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SEASONAL VARIATIONS IN AFRICAN ELEPHANT NUTRITION IN TSAVO NATIONAL PARK, KENYA.

BY

Chiaki Nakamura

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1996

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ABSTRACT

SEASONAL VARIATIONS IN AFRICAN ELEPHANT NUTRITION IN TSAVO NATIONAL PARK, KENYA.

BY

Chiaki Nakamura

Seasonal patterns of feeding activities by the African elephant (*Loxodonta africana*), nutrients in plants eaten and the chemical composition of elephant feces in Tsavo National Park in Kenya, Africa were studied to provide information for maintaining nutritional requirements.

Elephants spent more time grazing and drinking in the dry season than in the wet season, and relatively constant time browsing during daylight observation periods in the south of Tsavo East National Park. Plants eaten by elephants tended to contain lower concentrations of moisture, manganese, hemicellulose, possibly calcium and potassium in the mid and late dry season, while at the same time containing high sodium and possibly cellulose. The composition of feces for eight chemicals tended to seasonally reflect nutrients in grass-herb vegetation grazed by elephants.

Elephant habitat management during the mid and late dry season should focus on water distribution and quantity, and the moisture content of available vegetation.

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Chiaki Nakamura
1996

To strugglers for wildlife conservation
in Africa for Africans.

ACKNOWLEDGMENTS

This study has been supported by many people, residents of USA, Kenya and Japan.

In USA, I thank Prof. Niles R. Kevern for giving me an opportunity to undertake my graduate study in the Department of Fisheries and Wildlife at Michigan State University (FW/MSU). I also thank Dr. Henry Campa III and Dr. Peter Murphy, of my guidance committee, and Dr. Scott R. Winterstein, Dr. Duane Ullrey and Dr. George A. Petrides. In Kenya, Dr. Perez M. Olindo, Former Director of Kenya National Parks and Mr.Paul Chabeda, Former Assistant Director of Research in the Kenya Wildlife Service (KWS), arranged my field research and my laboratory work. My research could not have been done without their suggestions. I also thank the Director of the KWS and the Kenya Government for allowing my research to be undertaken.

Many staff in Tsavo East and West National Parks helped with my research. I particularly thank Mr. Steve Gichangi and Mr. Salesio I. Kubai, Senior and Deputy Wardens of Tsavo East National Park, and Mr. Paul Opiyo, Warden of Tsavo West National Park, Mr. James Ndung'u and Mr. John Wanguku at the Community Wildlife Service of Tsavo East National Park, and Ms. Wanjiku Waweru at Tsavo Education Center. Mr. Elkana Mwambacha at Tsavo Research Center and Mr. Christpher Cheseny of the KWS helped me with identification of plant samples. Mr. Francis C. Ndegwa, Ms. Jane Wangai, Mr. Johnston Shivachi, and Mr. Peter K. Njuguna assisted me with analyses of many samples at the University of Nairobi.

In Japan, Prof. Hideo Obara, Kagawa Nutrition College was always supportive of my research. I wish to thank the Toyota Foundation and the Nature Conservation Society of Japan for their support of my research funding and for 4WD vehicles. I also thank Dr. Isao Mototani at Wako University, Mr. Hisashi Hirata at Kagawa Nutrition College, and Ms. Yumiko Isaka, Seitoku Junior College. I thank my parents and my sister for support of my research in Kenya and my study in USA.

Finally, I appreciate the help given to me by Ms. JoAnna Lessard, an undergraduate student of FW/MSU. The help and advice of graduate students in FW/MSU also helped me to concentrate and complete my graduate study. I am thankful for all their kindness and assistance.

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INTRODUCTION

African elephant* (*Loxodonta africana*) management in Kenya has been influenced over the years by several historical factors. The most basic and important factors have been operations and personnel changes in the government organization of wildlife management, particularly, after the establishment of a National Park system in 1946.

Until early in this century, there was no consideration of ecological or social aspects for managing elephant populations in Kenya, the same as wildlife management in those days in other countries around the world. Heavy sport and trophy hunting for pleasure and "game control" as a means of eliminating pest animals was a method introduced and employed by European settlers to harvest the natural resources of the country and was the

* "African elephant" is referred to as "elephant" in this thesis.

main factor influencing elephant populations across Africa. On the other hand, traditional hunting by indigenous people for their own food had, perhaps an ecological role, but was also a form of coexistence between humans and elephants.

In Kenya, poaching was the main reason for the decline of elephant populations, especially after the late 1970's, and was one of the most important factors for management of elephant populations by the time of the international ban on ivory trade in 1989, enacted by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The lifestyles introduced by a monetary economy and by foreign property values were different from the indigenous historical, social and economic traditions. Some indigenous people, managers, researchers, policy makers as well as local people started to copy the lifestyle of property values through the sale of animal products such as ivory. The commencement of heavy poaching occurred under mismanagement and lack of funds in the federal government during the period from the late 1970's to the late 1980's. The activities of poachers in Kenya were accelerated by the expansion of international trade between African countries and the outside world, particularly Asian countries such as Japan and China where the demand

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Habitat destruction following human population growth, was another main factor in the decline of the elephant population in Kenya. Human-elephant conflict was unavoidable. Reports of human-elephant conflict, increasing since early in this century, probably started even earlier, but were not noted because of poor records. It was recently said that the hostility of local people living in areas surrounding the protected areas had been precipitated by disputed boundaries of the protected areas, particularly, those established before Kenya became independent in 1963. The resolution of conflicts in buffer zones, where multiple land use is constantly modified as an elephant management practice, is an urgent matter for all in the areas where elephants live in Africa. Meanwhile, poaching control is still used as a defensive mechanism for management of elephant populations in Africa.

The major elephant conservation and management problems in Tsavo National Park and its buffer zone underlying the subject of this case study are, the "Elephant problem" during the 1950's and the 1960's described as over-browsing, vegetation destruction and over population (Glover 1963, Glover and Sheldrick 1966), heavy poaching during the period between the 1960's and the 1970's, [illegible]

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the 1980's, and the severe drought in 1970/71 causing malnutrition and a decline of habitat quality.

The Tsavo National Parks (East and West) and the surrounding areas were targeted by poachers throughout the late 1970's and the 1980's. Poaching was a major cause of the elephant population decline, along with possible changes in habitat preference by Tsavo elephants. Tsavo National Park may be described as lying between Somalia to the east north and Tanzania to the west south. During 1991 and 1992 when civil war broke out again in Somalia, many small bands of heavily armed Somalian who were renegade soldiers started to come to the Tsavo area. It was said that their main reason for coming was poaching ivory. They still believed ivory could be sold on the black market despite the CITES ban. Kenya has better economic growth than Tanzania, and Tanzanians easily enter into Kenya through Tsavo West National Park. Economic recession has been observed to force local communities to change from their ordinary lifestyles of small and poor means to smuggling, even with all the risk, to earn easy and big money within a relatively short time. The attitude of local communities towards wildlife is very important if one is to avoid the increase in smuggling and other unlawful acts against wildlife.

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in the buffer zones of Tsavo National Park. The area sandwiched by the Tsavo East and West National Parks is settled by mainly the Taita people. A majority of them presently occupy themselves with subsistence agriculture with a few of their number as small business people. It is from this area that most human-elephant conflict, including the incidents of humans killed by elephants, is reported. The Taitas have traditionally lived in the hills to protect themselves against the aggressive Maasais and Akamba. They were also sure of more rainfall which could produce more crops and other foodstuffs than could be produced in the lowland. As the population grew and with the introduction of western culture by the missionaries, the Taita started to move and settle into the lowlands. This began in the late 1930's. This may be said to constitute the commencement of conflict between wildlife and human beings in that area. Some of the Taita hunter-gatherers were evicted and ordered to keep their settlements outside the park boundaries (e.g. the area of Birikani) at the time of establishment of the Tsavo National Park in 1948. Cultivation in the Tsavo area is dependent on rain and water supplies. Crops are cultivated for the rainy season in April, May and June. Anticipation of the commencement of the rains is difficult for farmers, because of the unpredictable weather. Most farmers use

oxen to plough their small patches of land, while others raise poultry, dairy cattle, sheep and goats. The establishment of cattle ranches in this area started in the late 1960's. A majority of ranch owners are presently the Taita people and they are interested in the establishment of tourism (Wanguku, Kenya Wildlife Service, pers. comm.).

The area to the south of Tsavo West National Park has been overgrazed. This problem is caused by the Maasai people originating from both Kenya and Tanzania. The Maasais are pastoralists. Some from Tanzania release large numbers of cattle inside the National Parks during the night, although the herds of cattle are arrested by the rangers of Kenya Wildlife Service (Opiyo, Kenya Wildlife Service, pers. comm.). In the area near Lake Jipe, fishermen from Lake Victoria (Luo people) have settled. People management is a serious problem.

Pastoral and hunting people such as the Akambas and the Ormas who live in the northern buffer zone of Tsavo East National Park have sustained their traditional life style. Pastoral people traditionally hunt elephants to protect their own lives. It is said that some of the poachers were pastoral ethnic groups during the late 1970's and 1980's when heavy poaching occurred in Kenya. In this area, elephants fear people because of heavy during

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hunting including poaching, while in the Taita area, people fear elephants due to the destruction of the crops (Ndung'u, Kenya Wildlife Service, pers. comm.), and the frequent killing of people.

Fire was not used, whether controlled or uncontrolled, in Tsavo National Park (East and West) during the study period from 1990 to 1994, because of the uncertainty of rain and unpredictable drought. In the southern part of Tsavo East National Park, fire had been used mainly in three year intervals (rotation) with mosaic forms ("mosaic burning") during the 1960's and the 1970's under the Kenya National Parks (Olindo, Former Director of Kenya National Parks, pers.comm.). The use of controlled fire usually was one to two weeks after rains started. Accidental fires historically were said to be common. Assessing when accidental fire impacted vegetation is difficult to determine because of inadequate historical records.

Some accidental fires occasionally occurred during the study period in both Tsavo East and Tsavo West National Parks. The records indicate that the causes of wild fire were the careless use of cigarettes and charcoal burning in the villages next to the National Parks which frequently spread into the Parks. The fires, out of control during the study period were in July 1991 and June

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1993 in the Voi area of the Tsavo East National Park. There was no fire of natural origin observed during the study period. Wild and uncontrolled fires made by fishermen is a common occurrence along the shores of Lake Jipe next to the Tsavo West National Park.

Management needs must be pro-active related to land-use policy and habitat management and based upon research knowledge of the needs undertaken without restricting animal migration and movement. Feeding ecology as observed through nutritional studies is one of the most important research needs for conflict resolution, although very little work had been done previously on the subject. One of the previous studies related to food and nutrition of elephants in the wild was the quantitative analysis of nutrients contained in plants or soils in some protected areas of different countries of Africa (Field 1971, Weir 1973, Laws et al. 1975). Other studies listed plants eaten by elephants and recorded qualitative observations on food habits and the relationship between feeding patterns and nutrients in Tsavo National Park (Dougall 1963, Bax and Sheldrick 1963), and other National Parks (McCullagh 1969, Field 1971).

Some quantitative analysis has been done through the study of stomach contents (Williamson 1975, Malpus 1977, Clemens and Maloiy 1982).

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Mineral requirements of elephants, particularly calcium, was debated extensively with particular reference to the relationships between debarking trees and the calcium content of the bark (Bax and Sheldrick 1963, McCullagh 1969, Weir 1973). Weir (1972a) reported the differences of mineral composition of dry feces among three different National Parks. Seasonal differences of the mineral concentrations of stomach contents were described by McCullagh (1969).

Little of the above studies described for the relationship between feeding patterns and nutritional values of plants eaten by elephants and/or chemical composition of elephant feces. A long-term research project on this case study in Tsavo National Park was planned and promoted for a management goal and was to describe the relationship between nutritional values of food and subsequent feces of elephants and how these relate to their feeding habits in Tsavo National Park. A further study still remains as a research need to investigate the relationship between feeding and movement or migration patterns and the nutrient contents of plants eaten by elephants and their feces in an effort to provide information relating to the resolution of human-elephant conflict.

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Specific objectives designed for a four-year study were focused on describing seasonal feeding patterns of elephants and seasonal variations of nutrients in plants eaten by elephants and subsequently in elephant feces. These objectives were:

i) to describe seasonal feeding patterns of elephants in Tsavo National Park,

ii) to quantify seasonal nutritional qualities of plants eaten by elephants and in elephant feces in the southern part of Tsavo East National Park,

iii) to describe seasonal trends of the chemical composition of elephant feces in Tsavo National Park (East and West),

iv) to relate elephant feeding patterns to the nutritional quantity of plants and the subsequent feces on a seasonal basis, and

v) to provide seasonal recommendations for the conservation and management of elephants.

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STUDY AREA

Location

Tsavo National Park in Kenya, Africa, is located between 2° and 4° S and between 37° 30' and 39° 30' E. The road connecting the two largest cities in Kenya, Nairobi and Mombasa, passes two local towns, Mtito Andei (around 300 km from Nairobi) and Voi (around 150 km from Mombasa), which are close to the National Park (Figures 1 and 2). The "Tsavo Ecosystem" includes the two Tsavo National Parks, Tsavo East (11,655 km^2) and Tsavo West (9,177 km^2), and the area surrounding the Parks as the buffer zone where people have settled. The ecosystem also has similar zone in the Mkomazi Game Reserve in Tanzania along the Kenya-Tanzania border. The "Tsavo Ecosystem" extends into the Coastline Ecosystem in the Tana River area towards the eastern north of Tsavo and to the Amboseli Ecosystem in the western north of Tsavo.

Tsavo National Park was established in 1948 and is the second largest National Park in Africa. Its size has been almost the same since its establishment while the

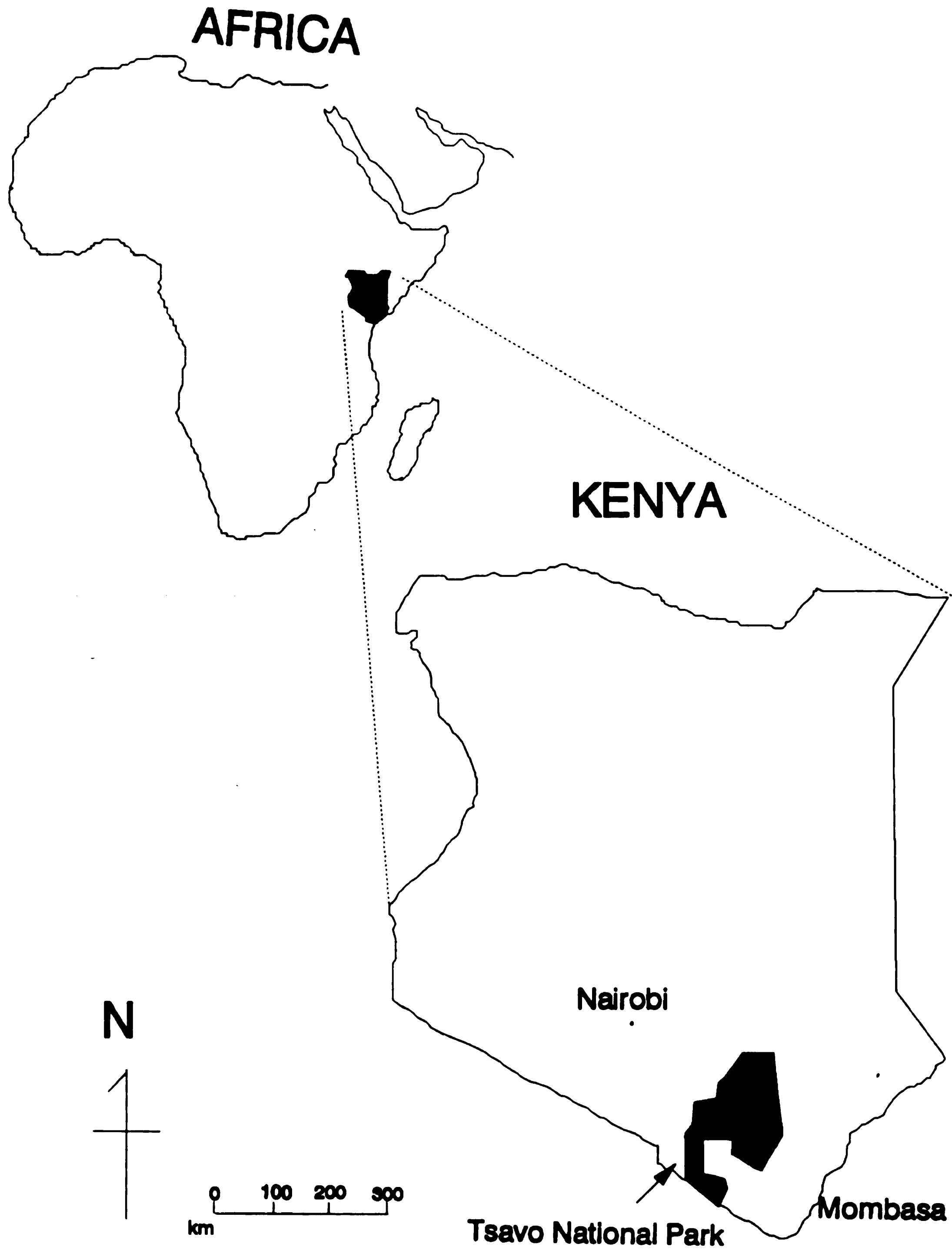

Figure 1. Location of Kenya in Africa and location of Tsavo National Park

Figure 2.

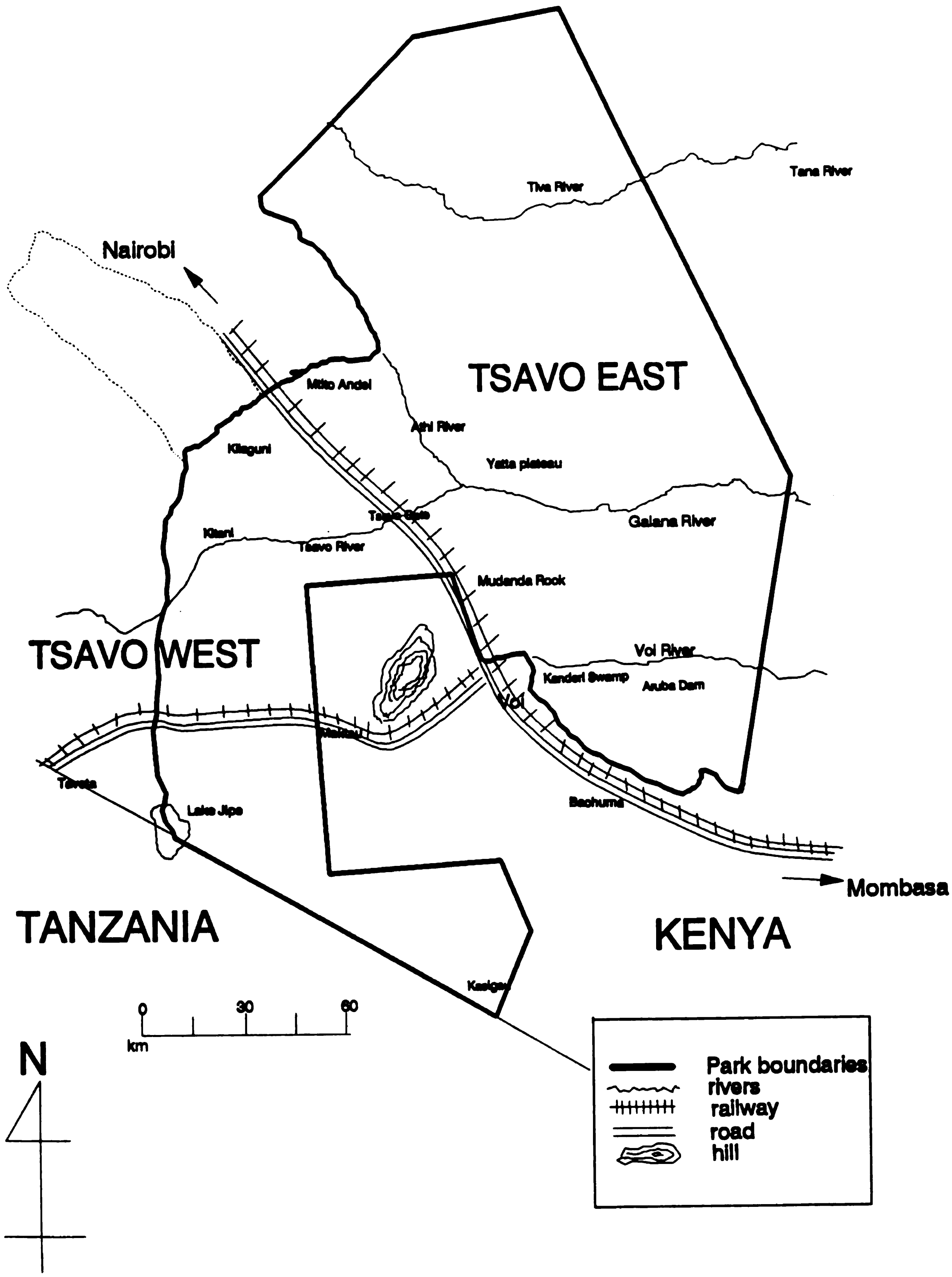

Figure 2. Tsavo National Park (East and West)

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boundaries were amended in 1953 and 1959 (Casebeer 1975). For administrative purposes, the Tsavo National Park legislatively established as one National Park, was divided into two National Parks: i.e. Tsavo West and Tsavo East National Parks.

This field study began in July 1990, and has continued until December 1994, with study periods divided into three consecutive times; from July 1990 to February 1992, from June 1992 to August 1993 and from December 1993 to December 1994.

Physical features

Climate

The climate in the Tsavo area is unpredictable, having annual and monthly fluctuations, and depends on regional, and other meteorological or global factors. There are two seasons, dry and wet. General seasonal changes are: a) two dry seasons in a year, normally expected in early or mid-January to late March, and late-May to mid- or late October, b) two wet seasons in a year normally expected in late-March or early April to mid or late May, and mid or late October to late December or early January.

