitate plant proteins and gastrointestinal enzymes, thereby reducing protein digestion (Owen-Smith, 1982; Zucker, 1983; Robbins *et al*, 1987). It is likely, therefore, that not all of the crude protein is available to the rhinos. Even so, given the excessively high ratios of extraction to requirements, it is reasonable to assume that protein is not limiting for these browsing mammals.

By way of contrast, although the captive rhinos were probably able to extract enough energy from the initial three test diets, examination of the mean ratio of ME to FMR showed that energy did become a limiting nutrient for these animals on the last diet. As already noted (section 5.2.1), a dramatic drop in the acceptability by the rhinos for many of the browse species included in this trial were recorded. In practice, when managing captive black rhinos, avoidance by these animals of a particular plant species invariably results in a decision to reduce or exclude the availability of that species and include other more readily acceptable species. Similarly, routine daily feeding at the beginning of the dry season included species from both diets 3 and 4 and thus, it is unlikely that such low levels of energy extraction would have been met by the rhinos during routine daily feeding at this time. That the ratios of energy extraction to requirements tended to follow a pattern of decline as the dry season approached suggests, however, that energy may well become limiting to captive animals during the critical late dry period. It is suggested that the inability to provide captive black rhinos with an adequate number of acceptable browse species from which to feed from during dry periods may lead to an energy deficit.

6. FINAL DISCUSSION

6.1 Relationship between captive and free-ranging black rhino feeding patterns

6.1.1 *Plant species eaten*

When the availability of browse species on offer is reduced, as was the case during the digestibility trials, captive rhinos will feed, to a limited extent, on species that are ignored by the free-ranging rhinos at that time of year. For example, *Commiphora mossambicensis* did not constitute an acceptable browse species for the wild population during the early dry season period but was consumed in small amounts by the captive animals during the final digestibility trial when it was one of only five species on offer over the five day trial period. In contrast, some highly preferred species were eaten sparingly in captivity. As already noted, *Dalbergia melanoxylon* was not readily acceptable to the captive animals and may be a reflection of the plant size class on offer. In fact, as Emslie and Adcock (1994a) point out, black rhinos are highly selective for both species and size class ("spizes") particularly with regard to members of the *Acacia* family. Although not an *Acacia*, *D. melanoxylon* is spinescent and it is very likely that the rhinos are also highly selective at the level of size class as opposed to simply species level for this woody browse.

In general, many similarities were noted between those species ignored by both the free-ranging and the captive rhinos. Two browse species, namely *Combretum eleaegnoides* and *Erthyroxylum zambesiacum*, that were completely ignored by the free-ranging population during the study period were also present in the paddock areas at the IMC. Interestingly, whilst all the other plant species available in the paddocks were eaten to ground level during the first two weeks of boma confinement, these two species remained untouched during the entire 3 ½ month period.

Similarly, when offered on two separate occasions during routine daily feeding *Terminalia brachystemma* and the herb *Ampelocissus obtusata* were also ignored.

Personal observations of rhinos held captive in other areas of Zimbabwe during the critical period between the late dry season and the first rains of the wet season revealed that the browse species *Pseudolachnostylis maprouneifolia* was only acceptable to these animals for a few weeks during the period of new leaf flush. As other woody browse species came into leaf, the relative acceptability of this species to captive rhinos dropped markedly until it became completely ignored after a three week period. Data were not collected on feeding preferences of the free-ranging rhinos at Sinamatella during this period of the seasonal cycle, but it is possible that like other browsing mammals certain unpalatable woody browse species become temporarily acceptable providing new leaf growth to bridge the nutritional gap between the critical late dry period and the first rains (Owen-Smith and Cooper, 1989).

Black rhinos are clearly predominantly browsers but were occasionally recorded grazing on *Panicum maximum* in the wet season. Similarly, as noted in previous captive situations (Joubert and Eloff, 1971), the rhinos at the IMC were also recorded grazing on the fresh stems of grasses during the wet season.

6.1.2 *Plant parts eaten and browsing height*

Where possible black rhinos are selective feeders, each bite normally consisting of the tips of shoots and the leaves (Goddard, 1968, 1970; Mukinya, 1977). Visual observations at Sinamatella suggest that this was also the case during the wet season, but that during the dry period, as the availability of nutrient rich leaf material became limiting, slightly larger amounts of twig material were included. Likewise, in captivity, the rhinos would commonly take bites including leaf and some twig material, but on occasions branches up to 2 cm in diameter were bitten off and consumed. It would seem that in captive situations, if nutritious plant material is limiting they will consume greater quantities of more fibrous twig material.