The average rainfall per month for 85 years from 1904 to 1989, shown in Figure 3, was recorded at the Voi

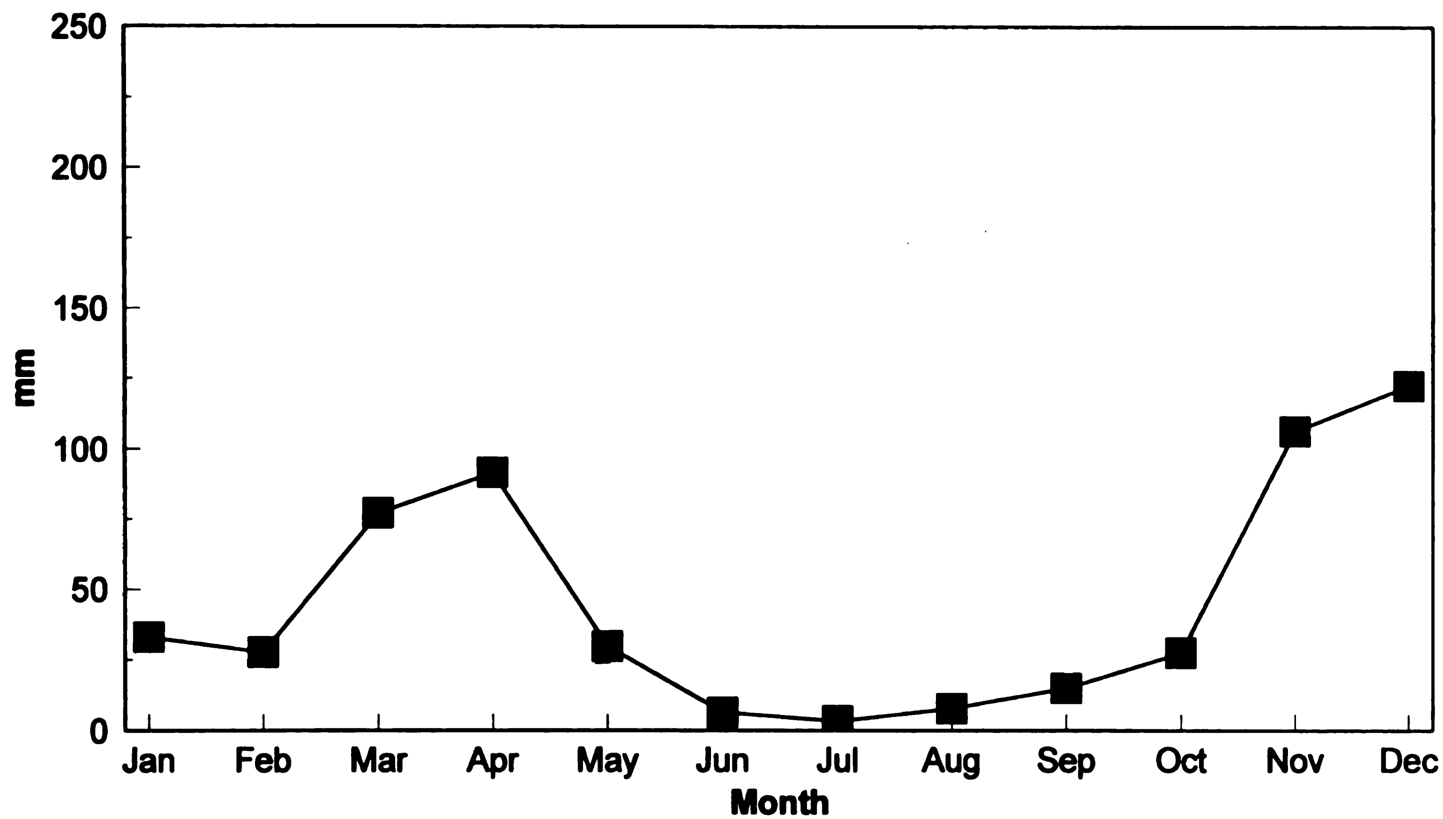

Figure 3. Monthly rainfall average for 85 years from 1904 to 1989 at Voi Meteorological Station.

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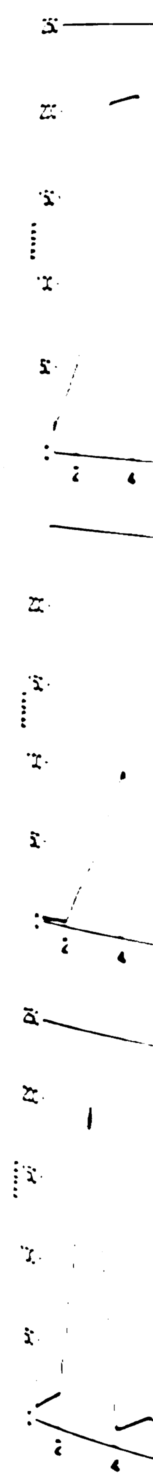
Rainfall is the primary factors in determining two seasons. The rainfall data at the Voi Meteorological station was used for the field studies of this study to determine the difference between wet and dry seasons. Figure 4 shows the rainfall variations from 1990 to 1994 for the study period. The date that the dry or the wet season starts and ends was determined from the rainfall data at the Voi Meteorological station. Table 1 shows the date and the number of days for wet and dry seasons from 1990 to January 1995 (Mushoki, Voi meteorological station, pers.comm.), for data collection and analyses in this study. There was an exceptionally long wet season from October 28, 1992 to February 21, 1993, compared with other wet seasons.

The date for the end and start for each season is important for sample collection in the field. However, the assignment of two seasons by rainfall records at one place, Voi, cannot cover all geographical differences for two seasons in the field. Geographical differences in the annual base during a given period was reported from the data for rainfall in several places in Tsavo National Park (e.g. Leothord and Sale 1973, Ayeni 1974). Seasonal changes in vegetation, mainly caused by rainfall changes, were clearly observed during the study period in different



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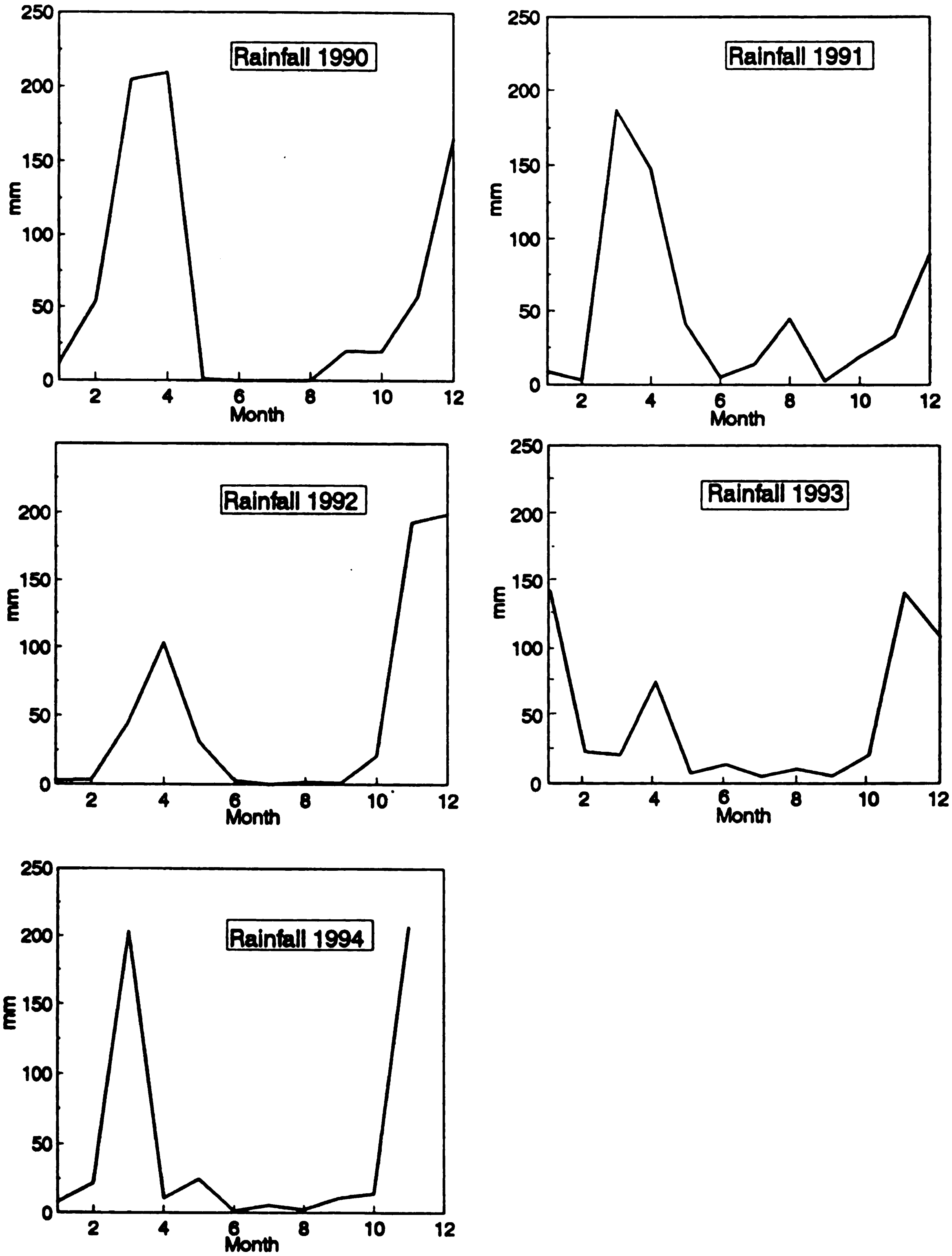

Figure 4. Rainfall from 1990 to 1994 at the Voi Meteorological Station.

Table 1. [illegible]

Dry season

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Jan. [illegible]-May [illegible]
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Dec. [illegible]
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Feb. [illegible]-May [illegible]
Apr. [illegible]
Jan. [illegible]-May [illegible]
May [illegible]
Total

Wet season

Period
Nov. [illegible]-Dec. [illegible]
Mar. [illegible] May [illegible]
Nov. [illegible]-Dec. [illegible]
Mar. [illegible]-May [illegible]
Oct. [illegible]
Mar. [illegible]
Nov. [illegible]
Mar. [illegible]-May [illegible]
Oct. [illegible]
Total

[illegible]

Table 1. The periods and days for two seasons (dry and wet) between April 1990 and January 1995.

Dry season

Period	Days
Apr. 26-Nov. 4, 1990	127
Jan. 1-Mar. 12, 1991	71
May 25-Nov. 10, 1991	170
Dec. 24, 1991-Mar.18, 1992	86
May 15-Oct. 27, 1992	166
Feb. 22-Mar. 19, 1993	26
Apr. 23-Nov. 19, 1993	211
Jan. 13-Mar.24, 1994	71
May 23-Oct. 11, 1994	142
Total	1,070 (64.4%)

Wet season

Period	Days
Nov. 5-Dec.31, 1990	57
Mar. 13-May 24, 1991	73
Nov. 11-Dec. 23, 1991	43
Mar. 19-May 14, 1992	58
Oct. 28, 1992-Feb.21, 1993	117
Mar. 20-Apr.22, 1993	34
Nov. 20, 1993-Jan.12, 1994	54
Mar. 25-May 22, 1994	59
Oct. 12, 1994-Jan.16, 1995	97
Total	592 (35.6%)

The beginning of wet season was determined by the first day of at least five consecutive days having more than 10mm in rainfall after the total amount of rainfall for at least ten consecutive days was less than 10mm (the late dry season). The end of wet season was determined by the last day having more than 0.1mm in rainfall before the total amount of rainfall for at least seven consecutive days was less than 10mm (the early dry season).

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geographic area on the same date. However, the rainfall data collected at several places for the monthly base was not available on a daily base, e.g. in Tsavo National Park, and thus could not be used for this study.

The average temperature for 43 years from 1938 to 1980 shows that the maximum temperature was 30.6°C and the minimum temperature was 19.3°C. Generally, the months from mid-June to early September are the cooler dry seasons and February and March are the warmer dry seasons (Figure 5).

Drought was recorded twice in the 1960's and 1970/71, 1975 and 1984. Severe drought recorded in the 1960's and the early 1970's modified wildlife populations through natural mortality within the ecosystem. Drought, like rain, is also unpredictable. Drought obviously contributes to the population status of wildlife including big game such as elephants and buffaloes (*Syncerus caffer*), and is a dynamic ecological and natural factor in the Tsavo area.

Frequent strong winds have been observed in the dry season. Small sand pillars can be observed particularly outside the National Park where vegetation, sought to satisfy food and firewood requirements, is damaged by cattle and humans. Wind is one of the major agents promoting the spread of accidental fires.

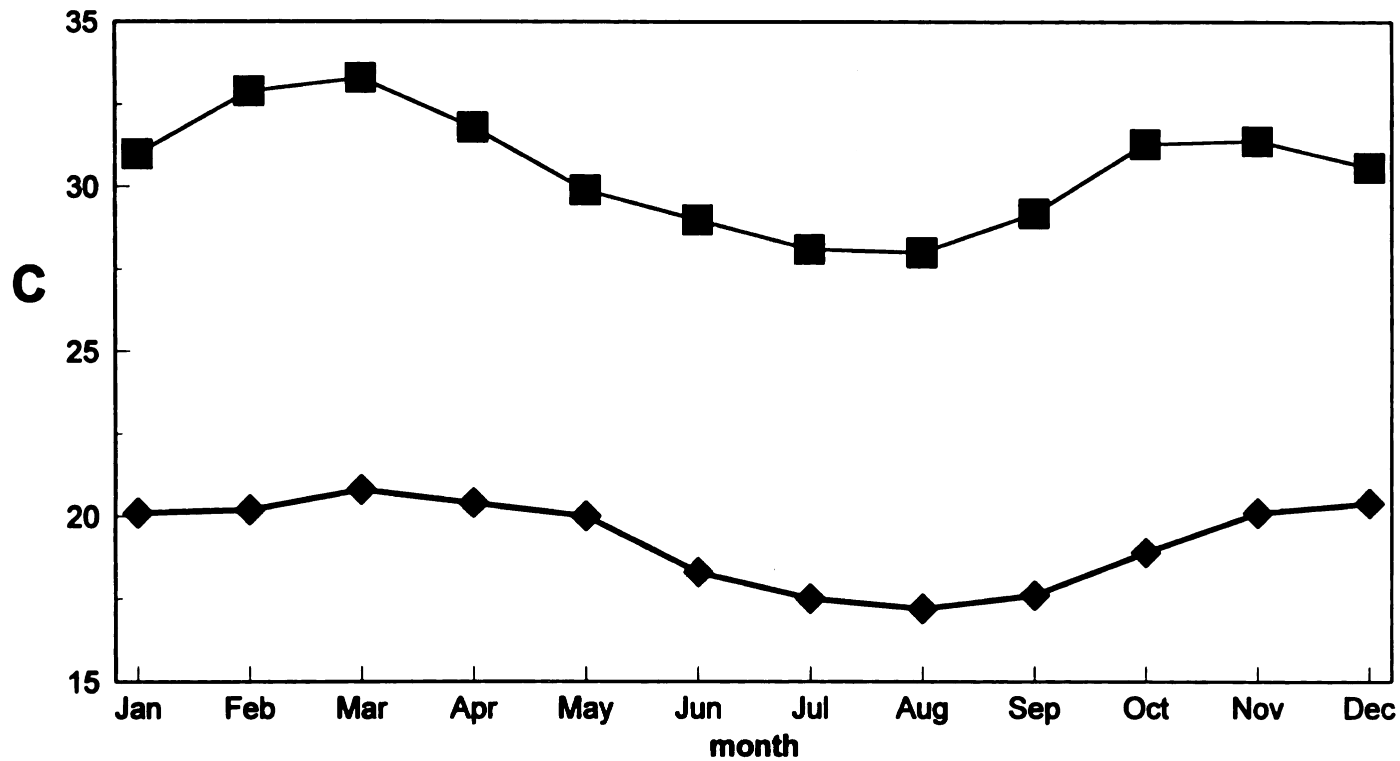

Figure 5. Monthly maximum (■)and minimum (◆)temperature average for 43 years from 1938 to 1980 at Voi Meteorological Station.

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Geology and Topography

The following description is based on the reviews of undated Tsavo Research Center manuscripts, Sanders (1963) and Wijngaarden (1985).

The geomorphology of the Tsavo area was created predominantly by volcanic activity, with unconsolidated deposits in the Tertiary and Quaternary Periods. The basement rock from the Precambrian and sandstone rock from the Mesozoic period also cover the area. The terrain is dominated by the occurrence of rock of sedimentary origin.

Fluviatile and continental deposits constitute most of the sandy sediments, while bay deposits are composed of clay sediments.

The Yatta Plateau and the Chyulu hills consist of volcanic rocks covered by Quaternary pyroclastic deposits and Miocene phonolites. These landforms are eminent landscape features in Tsavo, although they only partially occupy the area.

Most of inselbergs on the flat plains are more quartzitic. The content of the basement system rock is crystalline limestone.

Soils

Sandy clay soils dominate most of the Tsavo area. Dark red, red or dark reddish brown soils can be found widely, although the range of colors varies. Well drained, rarely imperfectly drained soils occupy a majority of landforms. The other variety of the soils is found in the hills and in the low ridges, some of the desert plains, the bottomlands, the sedimentary plains of the bay deposits, and the volcanic plains.

The hills and low ridges do not cover a large area in Tsavo. The soils of the hills are well drained, reddish or greyish brown, rocky and stony with various textures. The low ridges have black soils with calcareous gravelly loam.

The soils of the desert plains along the Galana River are well-drained and gravelly, yellowish to dark reddish brown, or imperfectly to well drained and strong brown soils, often stony.

The bottomlands, floodplains and valley basins are mostly alluvial deposits. These occupy very little of the area. The bottomlands have very poorly drained, black, calcareous clay soils.

The soils of the sedimentary plain of the bay deposits are found in both area along the boundaries of the north eastern parts of Tsavo East National Park. The soils are poorly drained, brown or dark greyish brown. The texture is very firm, calcareous, sodic and saline clay.

The Chyulu hills and their surroundings are composed

of various volcanic rocks. The soils are well-drained, loamy and gravelly (Sombroek et al. 1982, Wijngaarden 1984).

Distribution of water (hydrology) and water supply

Water availability is one of the most important factors for seasonal migration of water dependent animals (Western 1975). The elephant is a water dependent animal and the distribution of water and water supply are limiting factors for elephants. Particularly, in the dry seasons, management of water is one of the most important factors causing human-elephant conflict.

The distribution of water sources for elephants in the Tsavo area can be categorized as natural water for wildlife, artificial water for wildlife, and artificial water for livestock or human (Table 2).

Artificial water sources for livestock or humans

Table 2. Categorization for distribution of water and water supply for elephants in the Tsavo area

Natural water sources for wildlife	river, swamp, lake, spring, natural waterholes
Artificial water sources for wildlife	dams, artificial waterholes
Artificial water sources for livestock or human	water given to livestock, water for human consumption

outside the National Park are attractive water supplies for elephants in the dry season.

There are permanent and seasonal water sources sustaining the vast biological diversity in the area. The Athi, the Tsavo, and the Galana Rivers are permanent rivers, and two major seasonal rivers are the Voi and the Tiva Rivers. Some seasonal river traces show that some of the rivers never flow even during the wet seasons. These may be called "dormant seasonal rivers". The number of apparent seasonal rivers, the amount of water and the period of flow of the rivers depends on various characteristics of the rainfall and related physical factors. Seasonal dry rivers are mainly sandy riverbeds. Water can be found by digging shallow holes in the riverbeds, particularly by large mammals like elephants.

Kanderi Swamp, along the Voi River of Tsavo East National Park, is presently one of the largest swamps in the Tsavo area. This Swamp was originally an old ox-bow lake of the Voi River, but was further developed in 1950 (Greenway 1969). The Swamp is connected to the Voi River during the wet season. During heavy wet seasons, "Seasonal Swamp Grassland" (Greenway 1969) appears along the Voi River and the Tiva River, in the surrounding area where some of the waterholes are located, and in the grasslands, probably on poorly drained and firm soils. No

permanent swamps were observed. Overflowing water often can remove or change large stretches of vegetation.

Lake Jipe is located in the southern part of Tsavo West National Park. It also lies on the boundary of Kenya and Tanzania. This is an area abundant in wildlife, especially during the dry season, but hunting pressure from Tanzania was likely to influence habitat selection by wildlife. Two-thirds of the lake is located outside the National Park, and overgrazing by cattle owned by settlers, fishermen and pastoralists is a serious problem to desertification in this area.

Mzima Springs is located in the volcanic zone of Tsavo West National Park. In the springs, some 50 million gallons of sparkling crystal-clear water gush out daily from a lava ridge (Williams 1967). There are also small springs along the Yatta Plateau. The spring water is the main water source for human settlement to the east south and south of the Springs. A Mombasa pipeline, constructed in the 1950's, within the Tsavo National Park promises to become one of the ecological errors. Overuse of the water by humans causes problems for sustaining good environmental quality, especially for the aquatic integrity, and for the necessary quantity of spring water for the environment.

The number of waterholes present was not counted

during the study period. Ayeni (1974) estimated that the density of natural waterholes was 0.59 per km^2 by ground check in the southern part of Tsavo East National Park. Some natural waterholes contain water throughout the short dry season (Ayeni 1974). This was also observed during my study period in the southern part of Tsavo West National Park as well as to the south of the Voi River in Tsavo East National Park.

Artificial waterholes, fed by boreholes, were developed mainly under the Kenya National Parks, from the 1950's to early 1970's (Olindo, Former Director of Kenya National Parks, pers.comm.). Recently in 1994, further development of artificial waterholes has begun in order to help elephants to avoid moving towards the elephant-human conflict area (Gichangi, Kenya Wildlife Service, pers.comm.). The vegetation around large artificial waterholes is often removed through frequent utilization and trampling by wildlife. Total destruction of vegetation is avoidable and recovery of the vegetation can occur quickly if the artificial waterholes can be regulated and rotated intermittently instead of using them as a permanent water supply. Wildlife concentrating on the waterholes near the tourist lodges are one of the biggest attractions for the tourists in selected area of the National Park.

The majority of waterholes are attractive for much wildlife, especially for water-dependent animals during dry seasons. Many species of wildlife accumulate around waterholes and use the waterholes in peace, except when crocodiles (Crocodilus niloticus) and other predators move in or poachers disturb that peace. Intraspecific interruption was observed often in elephants. Elephants and buffaloes enlarge and deepen waterholes, wallowing in the water, during the dry season.

Aruba Dam in Tsavo East National Park was constructed on the Voi river in 1951. The average depth of water was 4m during flooding of the river and the surface area was 85.4 hectares (Ayeni 1974). Water in Aruba Dam was a permanent supply during the study period and one of the most attractive places for wildlife in dry seasons.

Dams and some boreholes for local communities in the area to north of Tsavo East National Park have been constructed and were planned since 1992, within the context of the Wildlife Community Program of KWS (Ndung'u, Kenya Wildlife Service, pers.comm.). The Kitui dam was completed for the Kamba people in 1994. The KWS provided water pipes from Tsavo East National Park as a donation to a woman's group in Taita (Birikani Women Water Project, a group helped by the author), for human water supplies in the same year. This area is the site of many

elephant-human conflicts. Since there are not good water supplies for wildlife, humans and livestock in the ranches in Taita-Taveta, the ranchers are enthusiastic about obtaining water supplies through the establishment of wildlife tourism (Wanguku, Kenya Wildlife Service, pers.comm.).

Vegetation types

Greenway (1969) categorized seven vegetation types at Tsavo East National Park; grassland, bushland, wooded grassland, woodland, forest, swamp vegetation and rocky vegetation. A vegetation map based on studies in the late 1970's was made by Wijngaarden and Engelen (1985). There is no present vegetation map and no intensive research on vegetation types to provide for a long term study base. Median-term vegetation changes over a ten-year period (1971-1981) in the Tsavo National Parks were discussed by Oweyegha-Afunadula (1984). The following description is for this study period, observed by the author.

Grassland (savanna) and Wooded Grassland

Grassland and wooded grassland are widespread in the southern part of both Tsavo East and West National Parks. Grassland ecosystems were rare, and the area presently covered by grassland or wooded grassland were previously dense bushland or woodland until the early-1970's (Olindo,

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Former Director of Kenya National Parks, pers.comm.). This change may be attributed to the combined action of elephants and wild fire.

The chief species of grasses (*Graminae*) in the area under observation are Chloris roxburgiana, Cenchrus ciliaris, Aristida adscensionis, Eragrostis caepitosa, Panicum maximum. Varieties depend on geographic and edaphic conditions. Brachieria serrifolia and Dactyloctenium giganteum are frequently found in the Voi area. Digera macroblephara, Latipes senegalensis and Themeda triandra are more frequent south of the Voi River and in the south of Tsavo West. Cynodon dactylon and Cynodon plectostachyus are common in the Voi area. Species richness of other dominant grasses vary, but the species number dominating the entire study area would be less than thirty. Cynodon dactylon and Bracheria serrifolia seem to be grasses more common in Tsavo East National Park. Cynodon plectostachyus is likely to be more frequent in Tsavo West National Park.

Abutilon fruticosum, Commelina erecta, Digera mucronata, Tephrosia noctifloa, Ipomea mombassana and Shida ovata are common herbs in the Park. Heliotropium steudneri and Moechma debile are more common south of the Voi River and Tsavo West south. Ecbolium revoltum is a shrub frequently found in the Voi area.

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Evergreen trees and shrubs, Boscia coriacea, Salvadora persica and Thylachium thomasii are common in the Voi area and scattered in grasslands or wooded-grasslands. Deciduous trees and shrubs, Premna hostii, Sericocomopsis pallida and Cordia gharaf are common in the Voi area and in Tsavo West south. Delonix erata is observed in most area of Tsavo. Platycelyphium voense, Commiphora sp. and Acacia tortilis are more south of the Voi River and in the southern part of Tsavo West National Park.

Bushland and Woodland

Bushland and woodland mainly cover the central part and the northern part of Tsavo East and West National Parks. Bushland of Disperma kilimandscharica or Anisotes parrifolius is observed close to grassland or forest along the Voi river. Bushland of Ochna inermis is also common in the Voi area. Bushland and woodland of Disperma kilimandscharica or Premna resinosa are common in the northern part of Tsavo West National Park. Boscia coriacea, Commiphora sp., Premna resinosa, Sericocomopsis pallida, Grewia nematopus and Grewia bicolor are woody components of bushland or woodland in the central part of Tsavo East National Park.

In the northern part of Tsavo West National Park, Baobab trees (Andansonia digitata) are frequent. The

southern part of Tsavo East National Park was previously occupied by <u>Acacia</u> / <u>Commiphora</u> bushland (Laws 1970). However, <u>Commiphora</u> sp. and other trees including <u>Andansonia digitata</u> were destroyed by elephants causing new vegetation patterns with plants preferable to most other hervibores. This open condition prevailed between the 1950's and the 1970's before the drought in 1971/72 (Glover 1970).

The understory of bushland has a variety of herbs, shrubs and grasses. <u>Ecbolium revoltum</u> is a common shrub. <u>Puplia lappacea</u>, <u>Tephrosia noctifloa</u>, <u>Indigofera arrecta</u> and <u>Abtilon fruticosum</u> are the most common herbs. <u>Cleome hirta</u> and <u>Hibiscus micranthus</u> are locally common herbs. <u>Cenchrus ciliaris</u>, <u>Aristida adscensionis</u> and <u>Entropogon macrostachyus</u> are grasses frequently observed.

<u>Forest and Swamp</u>

The forest in Tsavo National Park can be observed only along the banks of the rivers, e.g. the Voi River and the Galana River in Tsavo East National Park and the Tsavo River in Tsavo West National Park; this is the so-called "Riverine Forest" (Greenway 1969). The limited swamp forests usually occupy some parts of the riverine forest. Along the Voi River, <u>Newtonia hildebrandtii</u>, <u>Dobera glabra</u> and <u>Kigelia africana</u> are the predominant tree species. The chief components of midstory are <u>Maytenus</u> sp.,

Combretum aculeatum, Capparis tomentosa, and understories are Cynodon dactylon, Panicum coloratum and Echinochloa haploclada.

On the Galana River the composition is different and forest is more scattered. Hyphaena coriacea, Acacia elatia, Cassia longiracemosa and Salvadora persica are observed on the banks. The riverine forest has not been observed much along the Tiva River, because of frequent and extensive floods over long rainy seasons. The riverine forest is rarely found on the banks of other seasonal rivers.

Swamp vegetation can be observed in the area of the Kanderi Swamp and the Aruba Dam. Some other seasonal waterholes also have swamp vegetation. The Kanderi Swamp is surrounded by bushland and open grasslands patched with forest. Newtonia hildebrandtii, Capparis tomentosa and Combretum aculeatum are the main trees and shrubs, and Cynodon dactylon and Cenchrus ciliaris are common grass species in swamp vegetation. Cyperus sp. is also common in such area.

Four geographic areas were used for data collection throughout the study period. Figure 6 shows the four different areas ; the southern part of Tsavo East National Park, the central part of Tsavo East National Park, the northern part of Tsavo West National Park, and the

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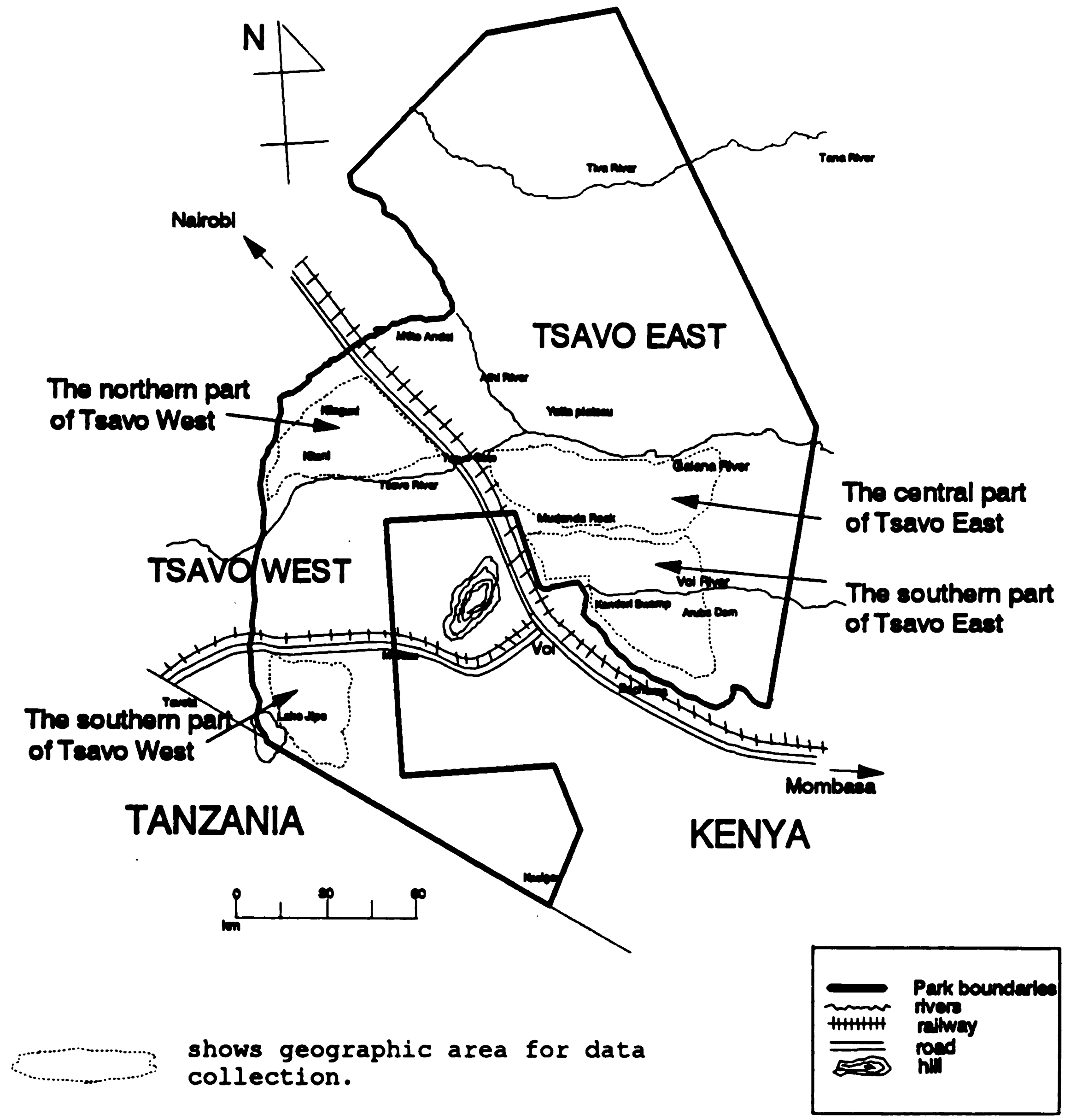

Figure 6. Geographic area in Tsavo National Park (East and West)

There are two parts in the southern parts of Tsavo East: the north and the south of the Voi River. Records for feeding activities and plants eaten by elephants were collected from the north of the Voi River. Samples of feces were collected from the north and the south.

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southern part of Tsavo West National Park.

The vegetation types in the southern part of Tsavo East National Park are represented by grassland. The vegetation types in the central part of Tsavo East National Park and in the northern part of Tsavo West National Park are similar, and represented by bushland and woodland.

The southern part of Tsavo East National Park covers mainly the area between Voi and Aruba along the Voi River. Grassland is the chief vegetation type, and often wooded grassland, bushland, and rarely forest along the Voi River are observed.

The central part of Tsavo East National Park covers mainly the area along the transect roads between Manyani and Lugard Falls along the Galana River, and Mudanda Rock along the boundaries of Tsavo East National Park, and close to Tsavo West National Park. The vegetation types are chiefly bushland and wooded-grassland, and often grassland, and rarely forest only along the Galana River.

The northern part of Tsavo West National Park covers mainly the area along the transect roads between the Tsavo Gate and Ngulia, Mtito Andei and Kilaguni or Kitani. The vegetation types are chiefly bushland and wooded-grassland, and often grassland, and rarely forest along the Tsavo River.

The geographic area for data collection of feeding observation for this study was expanded in January 1994 by adding the southern part of the Tsavo West National Park (Figure 6). The vegetation types are different from the northern part of the Tsavo West National Park, but similar to the southern part of the Tsavo East National Park. These are the areas along Lake Jipe and between Maktau Gate and Jipe, and between Kasigau and Jipe. The area surrounding Lake Jipe towards Maktau is covered mainly by grassland, with bushland being rare. The area between Kasigau and Jipe is covered mainly by grassland, wooded-grassland, bushland and woodland.

Three vegetation-type categories were used for data collection; grassland, bushland, and forest. Wooded-grassland was categorized as bushland. Woodland as a vegetation category for sampling was used a few times, depending on field conditions and observations. For this study, most of the collections and observations have been done in the southern part of Tsavo East National Park.

Population of elephants and their habitat use

The elephant population in Tsavo National Park and the surrounding area numbered approximately 20,300 in the dry season, 1965 (October) and the wet season in 1969 (April) (Glover 1970), and was seemingly stable during

that period. The severe drought in 1970/71 killed approximately 6,000 elephants in Tsavo National Park because of malnutrition (Corfield 1973). The aerial counts in the dry and the wet seasons 1972-1973 summarized by Leothold and Sale (1973) showed about 17,600 elephants in the dry season, 1972 (September) and 22,200 elephants in the wet or the early dry season in 1973. Seasonal variation as well as the severe drought may have affected the distribution of elephants, and possibly compensatory effects might have occurred after the drought in the 1970's.

Laws (1969b) criticized previous methods of counting and revised the estimate to over 25,000 elephants in 1967, and approximately 35,000 elephants in 1969 in the Tsavo National Park and the surrounding area. He mentioned that some 23,000 of the 35,000 were mainly within the Tsavo National Parks.

The elephant population in the entire Tsavo ecosystem, 43,300 km^2 or about twice the size of the Tsavo National Park, was estimated to be between 34,700 in May 1974 and 38,200 in December 1973, both counts being in the wet seasons or the early dry seasons (Cobb 1976). Recent unpublished data shows about 20,000 elephants throughout the 1960's and the 1970's. The reason for the discrepancy among the population estimates is still unclear. It might

be said that the estimate "30,000-38,000" is the "Laws count", while "20,300" is the "Glover count".

In 1976, 19,350 elephants, were reported in the Tsavo area by the Wildlife Conservation and Management Department (Ottichilo 1981). In the following year, in similar size area in the Tsavo area, 21,900 elephants were estimated in the wet season's counts and 16,500 elephants in the dry season's counts (Stelfox et al. 1981). If the "Glover count" was correct, the population of elephants was stable until 1977, except during the drought, and might show that the Kenya National Parks managed elephants well. If the "Laws count" was correct, a sharp decline would have started in 1975 or 1976, and might show that the Kenya National Parks failed in the management of elephants. The year 1976 was when the Kenya National Parks was amalgamated as a governmental organization from an autonomous organization under a Board of Trustees and heavy poaching started from July of that year (Olindo, Former Director of Kenya National Parks, pers.comm.).

In 1981, approximately 12,000 elephants were estimated to be in the Tsavo area (Ottichilo 1981). The seasonal fluctuations could be considered by coincidence with more active poaching in the dry season. The figure finally dropped to the lowest number of approximately 6,500 elephants in 1989 (EEC/WWF 1989). A recent census

showed approximately 7,400 elephants in June 1994 (Gichangi, Kenya Wildlife Service, pers.comm.).

The decline of the population was caused by poaching for ivory from the late 1970's to the late 1980's. The increase from 1989 to date has mainly been due to the effectiveness of the international ivory trade ban imposed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (the CITES), and the absence of severe drought affecting the Tsavo area.

According to observations by the author and information from staff in Tsavo National Park (East and West), old male elephants are very scattered, and rarely observed. The age composition of a population biased to mainly juveniles and sub-adults was described in the late 1970's as caused by heavy poaching (Ottichilo 1981, 1987, Olindo et al. 1988). A majority of older male elephants were said to have been targets of poachers for ivory. An increase in the number of young has been observed during this study period. Those individuals observed were mainly male calves.

Elephants use a variety of vegetation for food. They were observed in all vegetation types except volcanic area in Tsavo West. Although a variety of ungulates such as giraffe (<u>Giraffe camelopardalis</u>), impala (<u>Aepyceros melampus</u>), or Grant's (Peters') gazelle (<u>Gazella granti</u>

petersi Gunther) were observed in bushland or grassland next to the volcanic area, elephants were not observed in those vegetation types during the study period in the Tsavo area. The use of vegetation types by elephants depends on or is associated with seasons, year, and other related factors, particularly human factors such as poaching pressure and accidental fire. Previous poaching pressure seemed to be the most important factor considered for habitat preference of elephants in the Tsavo area. For example, elephants were observed mainly along the Galana River in the Tsavo East National Park between the 1960's and the early 1980's (Glover 1970, Leuthold and Sale 1973, Oweyegha-Afunabula 1984). Elephants were rarely observed during this study period in the area where heavy poaching occurred during the 1970's and the 1980's along the area of the Galana River and outside but close to the National Park, although the Galana River seemed to be a good permanent water supply for wildlife.

Elephant appearance in the cultivated and planted area of the human settlements constitutes a human-elephant conflict (Njoroge 1992). Figure 7 shows the migration and movement patterns of elephants during this study period through observation by the author and interpretation by communication with the staff and the local people.


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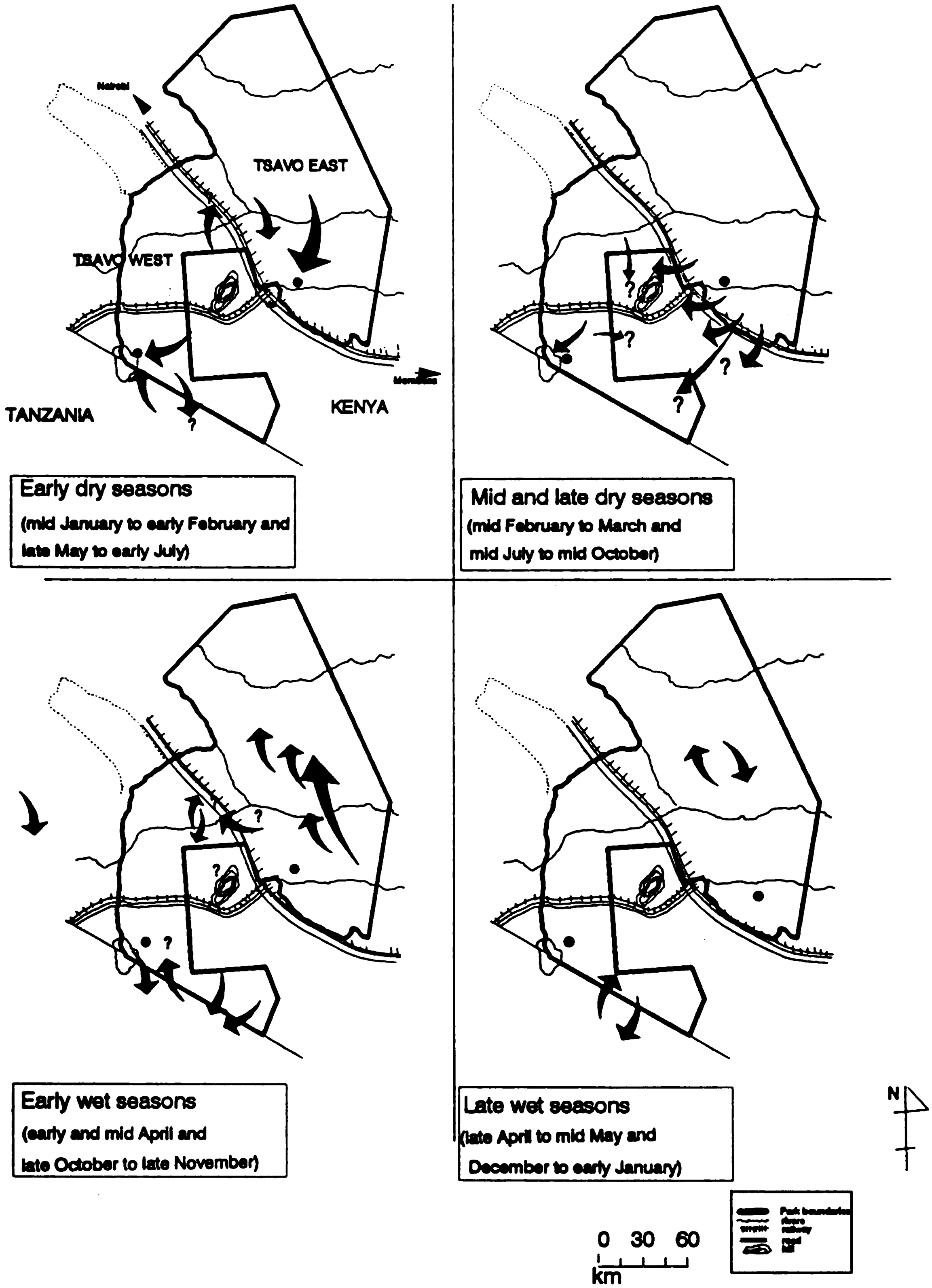

Figure 7. Seasonal migration and movement patterns of Tsavo elephants during the study period from 1990 to 1994. ● Residential groups. Months for seasons were flexible (see pages 14-19).

Residential groups in Figure 7 are groups that do not seem to migrate to wide area like other groups or individuals indicated by arrows (Figure 7), but stay in a particular area year-round. The number of residential groups in the southern part of Tsavo East National Park, staying in the area along Voi River, could be between fifty and two hundred, depending on reproduction, or immigration or emigration between migratory individuals and the residential groups. The number of residential groups in the southern part of Tsavo West National Park, staying in the area surrounding Lake Jipe, could be between twenty and forty.

Some patterns of elephant migration have been known and used for animal control at the Game Department until 1976 and were described in hunters' writings early this century. Tyrrell (1985) reconstructed elephant distribution in the Tsavo area in the late 19th century through historical records, and concluded that elephant distribution was less widespread than during the present time.

Vehicles for elephant study

A 4WD truck (2,400cc) used after December 1993 was powerful enough to drive anywhere in dry seasons. A 4WD vehicle, 1,400cc, used from July 1990 to August 1993, was

not powerful enough to drive into the bush for observations and collections in the area along rough transect roads. Frequent mechanical troubles forced the author to stay for many extra hours without help especially in mud area in wet seasons. Radio communications usually helped in the field study, but was not powerful enough for the hilly terrain.

Strong heavy-duty 4WD vehicles are necessary for long term elephant research. Costs of maintenance for vehicles often restrict field studies.

MATERIALS AND METHODS

Data collection in the field consisted of (a) observations of elephant feeding (grazing, browsing and drinking) and other activities (bathing, walking, standing and other categories such as defecating, rubbing or suckling), and (b) collection of plants eaten by elephants and (c) collection of elephant feces. Processing in the laboratory consisted of drying, grinding and chemically analyzing the samples.

Field conditions, costs, personnel and time limited experimental randomness and the number of observations and collections in the field studies. Road transects were limited, particularly in wet seasons. Most areas where elephants migrated were inaccessible in wet seasons; e.g. the northern area of Tsavo East National Park, where research could not be conducted for this study. It was difficult to observe elephants or collect samples in dense bushland and woodland from the ground. Bias of data collection was also introduced by sensitivity of elephants to vehicles, caused perhaps by their reactions to avoid poachers.

On the other hand, several unpredictable field conditions contributed to the bias of non-randomness. For example, a small amount of rain in wet seasons, and/or prolonged dry seasons helped the author with field conditions. Another example was construction of roads and/or waterholes under the management scheme opened dense bush areas and the author could access such areas. Considering the factors influencing observations and collections, a minimum acceptable level of statistical significance is chosen at alpha = 0.20 for all tests, this being less conventional than a level of 0.05 or 0.10.

Feeding patterns of elephants

Records of 287 observation periods along the driving transect were collected from September 1990 to October 1994 in the southern and the central parts of Tsavo East National Park, and in the northern and the southern parts of Tsavo West National Park. The "driving transect", an observation drive from one end of the study area to the other along the main road, was done by using the 4WD vehicle and binoculars throughout the study period. Recording forms and sheets were prepared for every transect. The total number of driving transects for this study was 446 in Tsavo East National Park and 81 in Tsavo West National Park. The total transect distances in Tsavo

National Park (East and West) were 40,104 km from July 1990 to December 1994. Table 3 shows the distances covered in two seasons in the Tsavo National Parks (East and West).

Three age classes were identified in the field according to the height of elephants; adults (approximately over 16 years), sub-adults (approximately 6-15 years), and infants (under approximately 5 years). Sexes were determined by the differences of head shape between sexes(Hanks 1979), or by sex organs.

Plant species eaten by elephants were recorded. The date and time, the location and vegetation types in the observation areas were also recorded.

Feeding activities (grazing, browsing, and drinking) and other activities (bathing, walking, standing and other categories such as defecating, rubbing or suckling) were recorded for one focal elephant for each observation at

Table 3. Transect distances from 1990 to 1994 in Tsavo National Park (East and West)

Season	Dry season		Wet season	
Tsavo	East	West	East	West
Jul.90-Feb.92	11,927km	1,470km	2,248km	754km
June 92-Aug.93	6,268	942	3,125	374
Dec.93-Dec.94	4,398	3,794	3,047	1,757
Total	22,593	6,206	8,420	2,885

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intervals of four or five minutes (Wyatt and Eltringham 1974, Guy 1976, Kalemera 1987, Kabigumila 1993a). Elephant groups were randomly selected. One focal elephant was chosen as the second individual from the first individual observed in one herd or group led by an adult female, or a bachelor group. Additionally, a solitary male adult elephant randomly selected was involved in one focal sampling because life in solitary for adult males was likely to be common among Tsavo elephants. All elephants observed and recorded were assumed to be different individuals. One observation was used for one data collection. The data were collected as one sample from one group or one individual at a given observation time at a given location. Records for this study using this method were made during daylight observation time from 06:00 am to 18:30 pm.

This method was used in open grasslands, at the edge between grasslands and other vegetation cover types such as bushland, woodland or forest, and in the areas surrounding waterholes. However, the method was not effective in bushland, woodland and forest where elephants could not be observed for more than three minutes and during the wet season.

Bias was unavoidable. The distribution of elephants, depending on seasons, year, other biotic and abiotic factors, and the behavioral reactions of elephants to human activities such as poaching were the main factors affecting data collection. Frequent interruption of observations occurred from loss of visibility in dense bush, inaccessibility to the field and the vehicle type and mechanical problems. The record bias favoring dry seasons in grassland could be minimized by using records collected from three to five minutes. Table 4 shows the number of observations for "5" minute intervals (3-5 minutes) for feeding and other activities of elephants collected in Tsavo National Park from September 1990 to December 1994, under categories of seasons, geographic areas, and vegetation cover types. The period observed for each activity in all study observation periods was five minutes for 249 observation periods and between three minutes and five minutes for 38 observation periods. Data collected in less than five minutes were not converted to a proportion of five minutes, rather the absolute values were used for statistical analyses. Total observation minutes of recording at the "5" minute interval were 1,398 minutes 38 seconds for all observation periods, and the mean interval was 4 minutes and 52 seconds (Appendix 1).