Although browse was secured to the inside walls of the bomas, hopefully thereby mimicking the presentation of food to that of natural conditions, free-ranging rhinos do spend a large proportion of their time feeding at ground level (Goddard, 1968, 1970). A few species offered to the rhinos occurred as shrubs and were difficult to secure with wire at an available feeding height. These species were therefore, placed in rubber feeding troughs on the floor of the bomas. After becoming accustomed to the troughs (approximately 12 hours) the rhinos accepted browse readily from the troughs. Thus, as with free-ranging rhinos, those in captivity fed at a variety of heights.

6.1.3 *Daily foraging times*

As also noted in previous free-ranging studies (Mukinya, 1977), a peak in daily foraging occurred during two distinct periods; the early morning up until between 9 and 11 am, depending on the season (and temperatures) and a second one resuming again by the mid-afternoon. As the captive rhinos were presented with freshly cut browse at these times, one would expect them to feed at the same times regardless of normal daily feeding patterns. On the few occasions, however, when logistical problems were encountered (vehicle breakdowns) and the morning feed presented later (9.30 am) than usual (7.30 am), the animals ate sparingly for a short period and then abandoned the fresh browse in search of shade. Except on overcast days, the late mornings were characterised by a rapid increase in ambient temperatures and as has been suggested for free-ranging rhinos, it is probable that this behaviour is an adaptation for reducing water loss (Mukinya, 1977).

The feeding patterns exhibited by the captive black rhinos at Sinamatella are, in general, very similar to those recorded for the free-ranging population. Both groups of animals accept a wide array of plant species in their diets, showing marked seasonal preferences for certain species. Under captive situations, however, rhinos will feed on species that are rejected or eaten in limited quantities by the free-ranging animals but, in most instances, the differences exhibited by the captive rhinos appear to be as a result of management.

6.2 Feasibility of maintaining captive black rhinos on cut browse

Adequate animal husbandry of the captive rhinos in this study required a complement of 15 staff (5 staff for daily cleaning and feeding of the animals and 10 to cut and transport browse to the IMC). This may appear excessively high compared to other studies (Walker, 1992), but the animals had to be maintained on a daily basis for 3 ½ months and consequently not all the staff were available at any one time. Additionally, the staff at the bomas were required to assist during the data collection periods and were, therefore, unavailable for browse collection. In the majority of cases, however, where rhinos are held captive for relatively short periods of time (4-6 weeks) prior to their release, the number of staff required could be reduced.

The collection of cut browse for the captive rhinos at Sinamatella was accomplished with relative ease at the beginning of the boma confinement period but it became increasingly more difficult to locate adequate browse over the 3 ½ month period that the animals were held captive. Transportation of the harvested browse was carried out using either a 2.5 or 5 ton vehicle which covered a distance of approximately 30 km per feed in January rising steadily to an average 80 km by the end of the confinement period. At current prices of about US \$0.24/ km (Zim:US \$ = 8.5:1) for a 2.5 ton vehicle, the monthly costs of collecting browse rose from roughly US \$425 in the wet season to US \$1130 in the dry season. Similarly, the number of hours required to collect a sufficient quantity and diversity of plant material increased from 1 ½ hours per feed in January to approximately 2 ½ hours by the end of April.

The relative ease with which large quantities of acceptable browse were located at the beginning of the study, compared to the difficulties encountered towards the end of the project, were in part due to the abundance of available vegetation during the wet season. In contrast, there was a sharp decline in browse availability with the approach of the dry season. An additional, and perhaps more critical reason was that acceptable species of woody browse had been harvested twice daily for 3 ½ months. Based on estimates of 150 kg of cut browse per rhino per feed, approximately 122 tonnes of selected browse species were removed from a variety of habitats in the Sinamatella area between mid-January and the beginning of May 1995.