Of 287 observation periods, 232 were collected in dry seasons and 55 were collected in wet seasons. Two seasons were divided into five categories; early dry, mid dry,

Table 4 The number of observation periods using the 5 min interval methods [illegible] for feeding and other activities of elephants collected in [illegible] National Park from September 1990 to December 1994

Period	Sept. 1990 – February 1992	June 1992 – August 1993	December 1993 – December 1994	Total
Total	87	[illegible]	[illegible]	[illegible]

Table 4. The number of observation periods using the "5"-min interval methods (3–5min) for feeding and other activities of elephants collected in Tsavo National Park from September 1990 to December 1994.

	Period	Sept. 1990-February 1992	June 1992-August 1993	December 1993-December 1994	Total
	Total	87	95	105	287
Seasonal variations	Dry season	81	72	79	232
	Wet season	6	23	26	55
Geographic differences (Tsavo East (TE) and Tsavo West (TW))	S.TE	87	92	78	257
	C.TE	0	1	3	4
	N.TW	0	2	8	10
	S.TW	0	0	16	16
Vegetation type differences elephants use	Grassland (Gr)	39	49	60	148
	Gr--Bu	16	17	23	56
	Gr--Fo	0	6	4	10
	Bushland (Bu)	17	11	13	41
	Bu--Fo	7	2	1	10
	Forest (Fo)	4	7	2	13
	Gr-Bu-Fo	4	3	2	9

1. S.TE= the southern part of Tsavo East National Park, C.TE=the central part of Tsavo East National Park, Park, N.TW=the northern part of Tsavo West National Park, S.TW=the southern part of Tsavo West National Park.
2. Gr=Grassland, Bu=Bushland, Fo=Forest. "--" on the table denote that elephants moved and used two different vegetation types.
3. Woodland: It was difficult to collect data in "5"-min intervals, although fresh elephant feces were observed depending on seasons, year and areas.

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late dry, early wet, and late wet. Two geographic areas for the 287 observation periods were Tsavo East National Park (261 observation periods) and Tsavo West National Park (26 observation periods). The number of samples for feeding and other activities is shown for the two National Parks under seasonal categories in Appendix 2.

Of the 261 observation periods reported from Tsavo East National Park, 257 were observed in the southern part, with 247 from north of the Voi River, and 10 from south of the Voi River. The other four were from the central part of Tsavo East National Park. Of the 26 reported from Tsavo West National Park, 10 were from the north, and 16 were from the south.

Since the number of study observation periods from Tsavo West National Park was not sufficient to consider for the two seasons, analyses to describe seasonal variations were not attempted.

The 247 observation periods from north of the Voi River in the southern part of Tsavo East National Park were described in an attempt to explain the relationship of plants and elephant feces collected from similar areas, from June 1992 to July 1993. The observation periods were described for the same seasonal categories as for the overall 287 observation periods. Elephant activities by age classes were described in 246 of 247 observation

periods, since the age class for one was not clear. There were 132 adults, 59 subadults and 55 infants. Seasonal feeding activities for each age class were also recorded. Elephant activities by sex were described in 207 of the 247, with sex determination for 40 observation periods being impossible. There were observations for 105 males, and 102 females. Seasonal feeding activities for each sex were noted (Appendix 3).

Results were summed for absolute time spent, each activity being expressed as a percentage of total time per each activity (grazing, browsing, drinking, walking, standing and other) divided by total time spent per each category within seasons, areas, sexes, or age classes respectively.

A Kruskal-Wallis test (Siegel 1956, Sokal and Rohlf 1981) was used to compare differences among seasons, between geographic areas, between sexes, and among age classes for each activity (grazing, browsing, drinking, bathing, standing and other).

Nutritional qualities of plants

Nutrients analyzed were moisture, crude ash, minerals (calcium, potassium, sodium, magnesium and manganese), fiber (cellulose and hemicellulose), lignin and crude protein.

Plants eaten by elephants

Plant samples collected from June 1992 to June 1993 from north of the Voi River in the southern part of Tsavo East National Park were used for chemical analyses.

Plants eaten were noted during or after random observations of feeding. All species were identified by personnel of the Tsavo Research Center or the Museum in Nairobi (Herbarium).

Plants observed eaten by elephants were collected for nutrient analysis within a week after the observations. The number of samples of each species used to determine one mean value for each nutrient was either two ("paired sample") or three ("tripled sample"), and the samples were collected systematically within the same vegetation types (grassland, bushland or forest). The first sample was collected at the point where the elephant feeding activities were observed. The second point was selected at least three kilometers away from the first point along the driving transect roads. When the same plant species, and/or the same vegetation type was not found after three kilometers driving, a second three kilometers was driven. The possibilities to find the same species in the same vegetation type depended on the species and vegetation types. Each plant collection was composed of at least three individuals of the one species at each sampling point. I

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point. The parts of plants collected were the same parts observed to be eaten by elephants.

Plant samples were also collected from the areas during the periods when elephants were seasonally absent more than one to two months because of their migration. These records are referred to as "absence" for this study. For comparison, the plant samples collected from the areas during the periods when elephants were present over some months was referred to as "presence". "Absence" samples were collected systematically by the same method as "presence", between late December 1992 and early January 1993, during the wet season.

Each sample was kept in a plastic bag with a numbered tag and a data sheet with the date, time, location, vegetation type, plant forms such as flowering, shade, its height and other additional observations of predictable age of plant or trace eaten by unknown animals.

The sample was carried to the laboratory and weighed before and after drying in air until the weight became constant. Dried samples were wrapped in newspaper and carried to Nairobi for nutrient analysis.

Five seasonal categories were used for chemical analyses of plants; early dry season, mid dry season, late dry season, and wet season (elephants; present and absent).

The collection of samples from the field was planned for more than three species for each seasonal category from each vegetation type (grassland, bushland, woodland and forest). However, the number of collections was unequal for each season and each vegetation type because the exact length of the season category was impossible or difficult to determine prior to the time the samples were observed and collected in the field, and thus bias occurred in the observations.

Ninety seven species were recorded by the author as plants eaten by elephants in Tsavo National Park (East and West) for four years from July 1990 to October 1994. Thirty five species were collected as "paired" samples respectively for the seasonal categories and for the vegetation cover types from June 1992 to June 1993 (Appendix 4).

Nutrient composition data for eleven plant species were used for comparing seasonal differences. The total number of samples collected for chemical analyses was 86 for the eleven species.

The classifications used for the eleven species were four species for grasses (*Graminae*), two non-grass species for herbs, and five species of trees and shrubs.

The eleven species for comparison were grasses less than 1m height, Aristida adscensionis, Chloris

roxburghiana, Cynodon dactylon and Cynodon plectostachyus; herbs less than 1.5m height, a non-leguminous creeper Ipomea mombassana (*Convolvulaceae*) and a leguminous herb, Tephrosia noctiflora (*Papilionaceae*); trees and shrubs less than 3m height, Capparis tomentosa (*Capparidaceae*), Combretum aculeatum (*Combretaceae*), Disperma kilimandscharica (*Acanthaceae*), Premna hostii (*Verbenaceae*) and Salvadora persica (*Salvadoraceae*).

Flowering was observed from the late wet season to the early dry season. The upper parts in grasses and a leguminous herb, Tephrosia noctiflora, were generally eaten. In a non-leguminous creeper, Ipomea mombassana, the whole plant less roots was eaten. Similar parts were collected as those eaten for the sample. Elephants at times eat a bunch of twigs or stems with leaves, flowers, shoots and fruits (except roots) of the shrubs in the late wet season and the early dry season. The shrub samples in the wet season included all of these parts.

Two species of herbs, Ipomea mombassana and Tephrosia noctiflora in grassland appeared only from the mid wet season to the early dry season.

Among shrubs, Combretum aculeatum, Disperma kilimandscharica and Premna hostii are deciduous. Capparis tomentosa and Salvadora persica are evergreens. The means of leaf samples and stem samples were used for overall data an

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data analyses except for Combretum aculeatum in the mid dry season and Premna hostii in the early dry season, although the quantitative proportion of leaves and stems as elephant food might not be 50%.

Leaves of Combretum aculeatum were shed in the early or the mid dry season in grasslands, and in the mid or late dry season in forest or swamp areas. Both leaves and stems were collected when available in sufficient quantities, while only stems were collected after leaves were shed in the dry season. The samples for this species were stems only for one sample from "paired" samples collected from forest in the mid dry season, and for "paired" samples collected from grasslands in the late dry season. The means in the mid dry season were determined by the mean of values averaged by leaves and stems and values of stems only.

Leaves of Premna hostii were shed in the early dry season in grasslands. One sample of this species had leaves, but leaves were absent from stems when collected in the early dry season in grasslands. The mean value was determined the same way as Combretum aculeatum in the mid dry season.

The number of collections of individual species in different seasons depended on the observations of elephants eating the species, and accessibility to vegetat

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vegetation types under seasonal conditions. Two collections occurred within each seasonal category for the three species; *Chloris roxburghiana*, *Cynodon dactylon* and *Disperma kilimandscharica*. The mean of two collections was used for data analyses.

Chloris roxburghiana (grass) in grasslands was collected in early December 1992 and in mid February 1993, during wet seasons where elephants were present. *Cynodon dactylon* (grass) was collected from grasslands and from forest within one day in late September 1992, during the late dry season. *Disperma kilimandscharica* (shrub) in bushland was collected in mid March 1993 and in early June 1993, during the early dry season.

The total number of the species means were twenty eight (twelve for grasses, five for herbs and eleven for shrubs). The number of the species means was nine (three for grasses, two for herbs and four for shrubs) for the early dry season, four (one for grasses and three for shrubs) for the mid dry season, and four for the late dry season (two for grasses and two for shrubs). For the wet season, the number of the species means was eight from the area where elephants were present (four for grasses, two for herbs and two for shrubs), and four from the area where elephants were absent (two for grasses, one for herbs and one for shrubs).

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Differences of vegetation types were not used for statistical analyses because of an insufficient number of samples, but were considered in the description for seasonal comparisons. The wet season was not divided into early and late because of insufficient number of samples.

The Kruskal-Wallis test (Siegel 1956, Sokal and Rohlf 1981) was used to compare seasonal differences by single classification for nutrient values of the plant species within each seasonal category. When a significant difference was reported, a multiple comparisons test was used to further define differences among five seasonal categories, using the equation described by Miller (1980:p166).

The range of seasonal values was described within grass-herb vegetation and within shrub vegetation. The range for stems and leaves of each plant was described separately. Grass-herb vegetation was represented by grasses and herbs as related to grazing, while shrub vegetation was represented by trees and shrubs as related to browsing.

Trends of chemical composition of feces

Fresh feces of elephants were analyzed for moisture, crude ash, minerals (calcium, potassium, sodium, magnesium and manganese), fiber (cellulose and hemicellulose) and ing.i.

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Chemical contents of feces were assumed to follow the nutritional qualities of plants eaten by elephants. Qualities for chemical contents of feces, however, may be reflected by various factors such as quantity of vegetation contained in feces, a proportion of a species eaten by elephant defecated in feces, or physiological efficiency related to the digestive system. Although the assumption could be violated if the stronger relationship between one of those factors and qualities for chemical contents of feces is found, the data for this study may be useful to verify or establish the value of using chemical contents of feces.

Fresh feces were collected along driving transect lines in the selected areas from July 1990 to October 1994, by categories of seasons and geographic areas. The total number of fecal samples for chemical analyses for this study was 283.

The area for fecal sampling was selected by elephant observations and/or fecal observations within ten km along the driving transect lines. Elephant observations determined the area for fecal collection where at least one group composed of more than three individuals (adult females, subadults and/or infants), and/or at least one adult male was observed within three days before fecal collect

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collection. Fecal observations determined the area where at least fifteen heaps of fresh dung were observed within 24 hours before sample collection.

Elephant observations and fecal observations frequently occurred in the area along the Voi River in the southern part of Tsavo East National Park. The locations of the fecal samples were close to the locations of plant sample collection.

Fecal observations were used in the central part of Tsavo East National Park and in the northern part of Tsavo West National Park because elephants were rarely observed in these areas during the study period.

A sample was collected from dung heaps found at one sampling plot, within a 5x5m square along a transect line. This was referred to as a "single sample". The number of dung heaps within a square sampling plot varied from one to several. Two "single samples" within one kilometer were also collected, and these two samples at a sampling location were referred to as a "paired sample". The mean of two samples at a sampling location was taken for a value of a "paired sample". A sampling point for a "single sample" and a first sampling point for a "paired sample" was randomly chosen along the ten km transect line for fecal observations. One or two samples were collected within the same vegetation type from the one area for sampling. The second sampling location for the one area was selected at least three km away from the first sampling location. The number of samples, the determination whether a sampling was a "single" or a "paired sample", or date and time for collections varied throughout the study period, being dependent on feeding observations, fecal observations, field conditions and/or the conditions of the vehicle. The total number of single samples and paired samples for this study was 135 and 74, respectively.

The feces for individuals (sex and age) in the southern part of Tsavo East National Park in the mid and the late dry season from October 1990 to August 1993 revealed little differences for sex and age (Appendix 5). The observations of individuals defecating were not frequent, and subsequently, the number of samples identified for sex and age was only 21.

Seasonal patterns of chemical compositions in feces for one year

The number of fecal samples collected from July 1992 to July 1993 in the southern part of Tsavo East National Park, to compare with nutrients in plant samples, analyzed chemically was 39 (ten single samples and twenty nine paired samples) for moisture and crude ash, 30 (one single sample and twenty nine paired samples) for five minerals (

calcium, potassium, sodium, magnesium and manganese) and 27 (paired samples) for lignin and fiber.

Three seasonal categories, early dry, mid and late dry and wet seasons were used. For moisture and crude ash, the number of fecal samples was seven (paired samples) for the early dry season, 15 (three single samples and twelve paired samples) for the mid and late dry season, and 17 (seven single samples and ten paired samples) for the wet season. For minerals, the number of samples was 7 (paired samples) for the early dry season, 13 (one single sample and twelve paired samples) for the mid and late dry season, and 10 (paired samples) for the wet season. For lignin and fiber, the number of samples was 7 (paired samples) for the early dry season, 10 (paired samples) for the mid and late dry season, and 10 (paired samples) for the wet season.

The Kruskal-Wallis test (Siegel 1956, Sokal and Rohlf 1981) was used to compare seasonal differences and a multiple comparisons test (Millar 1980: p166) was attempted when a significant difference was detected.

<u>Seasonal patterns of elephant feces by geographic area</u>

Seasonal trends of feces in three geographic areas were described to find the trend in the southern part of Tsavo East National Park, compared to the central part of Tsavo East National Park or the northern part of Tsavo

West National Park. The number of samples collected from July 1990 to October 1994 was 113 (62 single samples and 51 paired samples) for the southern part of Tsavo East National Park, 45 (32 single samples and 13 paired samples) for the central part of Tsavo East National Park, and 49 (30 single samples and 19 paired samples) for the northern part of Tsavo West National Park.

Three seasonal categories (early dry, mid and late dry, and wet seasons) were used for moisture, crude ash, and minerals (except for manganese). Two seasonal categories (dry and wet seasons) were used for manganese, fiber and lignin because of the insufficient number of samples in wet seasons in two of the three geographic areas.

The data for moisture and crude ash were from July 1990 to October 1994. Moisture was measured for 203 samples (120 single samples and 83 paired samples), and crude ash for 209 (125 single samples and 84 paired samples). The number of samples each season for moisture and crude ash was 49 (29 single samples and 20 paired samples) for the early dry season, 67 (30 single samples and 37 paired samples) for the wet season. In the mid and late dry season, moisture was determined using 87 samples (61 single samples and 26 paired samples), and crude ash using 93 (66 single samples and 27 paired samples).

The data for minerals (except manganese) were measured for 114 samples (63 single samples and 51 paired samples) from July 1990 to June 1993. The number of samples each season was 35 (19 single samples and 16 paired samples) for the early dry season, 48 (31 single samples and 17 paired samples) for the mid and late dry season, and 31 (13 single samples and 18 paired samples) for the wet season. Manganese was measured for 62 samples (13 single samples and 49 paired samples) from March 1991 to June 1993. Data for the dry season were determined using 41 samples (ten single samples and 31 paired samples) while the wet season using 21 (three single samples and 18 paired samples).

Lignin and fiber (cellulose and hemicellulose) were measured for 45 samples (paired samples) collected from July 1992 to June 1993. The number of samples was 27 for the dry season and 18 for the wet season.

The Kruskal-Wallis test (Siegel 1956, Sokal and Rohlf 1981) was used to compare differences for three seasonal categories within each geographic area. The Mann-Whitney test (Siegel 1956, Sokal and Rohlf 1981) was used for two seasonal categories within each geographic area. A multiple comparisons test (Millar 1980: p166) was attempted when a significant difference was detected.

Geographic differences within each season were compared by the Kruskal-Wallis test. A multiple comparisons test was attempted when a significant difference was detected.

Chemical analyses of samples

All plant and feces samples were weighed in the field laboratory. The plant samples were dried in air, and the fecal samples were dried at 60°C to constant weight. All samples were ground in the laboratory at the University of Nairobi, Kenya, or at the Department of Fisheries and Wildlife at Michigan State University (FW/MSU) to pass a sieve with circular openings of 1.0 mm diameter. Ground samples were kept in a labeled plastic container in a laboratory room in Nairobi or a laboratory room at FW/MSU. Moisture, crude ash, minerals, fiber, lignin and crude protein were determined at the Department of Animal Production of the University of Nairobi, Kenya, or at FW/MSU, or at the Department of Forestry at Michigan State University.

Moisture and crude ash

Moisture and crude ash were analyzed by the methods described by the Association of Official Analytical Chemists (A.O.A.C,1990). Replication to determine one mean value varied from one to four for a sample. Moisture was ex

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was expressed as percent (%) on a fresh weight basis. Crude ash was expressed as % on a dry weight basis.

Minerals

The minerals were analyzed by methods described by the A.O.A.C.. (1990). Replication to determine each mean mineral value for one sample collected varied from one to four. Minerals were expressed as % for Ca, K, Na and Mg, and ppm for Mn on a dry matter basis. Dry ashing was used for the samples of feces collected until February 1992 to determine each mineral value as a sequential analysis after determination of crude ash. Wet digestion was used for all plant samples and for fecal samples collected after July 1992. The sample after preparation by both dry ashing and wet digestion was analyzed by atomic absorption in an appropriate dilution. The final sample dilution and standard solutions contained 1% lanthanum or strontium to overcome potential interferences when determining Ca and Mg.

Fiber and Lignin

Neutral detergent fiber residue (NDF) and acid detergent fiber (ADF) were used for analyses to determine cellulose, hemicellulose, and lignin. NDF and ADF analyses were described by Goering and Van Soest (1970) and A.O.A.C.(1990). One sample of every ten was replicated to determine method precision. NDF and ADF analyses were not operated in sequence, but were determined by separate procedures. Cellulose content was determined by subtracting lignin values from the ADF. Hemicellulose was determined by the values of ADF subtracted from the NDF. Fiber and lignin were expressed as % on a dry weight basis.

Crude protein

Crude protein analysis was described by the A.O.A.C. (1990). One sample of every ten was replicated to determine method precision. Crude protein was expressed as % on a dry weight basis.

RESULTS

Feeding patterns of elephants

Season

Table 5 (Figure: Appendix 6) shows the differences of two seasons (dry and wet), in elephant feeding and other activities in Tsavo National Park (East and West). The proportion of feeding activities summed by grazing (37.7%), browsing (16.5%), and drinking (5.1%), in the dry season (59.3%) was higher than in the wet season (45.2%) summed by grazing (25.0%), browsing (18.3%), and drinking (1.9%). Grazing and drinking in the dry season were higher than in the wet season ($P < 0.20$), but browsing between the dry and the wet seasons was not different ($P > 0.20$). Walking in the wet season (39.3%) was higher than in the dry season (23.9%) ($P < 0.05$).

The patterns of the same observation periods in five seasonal categories (early dry, mid dry, late dry, early wet and late wet seasons) are shown in Table 6 (Figure: Appendix 7). The proportion of feeding activities, 38.1% summed by grazing (16.5%), browsing (20.5%) and drinking (1.1%) in the early wet season was the lowest among the

Table 5. Time (%) elephants spent feeding and other activities for dry and wet seasons in Tsavo National Park (East and West) from September 1990 to October 1994 (287 observation periods) .

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
		**		**		***			
Dry season	232	37.7	16.5	5.1	2.4	23.9	11.2	3.1	100
Wet season	55	25.0	18.3	1.9	1.9	39.3	10.9	2.6	100

*** Differed at P<0.05 between two seasons.
** Differed at P<0.10 between two seasons.
n : number of observation periods.

Table 6. Time (%) elephants spent feeding and other activities for five seasonal categories (early dry, mid dry, late dry, early wet and late wet) in the Tsavo National Park (East and West) from September 1990 to October 1994 (287 observation periods).

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Seasons		*		***	*	***			
Early dry	93	39.3	15.2	4.7	1.9	25.2	11.2	2.5	100
Mid dry	36	25.5	23.2	12.9	1.5	22.1	9.7	5.0	100
Late dry	103	40.6	15.2	2.7	3.2	23.5	11.7	3.1	100
Early wet	30	16.5	20.5	1.1	0.0	43.5	16.2	2.2	100
Late wet	25	35.3	15.7	2.9	4.2	34.4	4.5	3.0	100

*** Differed at P<0.05 among five seasonal categories.
* Differed at P<0.20 among five seasonal categories.
n : number of observation periods.

five seasonal categories, and the proportion of walking (43.5%) and standing (16.2%) was higher than in the other seasonal categories. The patterns of feeding activities in the late wet season tended to be similar to the early and the late dry seasons, described as 35-41% grazing, 15-16% browsing and 3-5% drinking. Grazing in the mid dry season (25.5%) and in the early wet season (16.5%) was lower ($P < 0.20$), and drinking in the mid dry season was the highest (12.9%) among the five seasonal categories ($P < 0.05$), while browsing was not different ($P > 0.20$).

Among three dry seasons, the total feeding activities did not differ, 59.2% in the early dry season, 61.6% in the mid dry season, 58.5% in the late dry season, although the proportion of feeding activities (grazing or drinking) was different.

Geographic differences

Table 7 (Figure: Appendix 8) shows the differences between Tsavo East and Tsavo West National Parks. Grazing (38.0%) was observed more than browsing (15.7%) in Tsavo East National Park, while browsing (27.7%) was observed more than grazing (8.3%) in Tsavo West National Park ($P \leq 0.20$). The proportion of time spent in feeding activities (the sum of grazing, browsing and drinking) was more in the Tsavo East National Park, 58.3% than in the Tsavo West National Park, 39.9%, while standing was observed more in

Table 7. ***Time (%) elephants spent feeding and other activities in Tsavo East and West National Parks from September 1990 to October 1994 (287observation periods).***

Geographic areas	n	Feeding activities		Other activities					Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
		***	*				*		
Tsavo East	261	38.0	15.7	4.6	2.1	26.3	10.5	2.7	100
Tsavo West	26	8.3	27.7	3.9	4.0	32.4	17.7	5.9	100

*** Differed at P<0.05 between two geographic areas.
* Differed at P<0.20 between two geographic areas.
n : number of observation periods.

the Tsavo West National Park, 17.7% than the Tsavo East National Park, 10.5% ($P < 0.20$).

The southern part of Tsavo East National Park

Table 8 (Figure: Appendix 9) shows the seasonal patterns of elephant activities in the southern part of Tsavo East National Park. In the dry season 61.3% was spent in feeding activities, while in the wet season the time was 55.6%. Drinking in the dry season was higher than in the wet season ($P < 0.05$). There were no significant differences in grazing and browsing between the dry season and the wet season ($P > 0.10$). However, the trend was elephants spent more time grazing in the dry season. Table 9 (Figure: Appendix 10) shows the seasonal patterns of the same observation periods as Table 8 divided into five seasonal categories. Drinking in the mid dry season was highest ($P < 0.05$) while no differences were observed in grazing and browsing ($P > 0.20$). The patterns tended to be similar to Table 6 for the total area of Tsavo East and West National Parks.

Seasonal differences in age classes in the southern part of Tsavo East National Park

Table 10 (Figure: Appendix 11) shows the activity patterns of elephants in different age classes in the southern part of Tsavo East National Park. The proportion of feeding activities (the sum of grazing, browsing and

Table 8. *Time (%) elephants spent feeding and other activities for dry and wet seasons in the southern part of Tsavo East National Park from September 1990 to October 1994 (247 observation periods).*

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
				*		***			
Dry season	208	41.0	15.1	5.2	2.8	22.9	11.0	2.2	100
Wet season	39	34.7	18.2	2.7	0.5	32.7	7.4	3.6	100

*** Differed at $P<0.05$ between two seasons.
* Differed at $P=0.20$ between two seasons.
n : number of observation periods.

Table 9. Time (%) elephants spent feeding and other activities for five seasonal categories (early dry, mid dry, late dry, early wet and late wet) in the southern part of Tsavo East National Park from September 1990 to October 1994 (247observation periods).

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Seasons				***					
Early dry	90	40.3	14.9	4.9	1.9	24.0	11.4	2.5	100
Mid dry	29	31.7	18.5	12.5	1.6	23.0	10.6	2.0	100
Late dry	89	44.8	14.1	3.1	3.5	21.8	10.7	2.0	100
Early wet	17	27.5	18.6	2.0	0.0	37.5	10.6	3.8	100
Late wet	22	40.4	17.9	3.3	0.9	29.0	5.0	3.5	100

*** Differed at $P<0.05$ among five seasonal categories.
n : number of observation periods.

Table 10. Time (%) elephants of different age classes spent feeding and other activities in the southern part of Tsavo East National Park from September 1990 to October 1994 (246 observation periods).

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Age classes		**				*	***	***	
Adults	132	36.0	15.5	5.0	1.4	26.0	14.0	2.1	100
Subadults	59	38.8	20.6	4.6	2.1	26.7	7.3	0.0	100
Infants	55	49.7	10.7	4.7	4.4	18.8	5.7	5.9	100

*** Differed at P<0.05 among age classes.
** Differed at P<0.10 among age classes.
* Differed at P<0.20 among age classes.
n : number of observation periods.

Table 11. Time (%) elephants of different age calsses spent feeding activities for dry and wet seasons in the southern part of Tsavo East National Park from September 1990 to October 1994 (246 observation periods).

		n	Feeding activities			Other activities				Total
			Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Age classes	Season									
Adults	Dry	111	38.0	14.5	5.7	1.7	23.7	14.6	1.8	100
	Wet	21	25.5	20.7	1.6	0.0	38.2	10.3	3.7	100
Subadults	Dry	48	38.8	22.5	4.1	2.1	24.9	7.5	0.0	100
	Wet	11	38.8	12.0	6.6	1.8	34.5	6.3	0.0	100
Infants	Dry	48	49.0	9.3	5.4	5.1	19.5	6.4	5.4	100
	Wet	7	55.2	20.8	0.0	0.0	13.9	1.0	9.2	100

n : number of observation periods.

drinking) in adults, 56.5% was lower ($P < 0.10$) than 64.0% in subadults and 65.1% in infants. Grazing in infants (49.7%) was higher than adults (36.0%) and subadults (38.8%) ($P < 0.10$). Browsing by subadults (20.6%) tended to be higher than adults (15.5%) and infants (10.7%).

Table 11 (Figure: Appendix 12) shows the seasonal differences of feeding activities (grazing, browsing, and drinking) in each age class. There were no differences between two seasons in grazing, browsing and drinking for all age classes ($P > 0.20$). However, the trend of more time browsing for infants appeared in the wet season while for subadults in the dry season. Within the dry season, grazing by infants (49.0%) was higher than in adults (38.8%) and subadults (38.8%) ($P < 0.10$). Within the wet season, similar trends appeared with grazing by infants.

In the dry season, browsing by subadults (22.5%) tended to be higher than for infants (9.3%) and adults (14.5%). However, browsing in the wet season by subadults (12.0%) tended to be lower than with adults (20.7%) and infants (20.8%).

<u>Seasonal differences in sexes in the southern part of Tsavo East National Park</u>

Table 12 (Figure: Appendix 13) shows the feeding patterns of male and female elephants, and Table 13 (Figure: Appendix 14) shows the seasonal differences in

Table 12. Time (%) male and female elephants spent feeding and other activities in the southern part of Tsavo East National Park from September 1990 to October 1994 (207 observation periods).

	n	Feeding activities			Other activities				Total
		Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Age class			**			***			
Male	105	37.0	14.7	4.8	2.3	24.8	14.3	2.1	100
Female	102	44.2	17.2	4.2	0.9	23.0	8.5	2.0	100

*** Differed at P<0.05 between sexes.
** Differed at P<0.10 between sexes.
n : number of observation periods.

Table 13. Time (%) male and female elephants spent feeding and other activities for dry and wet seasons in the southern part of Tsavo East National Park from September 1990 to October 1994 (207 observation periods).

		n	Feeding activities			Other activities				Total
			Grazing	Browsing	Drinking	Bathing	Walking	Standing	Others	
Age class	Season									
Male	Dry	84	37.5	13.9	6.0	2.9	22.3	16.2	1.2	100
	Wet	21	34.7	18.2	0.0	0.0	34.8	6.9	5.4	100
Female	Dry	90	45.6	16.9	4.4	1.1	21.9	8.1	1.9	100
	Wet	12	34.0	19.0	2.8	0.0	30.9	11.2	2.2	100

n : number of observation periods.

each sex. No differences were found between sexes for grazing and drinking ($P > 0.20$), but browsing by females was higher than males ($P < 0.10$). In males, browsing in the wet season (18.2%) was higher than in the dry season (13.9%) ($P < 0.10$), but no seasonal differences within each sex were observed in entire feeding activities ($P > 0.20$).

Nutritional qualities of plants

Moisture

Figures 8 (a, b and c) and Table 14 show the seasonal differences in moisture for each species. The values differed among five seasonal categories ($P < 0.20$). Results for seasonal differences identified by multiple comparisons test are shown by thick arrows in Figure 9, and no differences ($P > 0.20$) were shown by thin arrows in the same Figure. Directions of arrows show directions of seasonal change from June 1992 to June 1993. "High" ("low": significantly differed) or " higher" ("lower": trends differed) in Figure 9 described differences of moisture between two seasonal categories observed from the species shown in Figure 8 and Table 14. The values in the wet season where elephants were present were higher than in the late dry season ($P < 0.10$) for two grass species (Figure 8a) and tended to be higher than in the early dry

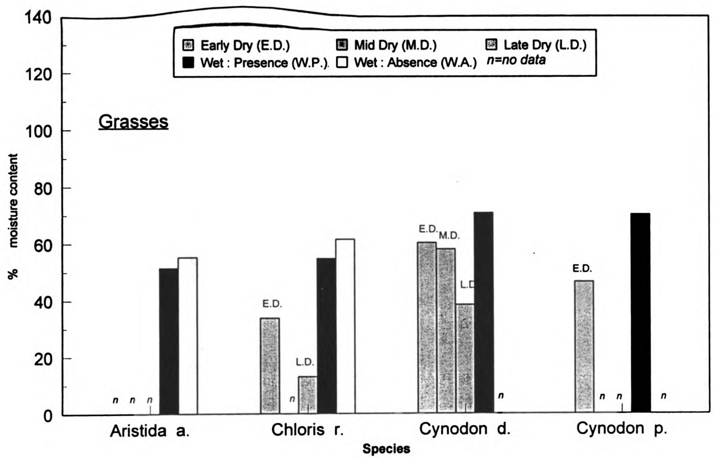


Figure 8-a. Moisture as % of plants eaten by elephants:seasonal differences from June 1992 to June 1993.
Standard Error (S.E.) is described in Table 14.
W.P.=Wet seasons where elephants were present.
W.A.=Wet seasons where elephants were absent.

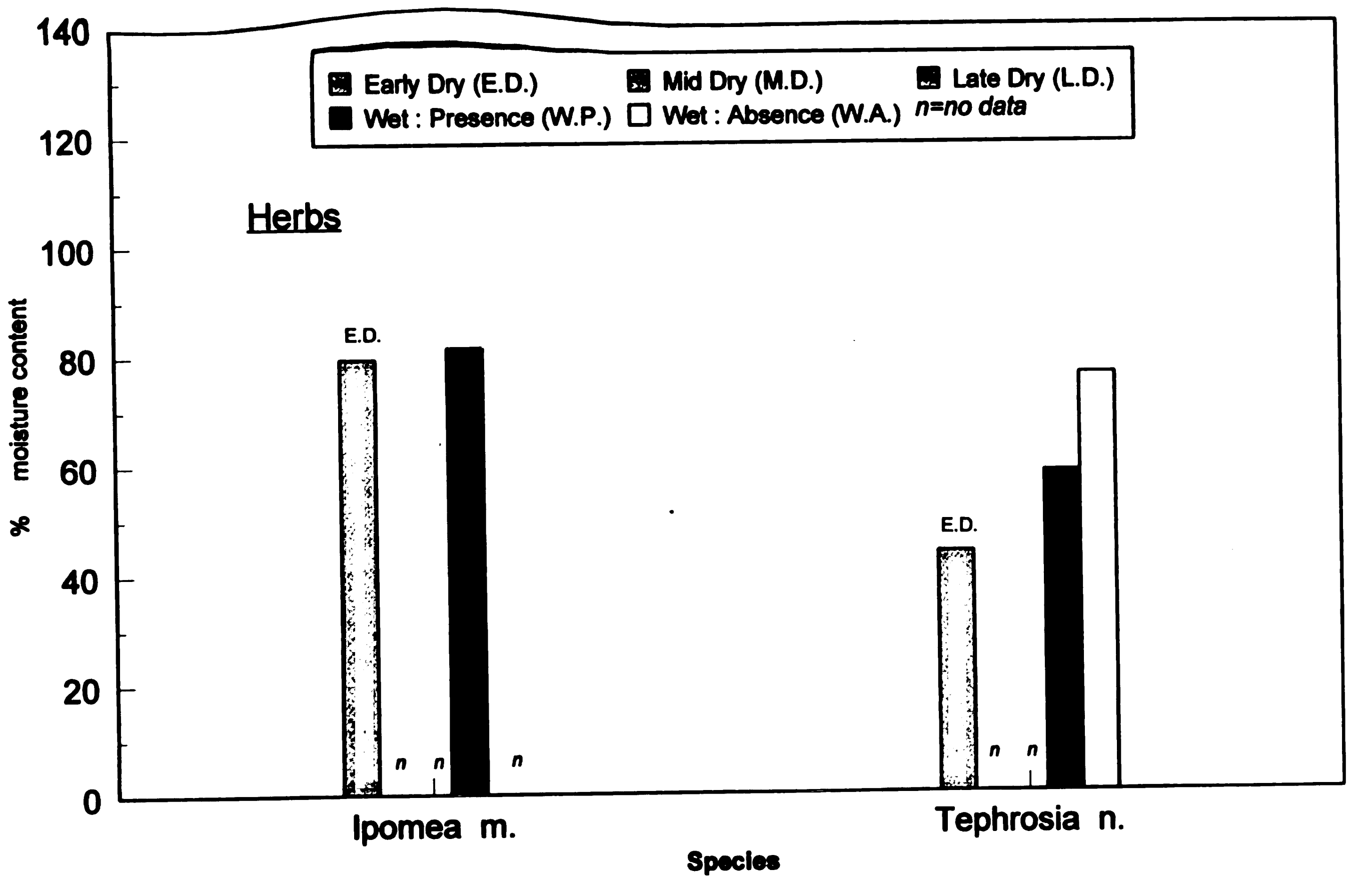


Figure 8-b. (cont'd)

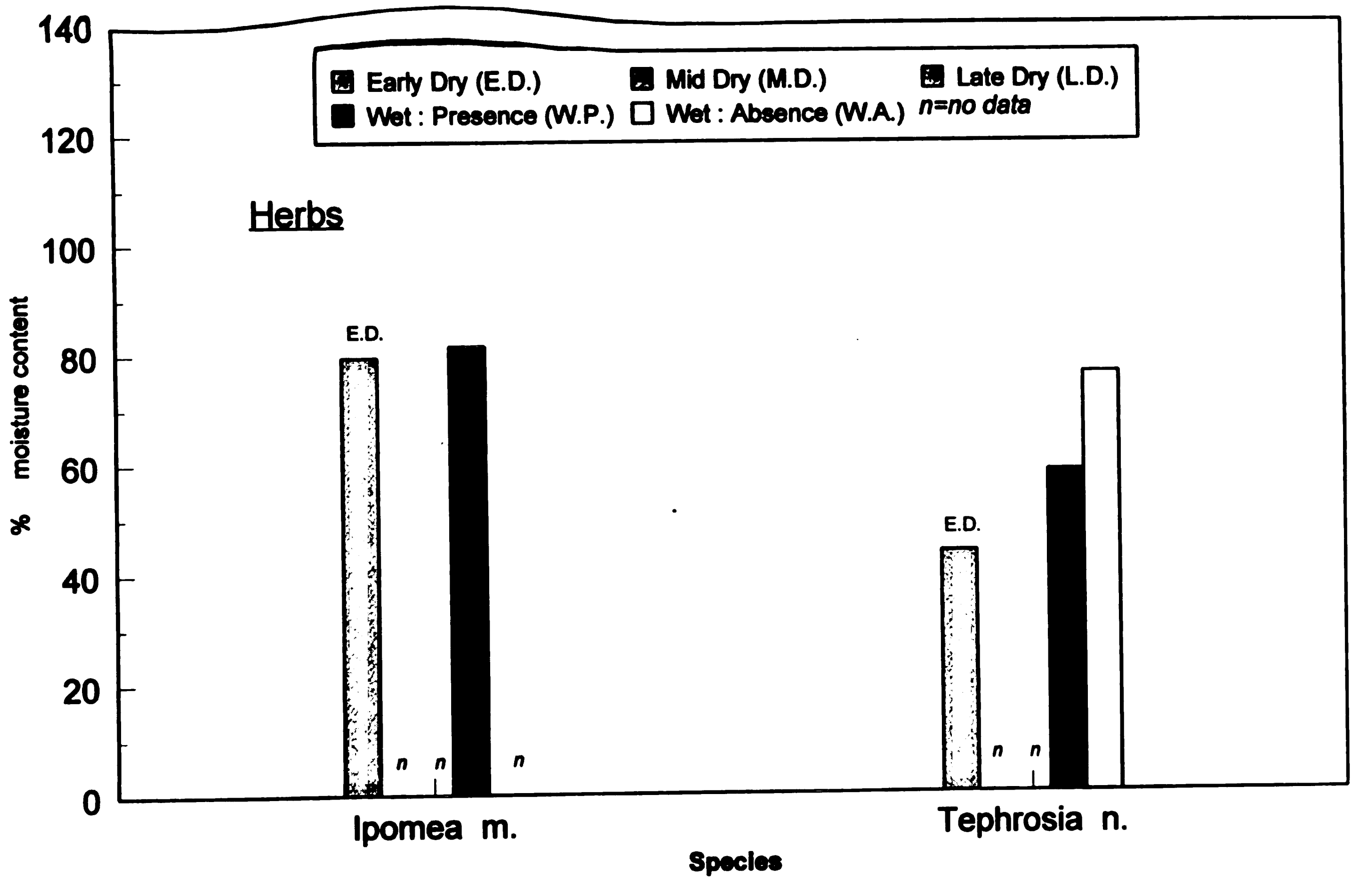


Figure 8-b. (cont'd)

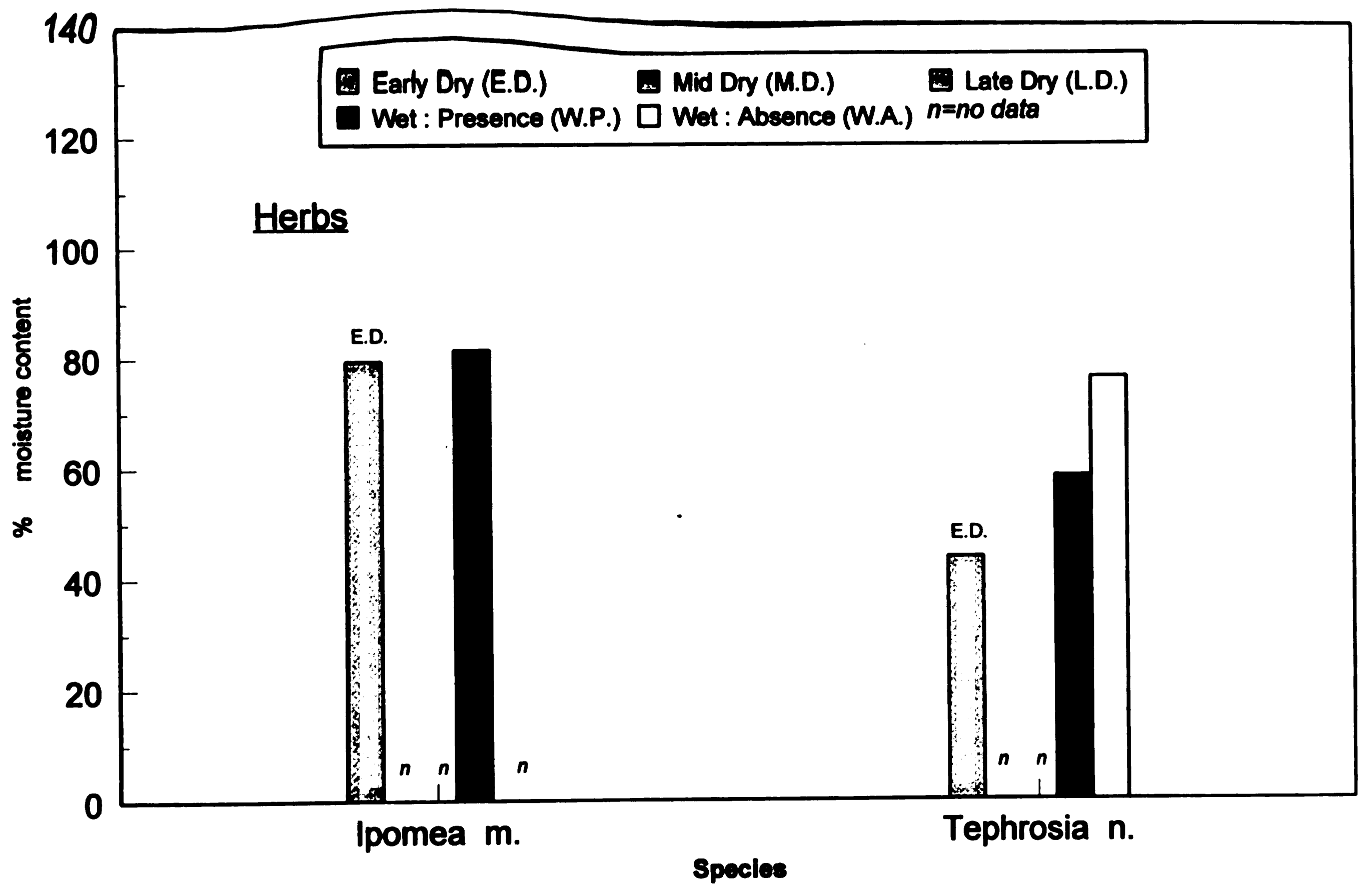


Figure 8-b. (cont'd)

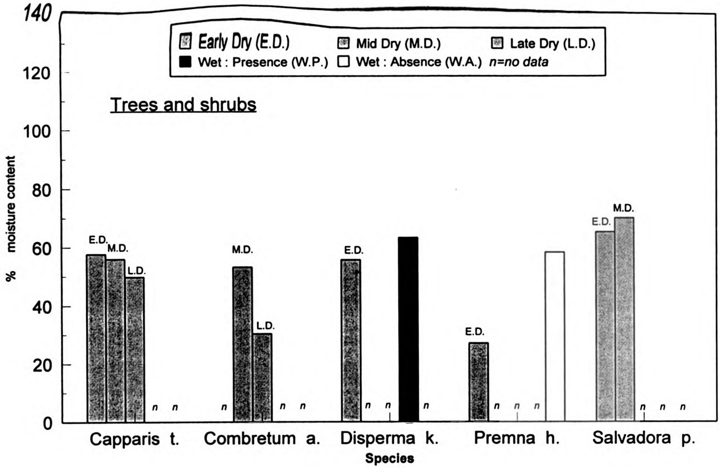


Figure 8-c. (cont'd)

Table 14. Moisture of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = percentage of moisture content)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	51.4 ± 4.50	
	(Bushland)					55.2 ± 2.54
Chloris roxburghiana	(Grassland)	33.8 ± n.a.	n.d.	13.1 ± 2.36	57.3 ± 3.95 (a-1)	61.6 ± 0.90
	(Grassland)				52.2 ± 2.11 (a-2)	
Cynodon dactylon	(Forest)	60.4 ± 4.87	58.2 ± 6.89	37.8 ± 4.03 (b-1)	71.0 ± 0.30	n.d.
	(Grassland)			39.4 ± 1.17 (b-2)		
Cynodon plectostachyus	(Grassland)	46.7 ± 8.12	n.d.	n.d.	70.4 ± 1.00	n.d.

Notes

1. (a): mean of two values averaged (a-1 and a-2), 54.8% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 38.6% was used for statistical analyses.
3. "n.d." denote no data.
4. "n.a." denote that "S.E." was not available because one sample was not determined on a wet matter basis.

Table 14. Moisture of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = percentage of moisture content)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	51.4 ± 4.50	
	(Bushland)					55.2 ± 2.54
Chloris roxburghiana	(Grassland)	33.8 ± n.a.	n.d.	13.1 ± 2.36	57.3 ± 3.95 (a-1)	61.6 ± 0.90
	(Grassland)				52.2 ± 2.11 (a-2)	
Cynodon dactylon	(Forest)	60.4 ± 4.87	58.2 ± 6.89	37.8 ± 4.03 (b-1)	71.0 ± 0.30	n.d.
	(Grassland)			39.4 ± 1.17 (b-2)		
Cynodon plectostachyus	(Grassland)	46.7 ± 8.12	n.d.	n.d.	70.4 ± 1.00	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 54.8% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 38.6% was used for statistical analyses.
3. "n.d." denote no data.
4. "n.a." denote that "S.E." was not available because one sample was not determined on a wet matter basis.

Table 14. Moisture of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = percentage of moisture content)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	51.4 ± 4.50	
	(Bushland)					55.2 ± 2.54
Chloris roxburghiana	(Grassland)	33.8 ± n.a.	n.d.	13.1 ± 2.36	57.3 ± 3.95 (a-1)	61.6 ± 0.90
	(Grassland)				52.2 ± 2.11 (a-2)	
Cynodon dactylon	(Forest)	60.4 ± 4.87	58.2 ± 6.89	37.8 ± 4.03 (b-1)	71.0 ± 0.30	n.d.
	(Grassland)			39.4 ± 1.17 (b-2)		
Cynodon plectostachyus	(Grassland)	46.7 ± 8.12	n.d.	n.d.	70.4 ± 1.00	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 54.8% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 38.6% was used for statistical analyses.
3. "n.d." denote no data.
4. "n.a." denote that "S.E." was not available because one sample was not determined on a wet matter basis.

Table 14. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	79.5 ± 3.58	n.d.	n.d.	81.5 ± 3.58	n.d.
Tephrosia noctiflora	(Grassland)	43.9 ± 0.53	n.d.	n.d.	58.5 ± 0.35	78.4 ± 1.03

Note: "n.d." denote no data.