Based on these observations, it is suggested that for periods of short term confinement during favourable times of the year, if managed properly, black rhinos can be adequately maintained on a diet of cut browse only. As energy may well be limiting for captive rhinos during the critical dry period, it is probable that their diet may have to be supplemented at this time, although the majority of their nutritional requirements could still be provided from cut browse. For long term confinement periods (>10 weeks), or where continued translocations to one particular site may occur, it is likely that the logistics and costs involved in collecting adequate browse will become increasingly more difficult and expensive over time. Thus, for long term or permanent *in-situ* confinement, it may not be practical or possible to maintain captive rhinos on a purely browse diet. Under such constraints, diets previously outlined for captive rhinos probably provide the best alternative (Rogers, 1993b).

6.3 Management recommendations

The following recommendations are based on both the findings of the study at Sinamatella and of a comparison of these results with those reported from other areas. Whilst some of these recommendations may be very site specific, others can be applied to *in-situ* captive rhinos in general.

1). As the availability and preferences exhibited by black rhinos for different browse species varies considerably between areas, it is recommended that every effort be made to gather data on acceptable browse species at the receiving site, prior to translocation. In situations where this is not possible (establishing a founder population), other resident large browsing mammals may provide a basis with which to begin.

2). Food intake has been shown to decline significantly when the number of available browse species are reduced and in order to maintain high food intakes, the daily diet of captive black rhinos should, therefore, include a wide variety of plant species. Ten to fifteen species per day, comprised primarily of woody browse species, is recommended. Depending on both the season and availability, other groups of plants such as creepers and herbs could be included.

3). As previously noted, harvesting browse will result in wastage as only a small proportion of each branch is potential food. In fact, on numerous occasions, it was noted that particularly large branches were being cut (>10 cm diameter). Whilst it was less time consuming collecting large branches, the quantity of potentially edible plant material was small. In order to provide an adequate quantity of browse material, it is suggested that, when maintained on cut browse only, between 120-150 kg of branches (up to 5 cm diameter) be presented per feed. This should provide in the region of 60 kg (wet weight) of available browse per rhino per day.

4). Particularly on hot days (>30 ^{0}C), substantial evaporative water loss occurred between the time when fresh browse was first offered and when it was removed at the end of each feed. It is felt, therefore, that cut browse should not be stored between feeds, but harvested immediately before each feed. More importantly, wilted browse can cause prussic acid poisoning and every effort should be made to remove old browse before the next feed (Rogers, 1993b).

5). Another important consideration is that of size class. For certain species of browse, namely *Dalbergia melanoxylon* and *Acacia* species, it may be necessary to restrict the collection of cut browse to low (sapling) size classes (Emslie and Adcock, 1994a, 1994b).

6). Creepers and other plants difficult to secure with wire (*Pterocarpus rotundifolius*, *Grewia monticola*, *Ipomoea* ssp) can be placed in rubber feeding troughs that are secured to the base of the boma walls, or alternately thrown on to the floor of the boma.

7). Feeding times should mimic those of free-ranging rhinos, the time of the morning feed being probably more critical than that of the afternoon.

8). As the captive rhinos exhibited similar preferences to those shown by the free-ranging population in the wet season and the free-ranging rhinos appeared to undergo a complete shift in browse preferences during the seasonal cycle (section 3.3.2), it is likely that species such as *Flueggea virosa*, *Vitex petersiana* and the thorny *Acacia* species will become more important to captive animals at Sinamatella in drier months. It is suggested, therefore, that lower preference plants continue to be presented regularly in small amounts to determine whether they become more palatable. In this way, any changes in preferences can be monitored and the quantities on offer altered accordingly.

9). In Zimbabwe, logistical constraints imposed on capture operations during the wet season (accessibility to areas for vehicles, visibility of animals) invariably result in the majority of these operations being undertaken in the dry season. As the availability of acceptable browse declines markedly during this period and riverine habitats provide important resource patches for free-ranging rhinos in dry periods, emphasis should be placed on collecting a large proportion of cut browse from riverine habitats during dry periods.

10). To avoid placing captive rhinos under any added nutritional stress at critical periods during the seasonal cycle, it is suggested that supplementary feeds (<10 % of total daily dry matter intake), in the form of high fibre rhino cubes (produced by: National Foods, Southerton, Harare, Zimbabwe) and lucerne hay, be provided along with a large quantity and diversity of cut browse.