Table 14 (cont'd)

Table 14. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet season Presence (W.P.) =where elephants were present % Mean ± S.E.	Wet season Absence (W.A.) =where elephants were absent % Mean ± S.E.
Capparis tomentosa	Leaves	59.5 ± 1.00	59.6 ± 1.65	54.5 ± 2.37		
(Forest)	Stems	55.8 ± 0.59	52.4 ± 0.05	44.8 ± 2.69	n.d.	n.d.
	Leaves and stems	57.7 ± 0.21	56.0 ± 0.85	49.8 ± 4.25		
Combretum aculeatum	Leaves		66.8 ± n.a.	-		
(Forest=Mid dry season)	Stems	n.d.	49.7 ± 3.24	30.3 ± 3.19	n.d.	n.d.
(Grassland=Late dry season)	Leaves and stems		53.2 ± 6.70 (c)	- (d)		
Disperma kilimandscharica	Leaves	71.0 ± 2.71			68.8 ± 2.20	
(Bushland=Early dry season)	Stems	50.1 ± 4.60			57.6 ± 1.92	
(Grassland=Wet season)	Leaves and stems	60.6 ± 3.65 (e-1)			63.2 ± 2.06	
			n.d.	n.d.		n.d.
	Leaves	59.9 ± 5.48				
	Stems	41.2 ± 4.79				
	Leaves and stems	50.6 ± 5.14 (e-2)				
Premna hostii	Leaves	29.0 ± n.a.				64.6 ± 0.68
(Grassland)	Stems	26.4 ± 0.13	n.d.	n.d.	n.d.	51.9 ± 6.05
	Leaves and stems	27.0 ± 0.76 (f)				58.2 ± 3.36
Salvadora persica	Leaves	75.3 ± 1.19	77.4 ± 0.63			
(Grassland=Early dry season)	Stems	55.0 ± 0.17	62.4 ± 3.01	n.d.	n.d.	n.d.
(Bushland=Mid dry season)	Leaves and stems	65.1 ± 0.51	69.9 ± 1.82			

Note for (e): mean of two values averaged (e-1 and e-2), 55.6% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

Table 14. (cont'd)

Notes for Trees and shrubs in Tables 14-24.

1. The values for "leaves and stems" was determined by mean for the values of "leaves" and "stems" with the exception of (c), (d) and (f). The values for "leaves and stems" were used for statistical
2. (d): leaves of this species in the late dry season have shed. Only stems were available for sampling.
3. (c) and (f): n.a." denote that "S.E." was not available because the number of sample was one. "Leaves and stems" was determined by the combination of sample means for "leaves and stems" and "stems" because of availability of sampling.
4. (e): the mean for the two of "leaves and stems" (e-1 and e-2) was used for statistical analyses.
5. "n.d." denote no data.

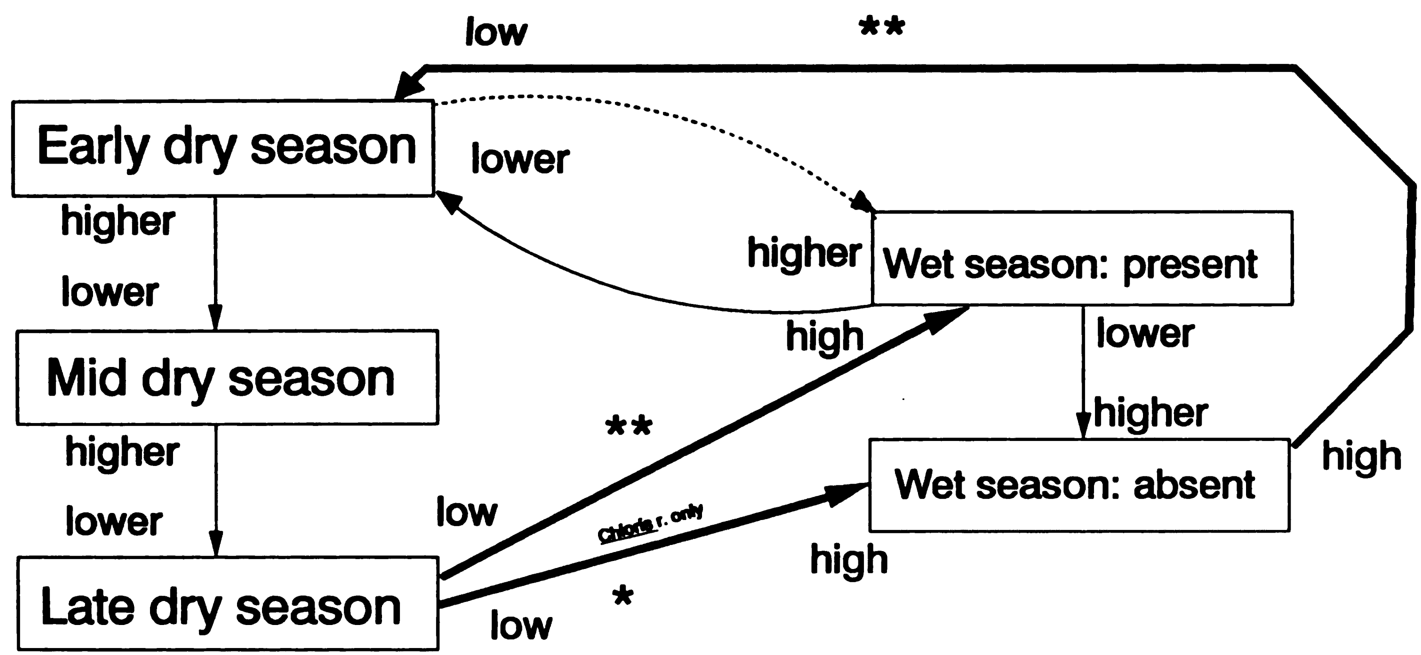


Figure 9. Seasonal patterns or trends of moisture of plants eaten by elephants in the southern part of Tsavo East National Park.

Notes: Directions of arrows show directions of seasons changed from June 1992 to June 1993.
Not differed at $P > 0.20$ between two seasonal categories
** Differed at $P < 0.10$ between two seasonal categories.
* Differed at $P < 0.20$ between two seasonal categories
Rare pattern (from Feb. to March 1993).
Wet season: present= Wet seasons where elephants were present
Wet season: absent= Wet seasons where elephants were absent due to migration.
Dry seasons= only where elephants were present

season (Figures 8a, 8b and 8c). The values in the wet season where elephants were absent were higher than in the late dry season ($P < 0.20$) for Chloris roxiburghiana (Figure 8a) and higher than in the early dry season ($P < 0.10$) for three species (Figures 8a, 8b and 8c). Within the dry season, the values seemed to decrease as the dry season changed for four species (Figures 8a and 8c). Within the wet season, the values seemed to be higher in areas where elephants were absent than where elephants were present for three species (Figures 8a and 8b).

Within grass-herb vegetation shown in Table 14, the range of moisture was 33.8-79.5% on a wet weight basis in the early dry season, and 13.1-58.2% in the mid and late dry season. In the wet season, the range was 51.4-81.5% where elephants were present, and 55.2-76.4% where elephants were absent. Chloris roxburghiana, a grass species in grassland in the late dry season tended to contain lower moisture (13.1 ± 2.36%, mean ± standard error; Table 14 and Figure 8a). Ipomea mombassana, a non-leguminous creeper in grassland tended to contain higher moisture (79.5 ± 3.58% in the early dry season, and 81.5 ± 3.58% in the wet seasons where elephants were present; Table 14 and Figure 8b).

Within shrub vegetation shown in Table 14, the range of moisture was 26.4-75.3% (29.0-75.3% for leaves and

26.4-55.8% for stems) in the early dry season and 30.3-77.4% (54.5-77.4% for leaves and 30.3-62.4% for stems) in the mid and late dry season. Leaves of Salvadora persica, an evergreen species in grassland and bushland tended to contain higher moisture (75.3 ± 1.19%, in the early dry season, and 77.4 ± 0.63% in the mid dry season; Table 14). Stems of Premna hostii, a deciduous shrub species in grassland in the early dry season tended to contain lower moisture (26.4 ± 0.13%; Table 14).

Crude Ash

Figure 10 (a, b and c) and Table 15 show the seasonal values for crude ash by species. No seasonal differences were identified ($P > 0.20$).

Within grass-herb vegetation, the range in the early dry season was 5.7-12.3% (Table 15) on a dry weight basis and 7.7-8.9% (Table 15) in the mid and late dry season. In the wet season, the range was 6.8-11.9% (Table 15) where elephants were present and 7.4-10.0% (Table 15) where elephants were absent.

Within shrub vegetation, the wide range for crude ash was found than within grass-herb vegetation, 2.6-30.0% (10.7-30.0% for leaves and 2.6-13.3% for stems: Table 15) in the early dry season and 4.2-39.4% (15.3-39.4% for leaves and 4.2-19.5% for stems: Table 15) in the mid and late dry season. Leaves of Salvadora persica in grassland

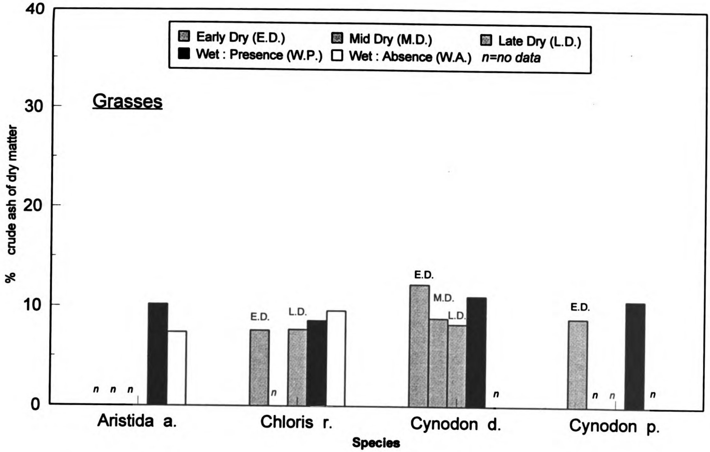


Figure 10-a. Crude ash content as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993.
Standard Error (S.E) is described in Table 15.
W.P.=Wet seasons where elephants were present.
W.A.=wet seasons where elephants were absent.

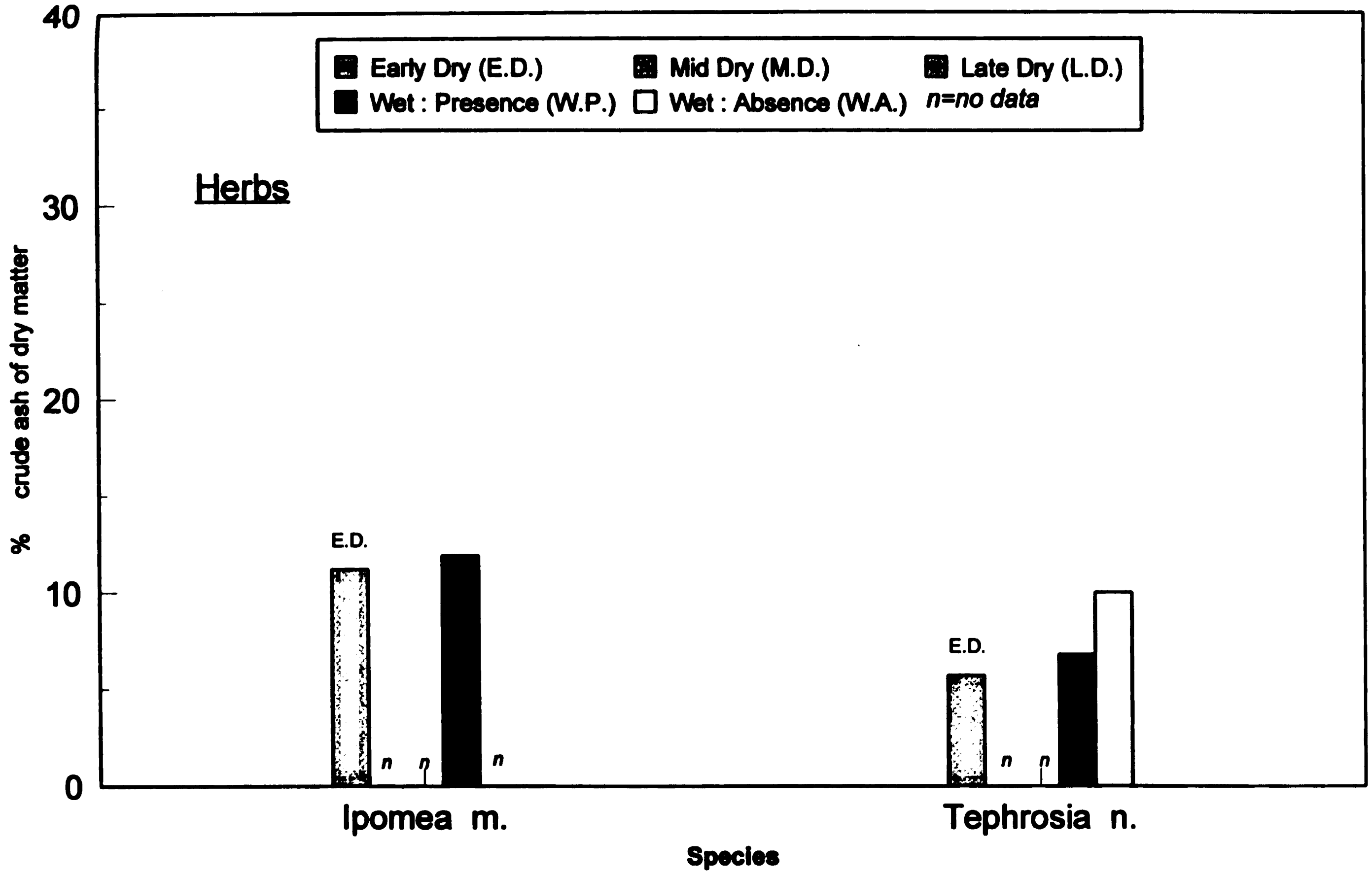


Figure 10-b. (cont'd)

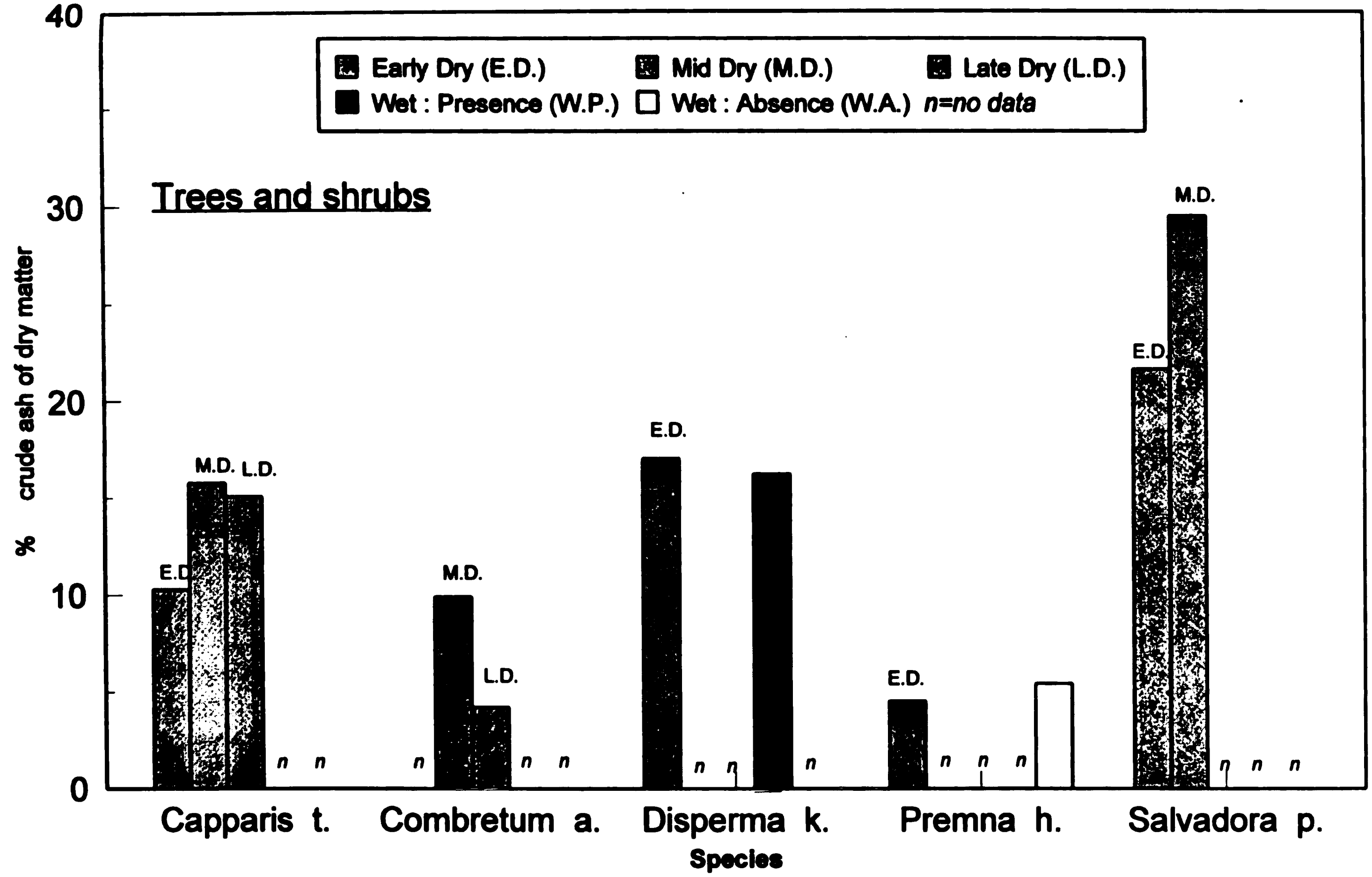


Figure 10-c. (cont'd)

Table 15. Crude ash of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d	n.d.	10.2 ± 0.44	
	(Bushland)					7.4 ± 0.48
Chloris roxburghiana	(Grassland)	7.6 ± 0.21	n.d.	7.7 ± 0.16	8.8 ± 0.89 (a-1)	9.6 ± 0.00
	(Grassland)				8.4 ± 0.05 (a-2)	
Cynodon dactylon	(Forest)	12.3 ± 1.51	8.9 ± 0.52	8.4 ± 1.03 (b-1)	11.1 ± 0.29	n.d.
	(Grassland)			8.2 ± 0.12 (b-2)		
Cynodon plectostachyus	(Grassland)	8.9 ± 0.42	n.d.	n.d.	10.7 ± 0.74	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 8.6 % was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 8.3 % was used for statistical analyses.
3. "n.d." denote no data.

Table 15. (con'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	11.2 ± 1.21	n.d.	n.d.	11.9 ± 0.20	n.d.
Tephrosia noctiflora	(Grassland)	5.7 ± 0.43	n.d.	n.d.	6.8 ± 0.31	10.0 ± 0.06

Note: "n.d." denote no data.

Table 15. *(con'd)*

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Capparis tomentosa	Leaves	13.6 ± 1.52	22.4 ± 1.05	20.6 ± 2.44		
(Forest)	Stems	7.1 ± 0.03	9.2 ± 0.31	9.6 ± 0.59	n.d.	n.d.
	Leaves and stems	10.3 ± 0.55	15.8 ± 0.48	15.1 ± 1.32		
Combretum aculeatum	Leaves		15.3 ± n.a.	-		
(Forest=Mid dry season)	Stems	n.d.	7.8 ± 1.03	4.2 ± 0.22	n.d.	n.d.
(Grassland=Wet season)	Leaves and stems		9.9 ± 0.79 (c)	- (d)		
Disperma kilimandscharica	Leaves	25.6 ± 2.58			23.2 ± 1.68	
(Bushland=Early dry season)	Stems	10.7 ± 1.70			9.1 ± 3.05	
(Grassland=Wet season)	Leaves and stems	18.1 ± 1.51 (e-1)			16.2 ± 1.67	
			n.d.	n.d.		n.d.
	Leaves	21.8 ± 5.23				
	Stems	10.0 ± 0.94				
	Leaves and stems	15.9 ± 1.52 (e-2)				
Premna hostii	Leaves	10.7 ± n.a.				7.0 ± 1.00
(Grassland)	Stems	2.6 ± 0.40	n.d.	n.d.	n.d.	3.9 ± 0.08
	Leaves and stems	4.5 ± 1.66 (f)				5.4 ± 0.38
Salvadora persica	Leaves	30.0 ± 1.42	39.4 ± 1.14			
(Grassland=Early dry season)	Stems	13.3 ± 1.08	19.5 ± 0.36	n.d.	n.d.	n.d.
(Bushland=Mid dry season)	Leaves and stems	21.6 ± 0.87	29.5 ± 0.28			

Note for (e): mean of two values averaged (e-1 and e-2), 17.0 % was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

and in bushland tended to contain higher crude ash in the early dry season (30.0 ± 1.42%; Table 15) and in the mid dry season (39.4 ± 1.14%; Table 15). Stems of Premna hostii in grassland in dry seasons tended to contain lower crude ash (2.6 ± 0.40% in the early dry season, 3.9 ± 0.08% in the wet season where elephants were absent; Table 15). Stems of Combretum aculeatum, a deciduous shrub in grassland in the late dry season also tended to have lower crude ash (4.2 ± 0.22%; Table 15).

Calcium

Figure 11 (a, b and c) and Table 16 show the seasonal values for calcium by each species. No seasonal differences were detected ($P > 0.20$). However, seasonal trends seemed to depend on species.

The range for grass-herb vegetation shown in Table 16 was 0.36-1.44% on a dry weight basis in the early dry season and 0.32-0.55% in the mid and late dry season. The range for the wet season was 0.19-1.21% where elephants were present and 0.12-1.51% where elephants were absent.