11). For pregnant or lactating females the quantity of nutrients required in excess of maintenance varies considerably during the reproductive cycle (McDonald *et al*, 1981). In general, however, they require greater amounts of energy than predicted from normal equations based on body mass. Thus, to avoid placing them under nutritional stress, their browse diet should be supplemented with artificial feeds (see above) regardless of season.

12). During the planning and construction of holding facilities, emphasis should be placed on ensuring that there is sufficient shade cover available for each rhino at any time of the day. This was achieved at Sinamatella using thatching grass and poles to construct shelters in the corners of the bomas. In addition, the remaining trees in the paddock areas provided shade. Alternatively, large strips of nylon shade cloth can be secured along the length of a boma wall (Walker, 1992). Rogers (1993b, 1994b) outlines the measures needed to be taken to provide adequate shade cover and suggests that plastic should not be used as it flaps in the wind and stresses the animals. In addition, it should be noted that at Sinamatella, shade cloth was secured along the adjoining paddock walls in an attempt to reduce visibility and hence aggression between the rhinos. This had to be removed as the rhinos pulled at the shade cloth and began chewing on it. Care should be taken, therefore, to place the shade cloth out of the reach of the rhinos.

13). Clean water should be available *ad libitum*. As browse frequently falls into the water troughs, the troughs should be emptied, cleaned and refilled with clean water twice daily. Information on the design and construction of water troughs is available in the literature (Rogers, 1993b, 1994b).

14). During the hottest period of the day, all the rhinos made use of the mud wallows, frequently spending up to an hour at the wallow, and it is suggested that where possible, these should be included in the design of the holding facility. If rhinos are confined to a single boma area, care should be taken, however, in ensuring that the whole area does not become too muddy.

15). Mineral licks were provided for the rhinos at Sinamatella and all of the animals were observed to use them. As it is possible that in captive situations not all of their mineral requirements are being met, it is suggested that these be made available.

16). Finally, it is felt that a maximum of 5 rhinos could be maintained adequately at any one time during the dry season. Above this number, it is suspected that it would become extremely difficult to collect a sufficient quantity and diversity of fresh browse before each feed.

6.4 Further research

As it is under dry season conditions that the metabolic tolerance of larger animals is most clearly expressed (Owen-Smith, 1992), there is a need to conduct a similar study under late dry season conditions to determine whether the nutrient requirements of captive rhinos can be met on a diet of cut browse. In addition, it is suspected that the free-ranging rhinos may well undergo a second shift in browse preferences between the early dry and critical late dry period. Such data would be required if rhinos were to be housed at the IMC during this time and it is suggested that data collection needs to continue throughout any one seasonal cycle.

To gain insights into the determinants of browse preferences exhibited by captive rhinos, there is a need to carry out more extensive preference trials and chemical analyses of those browse species. The assays carried out should probably include the measurement of other secondary plant metabolites, such as alkaloids. Chemical analyses of species totally ignored by the rhinos as well as those accepted may provide a better understanding of diet choice than analyses of those accepted, to varying degrees, alone.

By blocking the tannin-binding effects of plant tannins, the chemical polyethylene glycol (PEG) has been used experimentally to try and overcome the anti-feedant effects of plant tannins to herbivores (Owen-Smith *et al*, 1993). Recent research carried out in Zimbabwe on cattle during the 1991-92 drought has indicated that inclusion of either PEG or a commercial formula known as Browse Plus in the drinking water led to an increase in browsing activity (Duncan, in press). In fact, Browse Plus has been added to the drinking water of captive rhinos before but no trials were carried out (Kock, pers. comms.). A study of the effects of this compound on the acceptability of browse species to captive rhinos would be interesting as inclusion of this digestibility modifier could prove useful in helping to maintain animals during critical dry periods. In view of the black rhino's susceptibility to several diseases syndromes following exposure to certain drugs and chemicals (Paglia, 1994) it is suggested, however, that this chemical be tested *in vitro* to determine any possible adverse effects before any trials are carried out on black rhinos.

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APPENDIX A

Feeding preference index (FPI) values of browse species and their contribution to the diet of black rhinos when feeding in various habitat types during the wet and early dry seasons. Species common to both seasons are ranked according to their averaged rank of FPI values.

Note: "0" = species recorded as available but not eaten during that season; "-" = species not recorded as available during that season.