Within shrub vegetation shown in Table 16, the range was 0.53-8.92% (0.68-8.92% for leaves and 0.53-2.80% for stems) in the early dry season and 0.78-11.40% (2.93-11.40% for leaves and 0.78-3.93% for stems) in the mid and late dry season. Leaves of Salvadora persica in grassland and bushland tended to contain higher calcium (8.92 ±

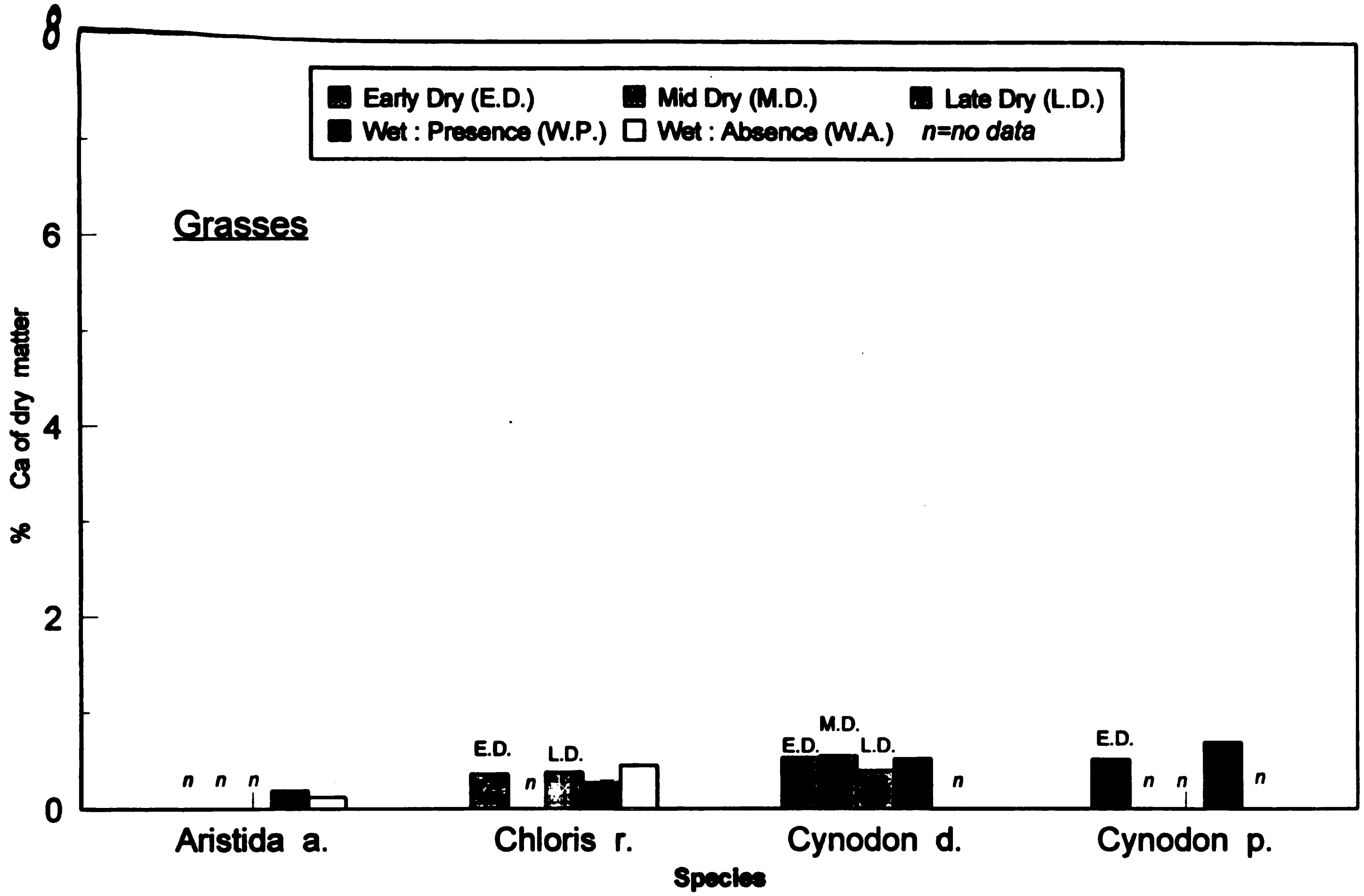


Figure 11-a. Calcium contetnt as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993. Standar Error (S.E.) is described in Table 16. W.P.=Wet seasons where elephants were present. W.A.=Wet seasons where elephants were absent.

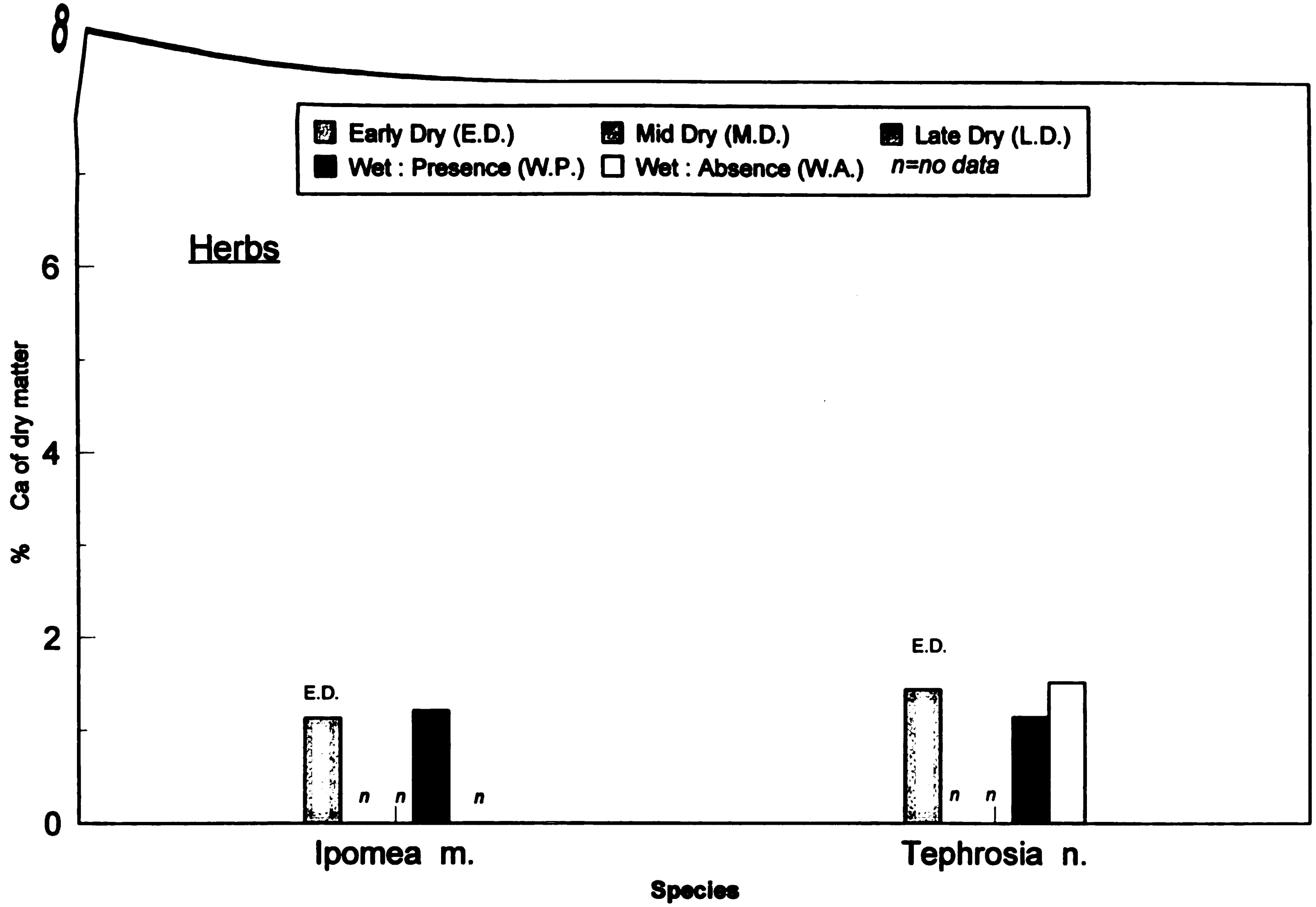


Figure 11-b. (cont'd)

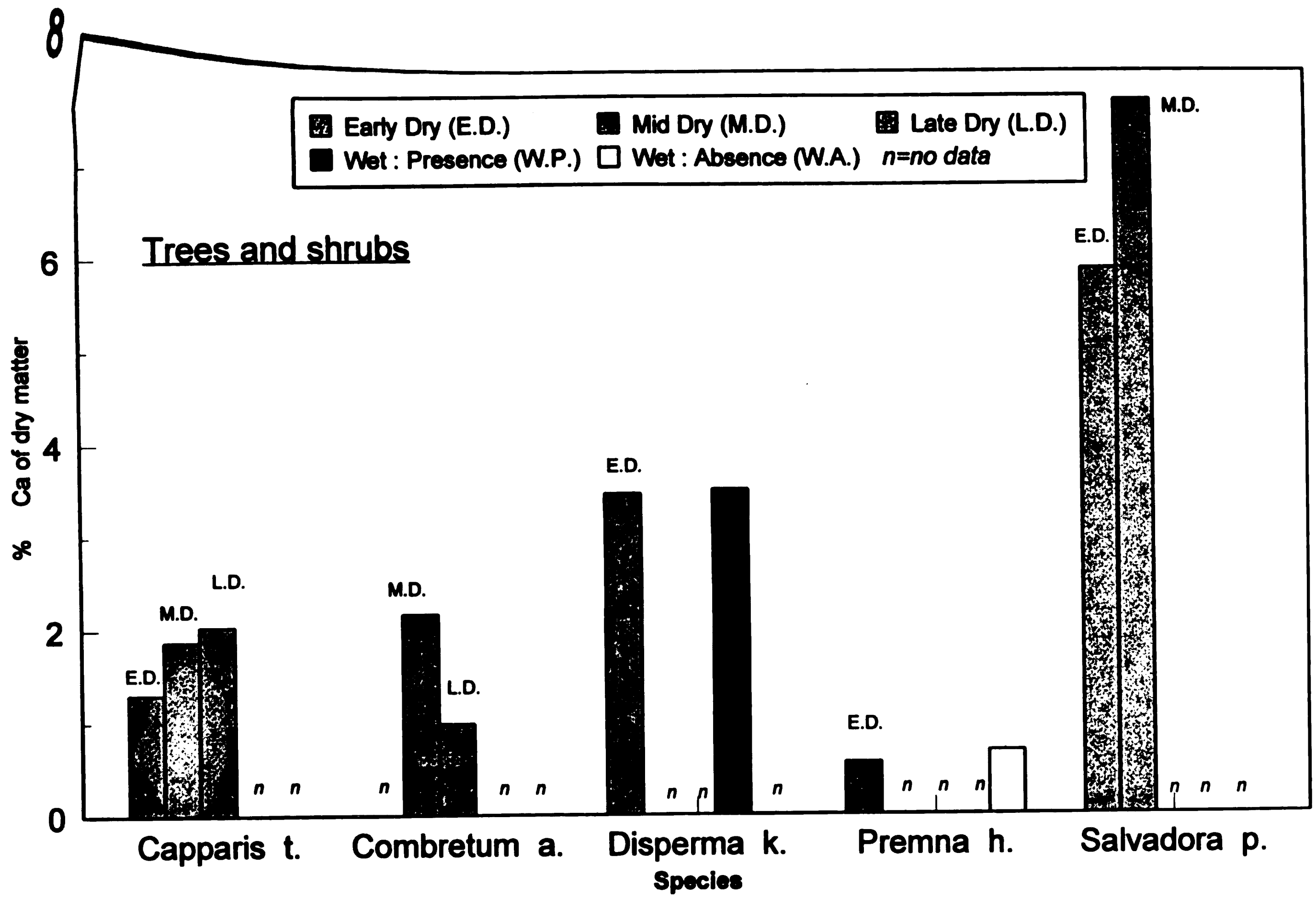


Figure 11-c. (cont'd)

Table 16. Calcium of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d	n.d.	0.19 ± 0.007	
	(Bushland)					0.12 ± 0.025
Chloris roxburghiana	(Grassland)	0.36 ± 0.047	n.d	0.38 ± 0.119	0.25 ± 0.106 (a-1)	0.45 ± 0.016
	(Grassland)				0.29 ± 0.003 (a-2)	
Cynodon dactylon	(Forest)	0.53 ± 0.022	0.55 ± 0.148	0.47 ± 0.047 (b-1)	0.52 ± 0.111	n.d.
	(Grassland)			0.32 ± 0.026 (b-2)		
Cynodon plectostachyus	(Grassland)	0.51 ± 0.055	n.d.	n.d.	0.69 ± 0.091	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 0.27% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 0.40% was used for statistical analyses.
3. "n.d." denote no data.

Table 16. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	1.13 ± 0.214	n.d.	n.d.	1.21 ± 0.207	n.d.
Tephrosia noctiflora	(Grassland)	1.44 ± 0.084	n.d.	n.d.	1.14 ± 0.033	1.51 ± 0.031

Note: "n.d." denote no data.

Table 16. (cont'd)

Trees and Shrubs (5 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
		% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
species (Vegetation type)	parts					
Capparis tomentosa	Leaves	1.93 ± 0.559	2.96 ± 0.482	2.93 ± 0.101		
(Forest)	Stems	0.66 ± 0.014	0.78 ± 0.016	1.14 ± 0.062	n.d.	n.d
	Leaves and stems	1.30 ± 0.273	1.87 ± 0.249	2.03 ± 0.070		
Combretum aculeatum	Leaves		3.02 ± n.a.	-		
(Forest=Mid dry season)	Stems	n.d.	1.68 ± 0.567	0.98 ± 0.196	n.d.	n.d
(Grassland=Late dry season)	Leaves and stems		2.16 ± 0.091 (c)	- (d)		
Disperma kilimandscharica	Leaves	4.95 ± 0.946			4.16 ± 0.444	
(Bushland=Early dry season)	Stems	1.54 ± 1.048			2.81 ± 1.225	
(Grassland=Wet season)	Leaves and stems	3.25 ± 0.997 (e-1)			3.49 ± 0.835	
			n.d.	n.d		n.d.
	Leaves	4.88 ± 1.036				
	Stems	2.39 ± 0.383				
	Leaves and stems	3.63 ± 0.327 (e-2)				
Premna hostii	Leaves	0.68 ± n.a.				0.88 ± 0.096
(Grassland)	Stems	0.53 ± 0.007	n.d.	n.d	n.d.	0.47 ± 0.079
	Leaves and stems	0.56 ± 0.044 (f)				0.68 ± 0.088
Salvadora persica	Leaves	8.92 ± 1.275	11.40 ± 0.287			
(Grassland=Early dry season)	Stems	2.80 ± 0.147	3.93 ± 0.280	n.d.	n.d.	n.d.
(Bushland=Mid dry season)	Leaves and stems	5.86 ± 0.564	7.67 ± 0.283			

Note for (e): mean of two values averaged (e-1 and e-2), 3.44% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

1.275% in the early dry season, 11.40 ± 0.287% in the mid dry season; Table 16). Three shrubs (leaves, stems) of five shrub species contained over 1.50%. One of two species contained less than 1.50% for calcium was Premna hostii in grassland in the early dry season (0.53 ± 0.007% in stems, 0.68% in leaves; Table 16) and in the wet season where elephants were absent (0.47 ± 0.079% in stems, 0.88% ± 0.096% in leaves; Table 16). Another one was the stems of Capparis tomentosa in the dry season (0.66 ± 0.014% in the early dry season, 0.78 ± 0.016% in the mid dry season, and 1.14 ± 0.062% in the late dry season; Table 16).

Potassium

Figure 12 (a, b and c) and Table 17 show the seasonal values for potassium by each species. No seasonal differences were found ($P > 0.20$). However, the values in the wet season (presence or absence) tended to be higher than in the late or early dry season for seven species (Figures 12a, 12b and 12c). The values in the mid dry season tended to be higher than in the early or late dry season for four species (Figures 12a and 12c).

Within grass-herb vegetation shown in Table 17, the range for grass-herb vegetation was 0.90-2.44% on a dry weight basis in the early dry season, and 1.15-1.70% in the mid and late dry season. In wet seasons, the range was 0.73-2.91% where elephants were present, and 0.90-

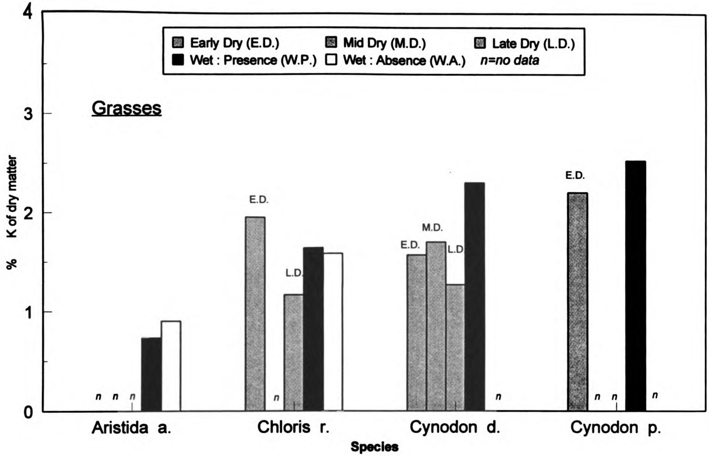


Figure 12-a. Potassium content as % dry weight of plants eaten by elephants : seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 17.
W.P.=Wet seasons where elephants were present.
W.A.=Wet seasons where elephants were absent.

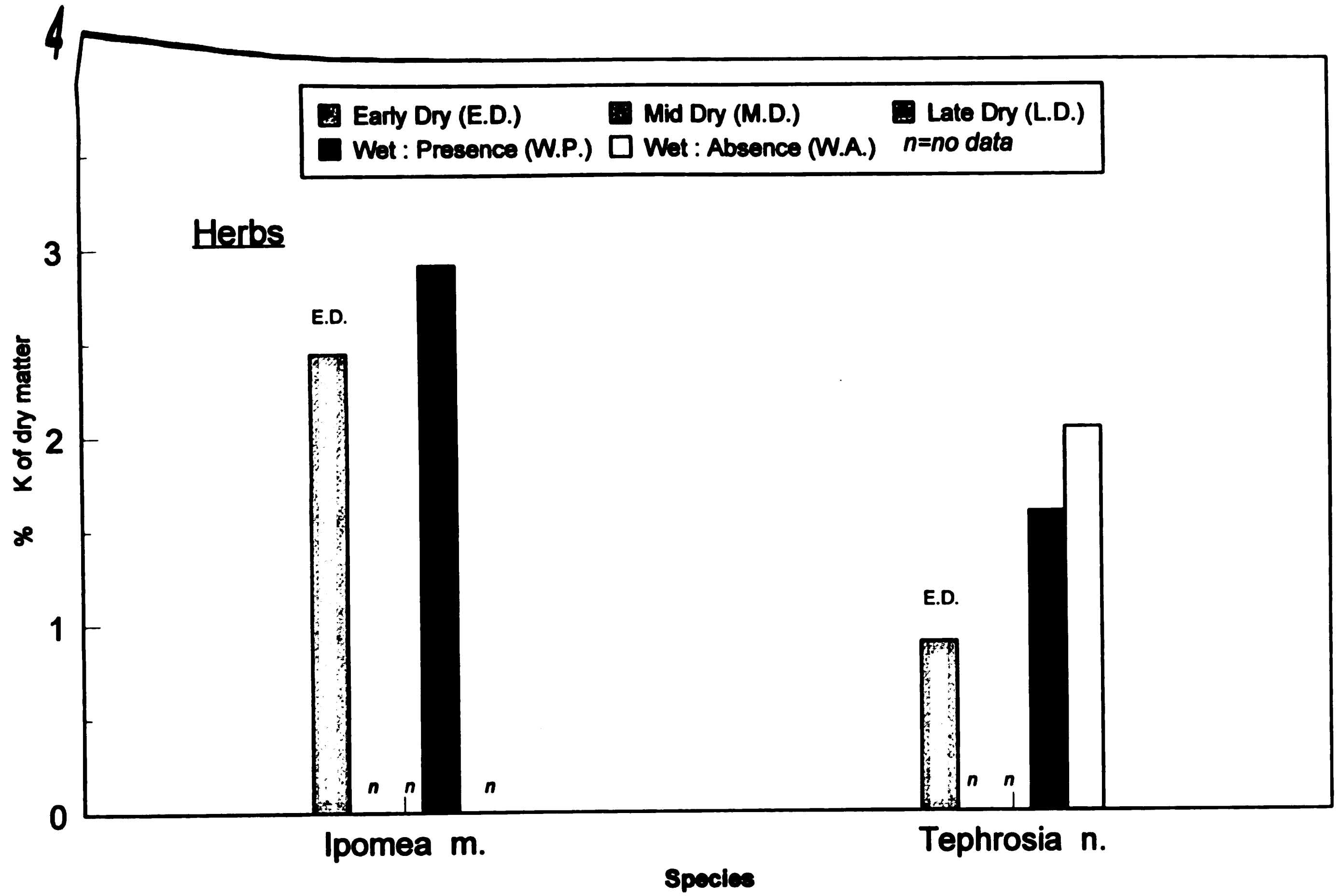


Figure 12-b. (cont'd)

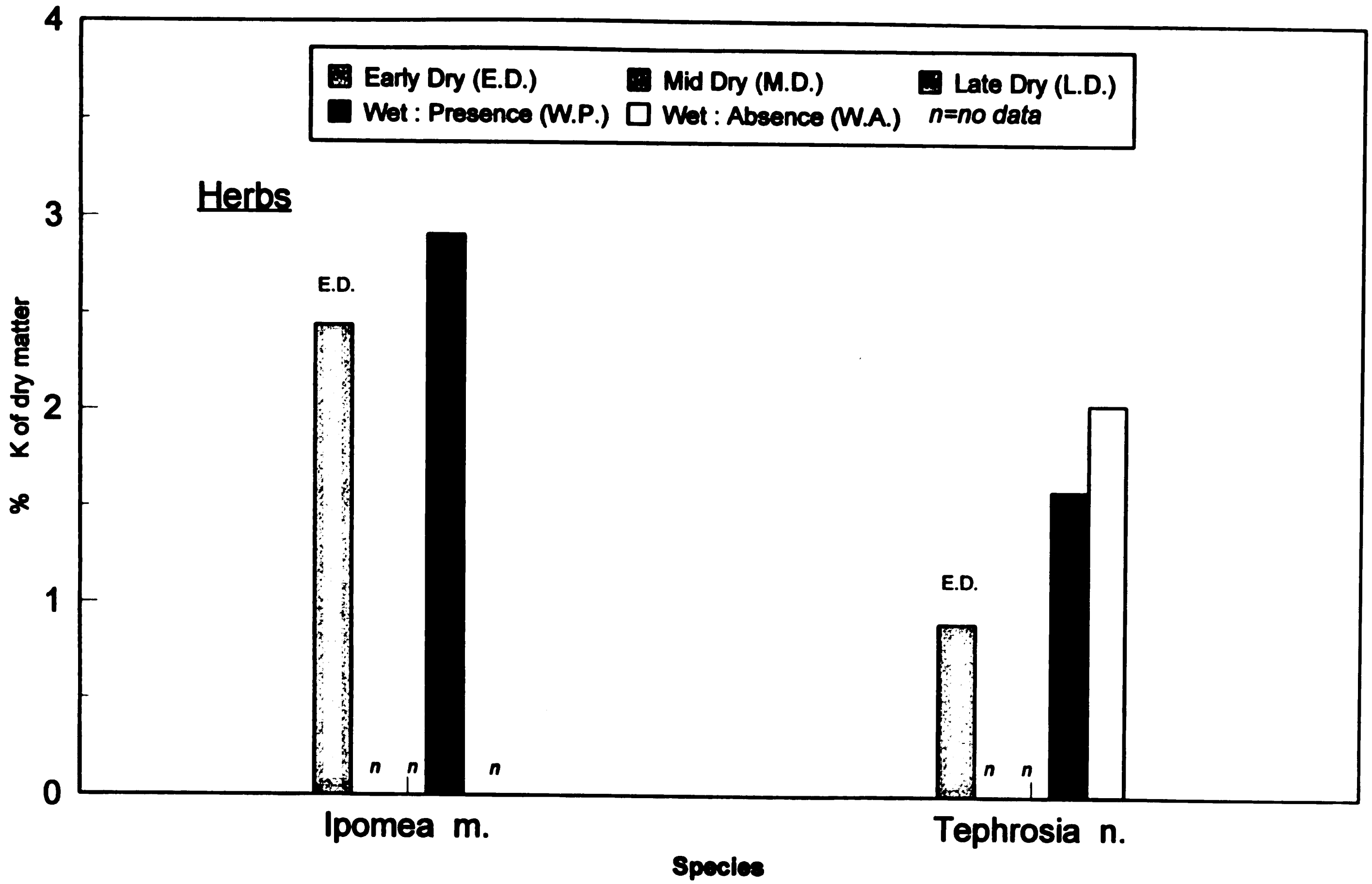


Figure 12-b. (cont'd)

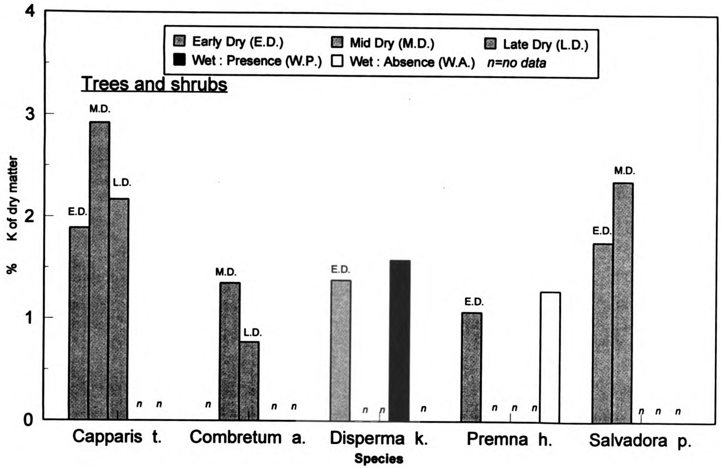


Figure 12-c. (cont'd)

Table 17. Potassium of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d	n.d.	0.73 ± 0.076	
	* (Bushland)					0.90 ± 0.094
Chloris roxburghiana	(Grassland)	1.95 ± 0.000	n.d	1.17 ± 0.079	1.56 ± 0.096 (a-1)	1.58 ± 0.027
	(Grassland)				1.72 ± 0.172 (a-2)	
Cynodon dactylon	(Forest)	1.57 ± 0.319	1.70 ± 0.156	1.39 ± 0.136 (b-1)	2.30 ± 0.034	n.d.
	(Grassland)			1.15 ± 0.190 (b-2)		
Cynodon plectostachyus	(Grassland)	2.20 ± 0.115	n.d.	n.d.	2.52 ± 0.033	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 1.64% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 1.27% was used for statistical analyses.
3. "n.d." denote no data.