Castle kopje

	WET	SEASON	DRY	SEASON
Browse species	% contribution to diet (Pb)	FPI	% contribution to diet (Pb)	FPI
Pterocarpus rotundifolius	22.6	3.47	19.9	4.92
Dalbergia melanoxylon	24.7	4.33	5.4	2.05
Diplorynchus condylocarpon	11.2	2.23	16.6	6.04
Combretum apiculatum	1.0	0.17	14.8	4.02
Catunaregum spinosa	0.7	0.20	4.7	1.96
Commiphora mossambicensis	21.6	3.33	0.2	0.15
Dichrostaychs cinerea	1.9	0.83	1.6	0.74
Diospyros quiloensis	0	0	8.3	12.71
Combretum zeyheri	1.2	0.28	0.9	0.47
Jasminum stenlobum	0.2	0.10	1.6	1.74
Bauhinia petersiana	3.1	1.93	0	0
Elephantorrhiza goetzei	4.3	1.86	0	0
Duosperma crenatum	0	0	0.9	0.99
Terminalia stenostachya	0	0	1.3	0.96
Asparagus africana	0.2	0.10	0	0
Colophospermum mopane	0	0	1.3	0.37
Acacia nigrescens	0.2	0.13	-	-
Acacia karoo	-	-	10.3	13.69
Bauhinia tomentosa	-	-	1.6	2.40
Strychnos cocculoides	-	-	1.3	1.7

Combretum thicket / woodland

Browse species	WET SEASON		DRY SEASON	
	% contribution to diet (Pb)	FPI	% contribution to diet (Pb)	FPI
Carphalea pubescens	1.0	0.32	17.1	4.44
Combretum zeyheri	20.0	3.69	3.0	0.69
Combretum apiculatum	18.1	1.61	2.3	0.31
Dalbergia melanoxylon	3.0	1.01	0.2	0.11
Catunaregam spinosa	0	0	3.3	7.96
Commiphora mossambicensis	33.4	4.25	0	0
Diospyros quiloensis	0	0	6.1	1.44
Commiphora pyracanthoides	4.0	1.46	0	0
Colophospermum mopane	0	0	0.2	0.06
Schrebra trichoclada	0.90	0.17	-	-
Sida cordifolia	-	-	6.5	2.39
Diplorynchus condylocarpon	-	-	9.2	1.90
Pterocarpus rotundifolius	-	-	8.1	1.90
Combretum celastoides	-	-	2.3	1.27
Duosperma crenatum	-	-	0.8	0.42
Jasminum stenlobum	-	-	1.2	0.28
Grewia flavenscens	-	-	0.2	0.11

Colophospermum mopane woodland

Browse species	WET SEASON % contribution to diet (Pb)	WET SEASON FPI	DRY SEASON % contribution to diet (Pb)	DRY SEASON FPI
Diospyros quiloensis	1.4	0.03	69.4	6.68
Colophospermum mopane	1.1	0.30	13.0	1.25
Grewia monticola	4.2	1.72	1.0	0.09
Dalbergia melanoxylon	15.6	8.42	-	-
Elephantorrhiza goetzei	17.0	5.53	-	-
Commiphora mossambicensis	11.2	4.91	-	-
Commiphora africana	14.8	3.31	-	-
Combretum celastroides	3.3	2.69	-	-
Pterocarpus rotundifolius	3.5	2.38	-	-
Canthium glaucum	2.3	1.82	-	-
Ipomoea shirambensis	2.6	1.75	-	-
Commiphora pyracanthoides	4.5	1.51	-	-
Commiphora karibensis	2.0	1.29	-	-
Asparagus africana	0.7	1.27	-	-
Combretum apiculatum	2.6	1.09	-	-
Ipomoea shupangensis	0.9	0.91	-	-
Markhamia acuminata	0.4	0.74	-	-
Dichrostachys cinerea	0.3	0.36	-	-
Gardenia resiniflua	0.7	0.31	-	-
Acacia nilotica	0.1	0.18	-	-
Chlorophytum blepharophy	0.1	0.18	-	-
Flueggea virosa	0.1	0.18	-	-
Terminalia stulhmannii	0.3	0.13	-	-

Riverine thicket / drainage line

Browse species	WET SEASON		DRY SEASON	
	% contribution to diet (Pb)	FPI	% contribution to diet (Pb)	FPI
Vitex petersiana	1.7	0.81	6.6	5.09
Duosperma crenatum	4.9	1.16	5.3	1.18
Canthium glaucum	3.4	1.63	0.7	0.37
Dalbergia melanoxylon	5.6	1.02	0.47	0.64
Grewia monticola	3.7	0.58	2.2	1.12
Combretum celastoides	3.4	1.18	0.4	0.10
Flueggea virosa	0	0	23.4	3.65
Commiphora mossambicensis	8.3	1.51	0	0
Diospyros quiloensis	0	0	15.4	2.54
Asparagus africana	6.1	1.45	0.2	0.07
Terminalia prunoides	2.1	0.51	0.6	0.49
Grewia flavenscens	0	0	3.1	1.37
Commiphora pyracanthoides	5.1	1.02	0	0
Colophospermum mopane	0	0	2.6	0.65
Combretum hereroense	0	0	0.4	0.16
Ipomoea shupangensis	0.5	0.20	0	0
Elephantorrhiza goetzei	42.4	7.72	-	-
Acacia nigrescens	1.2	0.58	-	-
Commiphora africana	3.4	0.51	-	-
Stylochilon puberulus	1.3	0.36	-	-
Combretum zeyheri	-	-	2.7	3.67
Acacia luederitzii	-	-	5.4	3.39
Maytenus senegalensis	-	-	2.6	2.89
Hibiscus ssp.	-	-	5.4	1.81
Strychnos potatorum	-	-	3.4	1.63
Bauhinia petersiana	-	-	1.9	1.18
Terminalia sericea	-	-	0.1	1.16
Ziziphus abyssinica	-	-	0.6	0.80

Riverine thicket / drainage line (cont.)

	WET SEASON		DRY SEASON	
Browse species	% contribution to diet (Pb)	FPI	% contribution to diet (Pb)	FPI
Plumbago zeylanica	-	-	0.7	0.79
Lonchocarpus capassa	-	-	8.2	0.64
Dichrostachys cinerea	-	-	1.3	0.62
Combretum apiculatum	-	-	0.4	0.48
Solanum incanum	-	-	1.1	0.40
Hippocratea indica	-	-	0.8	0.33
Freisodielsia obovata	-	-	1.2	0.32
Combretum mossambicense	-	-	0.4	0.19
Bauhinia tomentosa	-	-	0.5	0.18
Boscia albitrunca	-	-	0.1	0.13
Astyetsia gangetica	-	-	0.1	0.05
Euclea divinorum	-	-	0.1	0.03

Ecotone between castle kopje and *C. mopane* - *Julbernardia* - *Combretum* woodland

Browse species	WET SEASON	
	% contribution to diet (Pb)	FPI
Elephantorrhiza goetzei	25.0	5.76
Diplorynchus condylocarpon	19.1	5.46
Ipomoea shirambensis	10.5	2.16
Dalbergia melanoxylon	13.5	1.54
Commiphora mossambicensis	8.9	1.46
Pterocarpus rotundifolius	7.6	1.34
Combretum zeyheri	3.8	1.25
Brachystegia boehmii	1.3	0.59
Acacia nigrescens	1.0	0.47
Commiphora karibensis	1.0	0.47
Commiphora pyracanthoides	0.8	0.35
Diospyros quiloensis	0.8	0.35
Carphalea pubenscens	0.5	0.24
Terminalia randii	0.6	0.24
Combretum apiculatum	0.5	0.10

APPENDIX B

Additional list of plant species eaten by rhinos at Sinamatella but recorded less than five times in availability circles during the wet and/or dry seasons

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Acacia ataxacantha
Acacia tortilis
Acacia xanthophloea
Aerva leucura
Albizia amara
Allophyllus africanus
Azanza garckeana
Boscia salicifolia
Brachystegia spiciformis
Combretum collinum
Combretum imberbe
Commelina benghalensis
Commiphora edulis
Ehretia obtrusifolia
Gardenia volkensii subs. spatulifolia
Grewia micrantha
Haplocoelum foliolosum
Ipomoea welwitschii
Indigofora setiflora
Lantana angolensis
Maytenus heterophylla
Mundulea sericea
Neorautanenia mitis
Panicum maximum
Pavetta gardeniifolia
Pavetta schumanniana
Rhus lancea
Rhus lucens
Rhus tenuinervis
Rhynchosia totta
Senna singueana
Steganotaenia araliacea
Strychnos madagascariensis
Tephrosia purparea
Tephrosia villosia
Terminalia stenostachya
Urginea altissima
Vangueria randii
Vernonia bainesii
Vernonia glabra
Vitex payos
Ximenia caffra
Ziziphus mucronata

APPENDIX C

List of plant species recorded in availability circles at least five times during the wet and/or dry seasons but never recorded as food plants for black rhinos at Sinamatella

Ampelocissus obtusata
Bridelia mollis
Cissus cornifolia
Combretum elaeagnoides
Crossopteryx febrifuga
Diospyros kirkii
Diospyros mespiliformis
Erthyroxylum zambesiacum
Ocimum canum
Peltophorum africanum
Pseudolachnostylis maprouneifolia
Terminalia brachystemma
Xerophyta equitoides

APPENDIX D

Estimation of body mass for black rhinos at Sinamatella IMC.

Approximately once a month all four rhinos were immobilised to allow blood samples to be collected as part of an ongoing veterinary monitoring programme. During this time body measurements were recorded for each animal and used to calculate their estimated body mass using the following formula (Freeman and King, 1969):

$$\log M = 1.665 \log L + 1.650 \log G + 1.653$$

where M = mass of animal (kg)

L = vertebral column length, along body contours (m)

G = chest girth, from vertebral spine to mid-line of sternum × 2 (m)

The masses (kg) of the four black rhinos estimated during the feeding preference trials (FPT) and digestiblity trials (DgT) are listed below along with their metabolic weights.

	Estimated body mass		Metabolic mass ($M^{0.75}$)	
Rhino I.D.	FPT	DgT	FPT	DgT
1 (♂)	900	900	164	164
2 (♀)	540	540	112	112
3 (♀)	820	860	153	159
4 (♂)	780	800	148	150

APPENDIX E

Digestibility coefficients of tissue fractions for different test diets fed to captive black rhinos

Rhino	DM	CP	OM	NDF	ADF	Cellulose	Hemicel.	ADL
Diet 1								
1 (♂)	0.52	0.70	0.53	0.38	0.36	0.36	0.45	0.36
2 (♀)	0.53	0.60	0.57	0.46	0.40	0.40	0.61	0.40
3 (♀)	0.42	0.67	0.43	0.23	0.27	0.21	0.21	0.32
4 (♂)	0.53	0.71	0.63	0.40	0.31	0.25	0.62	0.49
Mean $\bar{x}$	0.50	0.67	0.54	0.37	0.34	0.31	0.47	0.39
Diet 2								
1 (♂)	0.42	0.71	0.47	0.12	0.22	0.24	0.00	0.15
2 (♀)	0.49	0.62	0.54	0.37	0.38	0.36	0.32	0.19
3 (♀)	0.38	0.68	0.46	0.10	0.04	0.10	0.27	0.00
4 (♂)	0.39	0.70	0.45	0.14	0.23	0.24	0.00	0.19
Mean $\bar{x}$	0.42	0.68	0.48	0.18	0.22	0.24	0.15	0.13
Diet 3								
1 (♂)	0.32	0.73	0.39	0.19	0.00	0.00	0.85	0.11
2 (♀)	0.31	0.55	0.38	0.18	0.12	0.02	0.46	0.45
3 (♀)	0.41	0.65	0.47	0.20	0.08	0.00	0.57	0.40
4 (♂)	0.51	0.78	0.54	0.39	0.36	0.34	0.57	0.43
Mean $\bar{x}$	0.39	0.68	0.45	0.24	0.14	0.09	0.61	0.35
Diet 4								
1 (♂)	0.32	0.61	0.37	0.18	0.15	0.28	0.29	0.00
2 (♀)	0.25	0.50	0.29	0.08	0.13	0.10	0.00	0.29
3 (♀)	0.24	0.64	0.29	0.09	0.12	0.25	0.00	0.00
4 (♂)	0.29	0.56	0.35	0.10	0.29	0.35	0.00	0.06
Mean $\bar{x}$	0.28	0.58	0.33	0.11	0.17	0.25	0.07	0.09

Note: Hemicel. = hemicellulose fraction