Table 17. (cont'd)

Herbs (2 species) species (Vegetation type)		Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Ipomea mombassana	(Grassland)	2.44 ± 0.550	n.d.	n.d.	2.91 ± 0.250	n.d.
Tephrosia noctiflora	(Grassland)	0.90 ± 0.033	n.d.	n.d.	1.59 ± 0.106	2.04 ± 0.192

Note: "n.d." denote no data.

Table 17. (cont'd)

Trees and Shrubs (5 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species (Vegetation type)	parts	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Capparis tomentosa	Leaves	2.15 ± 0.340	3.54 ± 0.072	2.41 ± 0.001		
(Forest)	Stems	1.62 ± 0.215	2.29 ± 0.267	1.93 ± 0.142	n.d.	n.d.
	Leaves and stems	1.89 ± 0.063	2.92 ± 0.169	2.17 ± 0.070		
Combretum aculeatum	Leaves		1.53 ± n.a.	-		
(Forest=Mid dry season)	Stems	n.d.	1.39 ± 0.312	0.77 ± 0.028	n.d.	n.d.
(Grassland=Late dry season)	Leaves and stems		1.35 ± 0.268 (c)	- (d)		
Disperma kilimandscharica	Leaves	1.76 ± 0.183			1.69 ± 0.259	
(Bushland=Early dry season)	Stems	1.12 ± 0.067			1.48 ± 0.494	
(Grassland=Wet season)	Leaves and stems	1.44 ± 0.058 (e-1)			1.58 ± 0.377	
			n.d.	n.d.		n.d.
	Leaves	1.85 ± 0.360				
	Stems	0.78 ± 0.094				
	Leaves and stems	1.31 ± 0.133 (e-2)				
Premna hostii	Leaves	1.89 ± n.a.				1.41 ± 0.224
(Grassland)	Stems	0.83 ± 0.118	n.d.	n.d.	n.d.	1.14 ± 0.238
	Leaves and stems	1.07 ± 0.352 (f)				1.28 ± 0.231
Salvadora persica	Leaves	2.01 ± 0.267	2.61 ± 0.860			
(Grassland=Early dry season)	Stems	1.52 ± 0.099	2.11 ± 0.036	n.d.	n.d.	n.d.
(Bushland=Mid dry season)	Leaves and stems	1.76 ± 0.183	2.36 ± 0.447			

Note for (e): mean of two values averaged (e-1 and e-2), 1.38% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

2.04% where elephants were absent. Cynodon dactylon, Cynodon plectostachyus, and Ipomea mombassana tended to contain higher values in the wet season (2.30 ± 0.034%, 2.52 ± 0.033%, and 2.91 ± 0.250% respectively; Table 17 and Figures 12a and 12b). Aristida adscensionis in grassland in the wet season, and a leguminous herb species, Tephrosia noctiflora from grassland in the early dry season tended to contain lower potassium (0.73 ± 0.076% and 0.90 ± 0.033% respectively; Table 17).

Within shrub vegetation shown in Table 17, the range was 0.78-2.15% in the early dry season (1.76-2.15% for leaves and 0.78-1.62% for stems) and 0.77-3.54% (1.53-3.54% for leaves and 0.77-2.29% for stems) in the mid and late dry season. Salvadora persica, an evergreen species in grassland and bushland tended to contain higher values in the mid dry season (2.61 ± 0.860% in leaves and 2.11 ± 0.036% in stems; Table 17). Capparis tomentosa, an evergreen species in forest also tended to contain higher values in the mid dry season (3.54 ± 0.072% in leaves and 2.29 ± 0.267% in stems, Table 17). Stems of Premna hostii in grassland in the early dry season and stems of Combretum aculeatum in grassland in the late dry season tended to contain lower potassium (0.83 ± 0.118% and 0.77 ± 0.028% respectively; Table 17).

Sodium

Figure 13 (a, b and c) and Table 18 show the seasonal differences for sodium by each species. The values differed among the five seasonal categories ($P < 0.10$). The results for seasonal differences in sodium identified by multiple comparisons test are shown in Figure 14.

Sodium in the wet season where elephants were absent was lower than in the late dry season ($P < 0.10$) for one grass species, *Chloris roxburghiana* (Figure 13a). The values in the wet season generally tended to be lower than in the dry season. In the mid dry season, the values seemed to be lower among seasonal categories (Figure 13a and 13c) with the exception of *Salvadora persica* (Figure 13c). The seasonal trends appeared contrary to the ones shown for moisture, Figure 9.

Within grass-herb vegetation shown in Table 18, the range was 0.009-0.295% on a dry weight basis in the early dry season, and 0.041-0.191% in the mid and late dry season. The range in wet seasons was 0.007-0.086% where elephants were present, and 0.004-0.008% where elephants were absent. *Cynodon dactylon* in forest in the early dry season tended contain higher values (0.295 ± 0.029%; Table 18). With the exception of *Cynodon dactylon*, all grass-herb vegetation shown in Table 18 tended to contain lower values, between 0.008% and 0.058%, throughout the year.

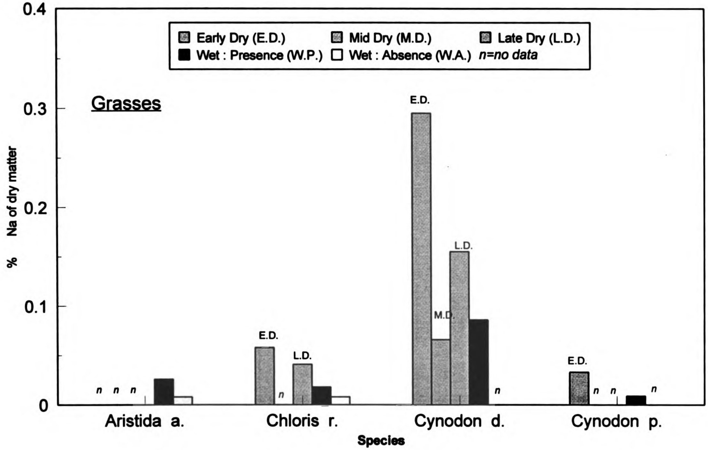


Figure 13-a. Sodium content as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993.
Standard Error (S.E.) is described in Table 18.
W.P.=Wet seasons where elephants were present.
W.A.=Wet seasons where elephants were absent.

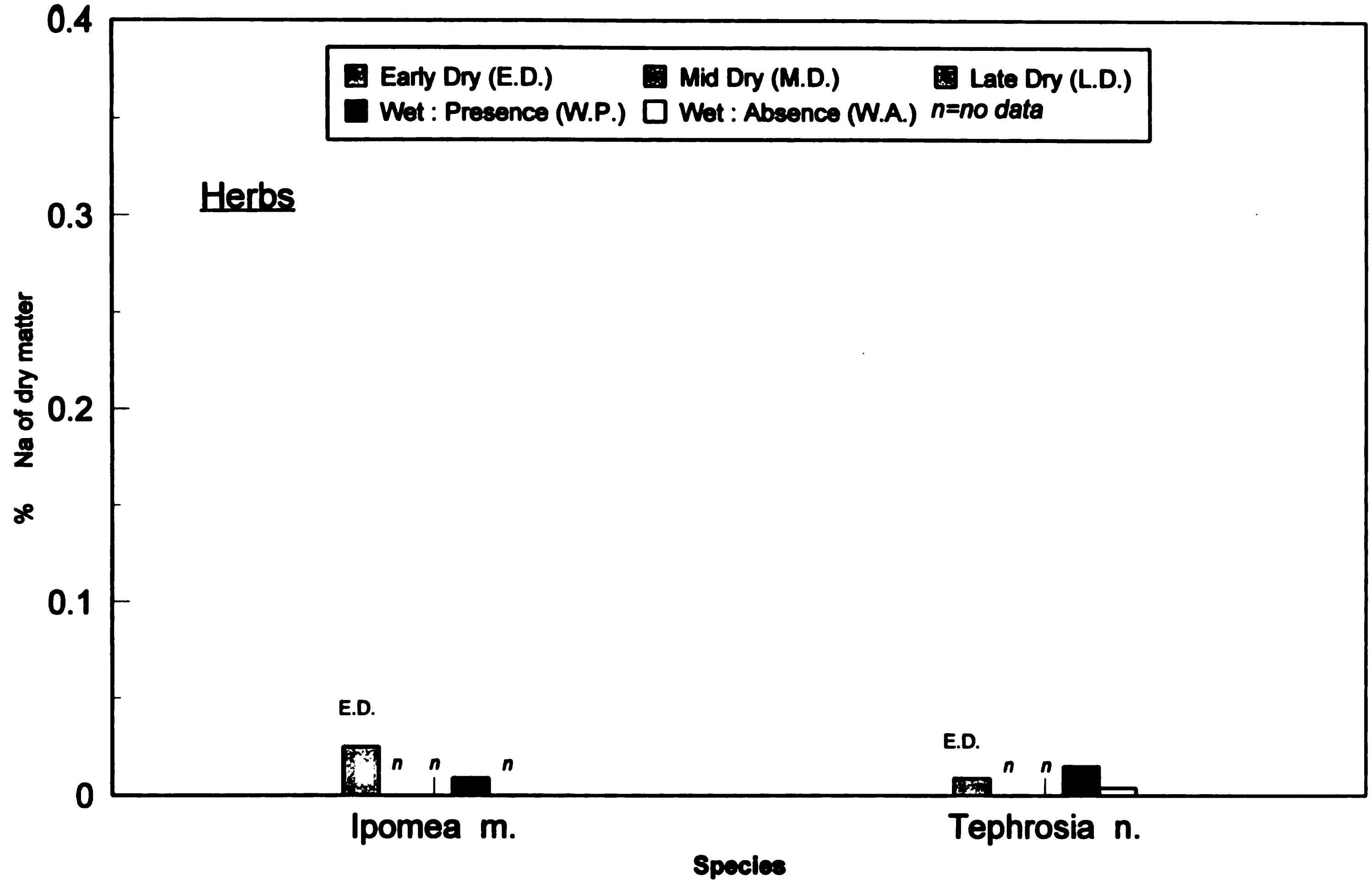


Figure 13-b. (cont'd)

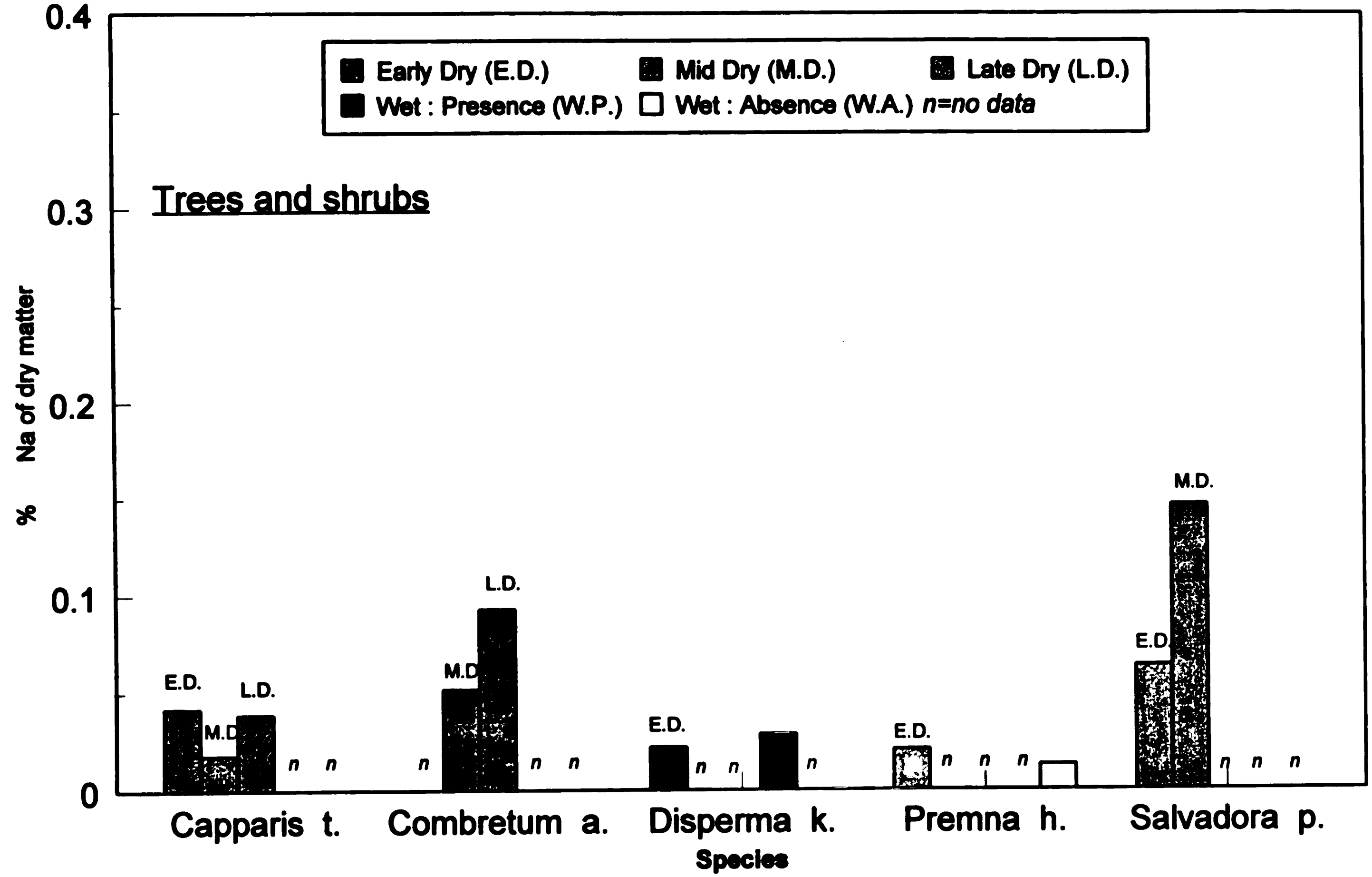


Figure 13-c. (cont'd)

Table 18 ***Sodium of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park*** (% = g/100 dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	0.026 ± 0.006	
	(Bushland)					0.008 ± 0.000
Chloris roxburghiana	(Grassland)	0.058 ± 0.016	n.d.	0.041 ± 0.006	0.007 ± 0.000 (a-1)	0.008 ± 0.000
	(Grassland)				0.029 ± 0.002 (a-2)	
Cynodon dactylon	(Forest)	0.295 ± 0.029	0.066 ± 0.019	0.191 ± 0.022 (b-1)	0.086 ± 0.072	n.d.
	(Grassland)			0.119 ± 0.057 (b-2)		
Cynodon plectostachyus	(Grassland)	0.033 ± 0.024	n.d.	n.d.	0.009 ± 0.001	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 0.018% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 0.155% was used for statistical analyses.
3. "n.d." denote no data.

Table 18. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	0.025 ± 0.012	n.d.	n.d.	0.009 ± 0.001	n.d.
Tephrosia noctiflora	(Grassland)	0.009 ± 0.006	n.d.	n.d.	0.015 ± 0.007	0.004 ± 0.001

Note: "n.d." denote no data.

Table 18. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Capparis tomentosa	Leaves	0.046 ± 0.013	0.020 ± 0.001	0.050 ± 0.001		
(Forest)	Stems	0.038 ± 0.019	0.016 ± 0.003	0.027 ± 0.008	n.d.	n.d.
	Leaves and stems	0.042 ± 0.003	0.018 ± 0.001	0.039 ± 0.005		
Combretum aculeatum	Leaves		0.044 ± n.a.	-		
(Forest=Mid dry season)	Stems	n.d.	0.064 ± 0.029	0.093 ± 0.027	n.d.	n.d.
(Grassland=Mid dry season)	Leaves and stems		0.052 ± 0.017 (c)	- (d)		
Diosperma kilimandscharica	Leaves	0.035 ± 0.028			0.020 ± 0.002	
(Bushland=Early dry season)	Stems	0.021 ± 0.000			0.039 ± 0.015	
(Grassland=Wet season)	Leaves and stems	0.028 ± 0.014 (e-1)			0.029 ± 0.008	
			n.d.	n.d.		n.d.
	Leaves	0.010 ± 0.008				
	Stems	0.020 ± 0.009				
	Leaves and stems	0.015 ± 0.001 (e-2)				
Premna hostii	Leaves	0.041 ± n.a.				0.005 ± 0.002
(Grassland)	Stems	0.015 ± 0.001	n.d.	n.d.	n.d.	0.021 ± 0.006
	Leaves and stems	0.021 ± 0.007 (f)				0.013 ± 0.004
Salvadora persica	Leaves	0.019 ± 0.005	0.057 ± 0.031			
(Grassland= Early dry season)	Stems	0.109 ± 0.009	0.238 ± 0.117	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	0.064 ± 0.002	0.147 ± 0.074			

Note for (e): mean of two values averaged (e-1 and e-2), 0.022% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

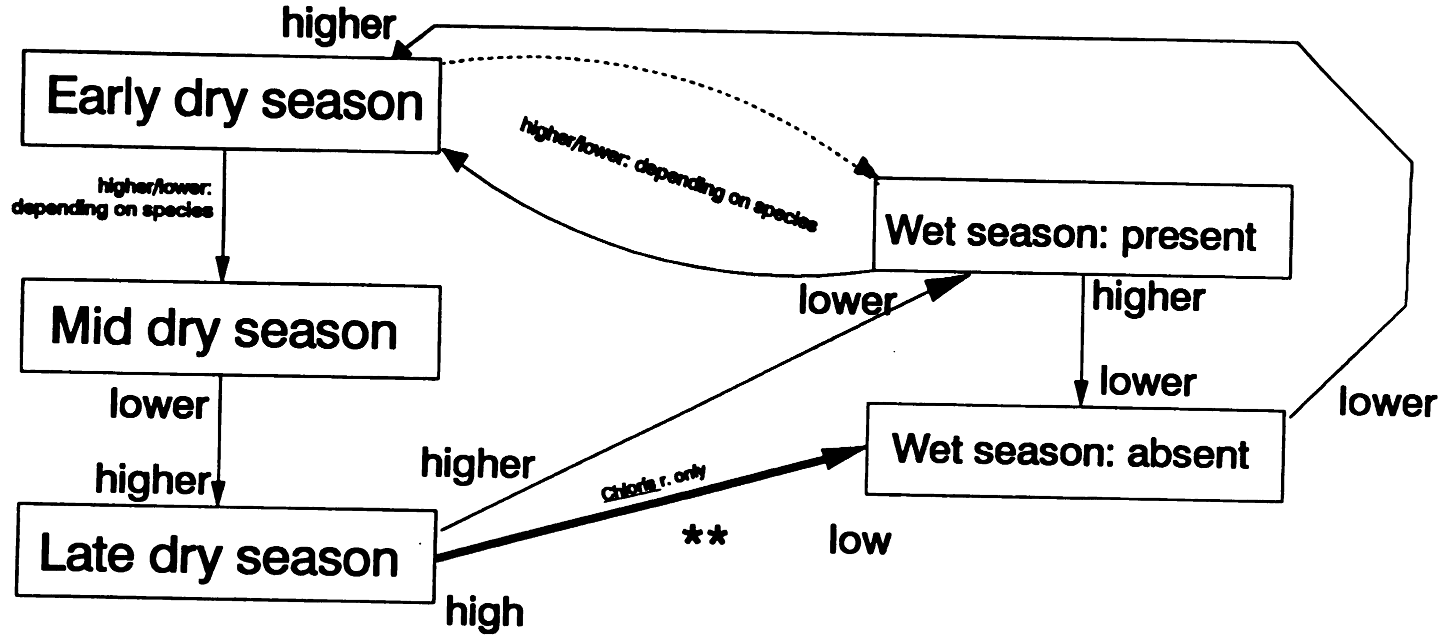


Figure 14. Seasonal patterns or trends of sodium of plants eaten by elephants in the southern part of Tsavo East National Park.
Notes: Directions of arrows show directions of seasons changed from June 1992 to June 1993.
Not differed at $P > 0.20$ between two seasonal categories
** Differed at $P < 0.10$ between two seasonal categories.
Rare pattern (from Feb. to March 1993).
Wet season: present= Wet seasons where elephants were present
Wet season: absent= Wet seasons where elephants were absent due to migration.
Dry seasons = Only where elephants were present.

Within shrub vegetation shown in Table 18, the range for sodium in the early dry season was 0.010-0.109% (0.010-0.046% for leaves and 0.015-0.109% for stems; Table 18) and the range in the mid and late dry season was 0.016-0.238% (0.020-0.057% for leaves and 0.016-0.238% for stems; Table 18). Sodium in the late dry season tended to be higher than in the mid dry season. Salvadora persica in grassland and in bushland tended to contain higher values, particularly in stems in the mid dry season (0.238 ± 0.117%; Table 18). Leaves of Premna hostii in grassland in the wet season where elephants were absent, and leaves of Disperma kilimandscharica, a deciduous shrub in bushland in the early dry season tended to contain lower sodium (0.005 ± 0.002% and 0.010 ± 0.006% respectively; Table 18).

Magnesium

Figure 15 (a, b and c) and Table 19 show the seasonal concentrations of magnesium for each species. There were no seasonal differences ($P > 0.20$). However, the values in the early dry season tended to be lower than in the wet season where elephants were absent for three species (Figures 15a, 15b and 15c), and lower than in the mid dry season for three species (Figures 15a and 15c). Seasonal differences or similarities between two seasonal categories seemed to depend on species.

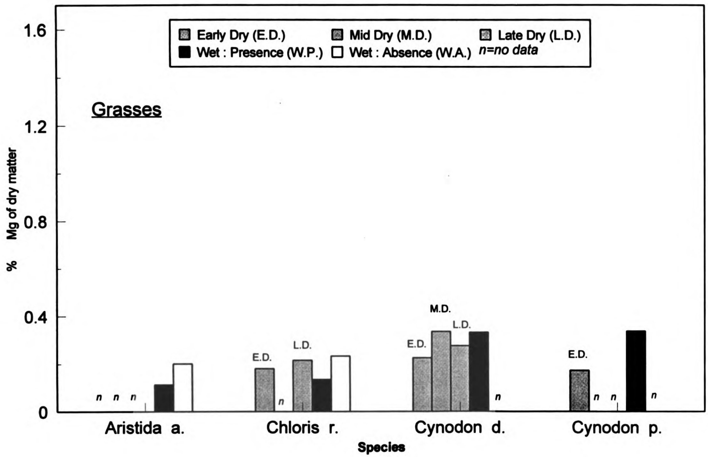


Figure 15-a. Magnesium content as % dry weight of plants eaten by elephants:seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 19. W.P.=Wet seasons where elephants were present. W.A.=Wet seasons where elephants were absent.

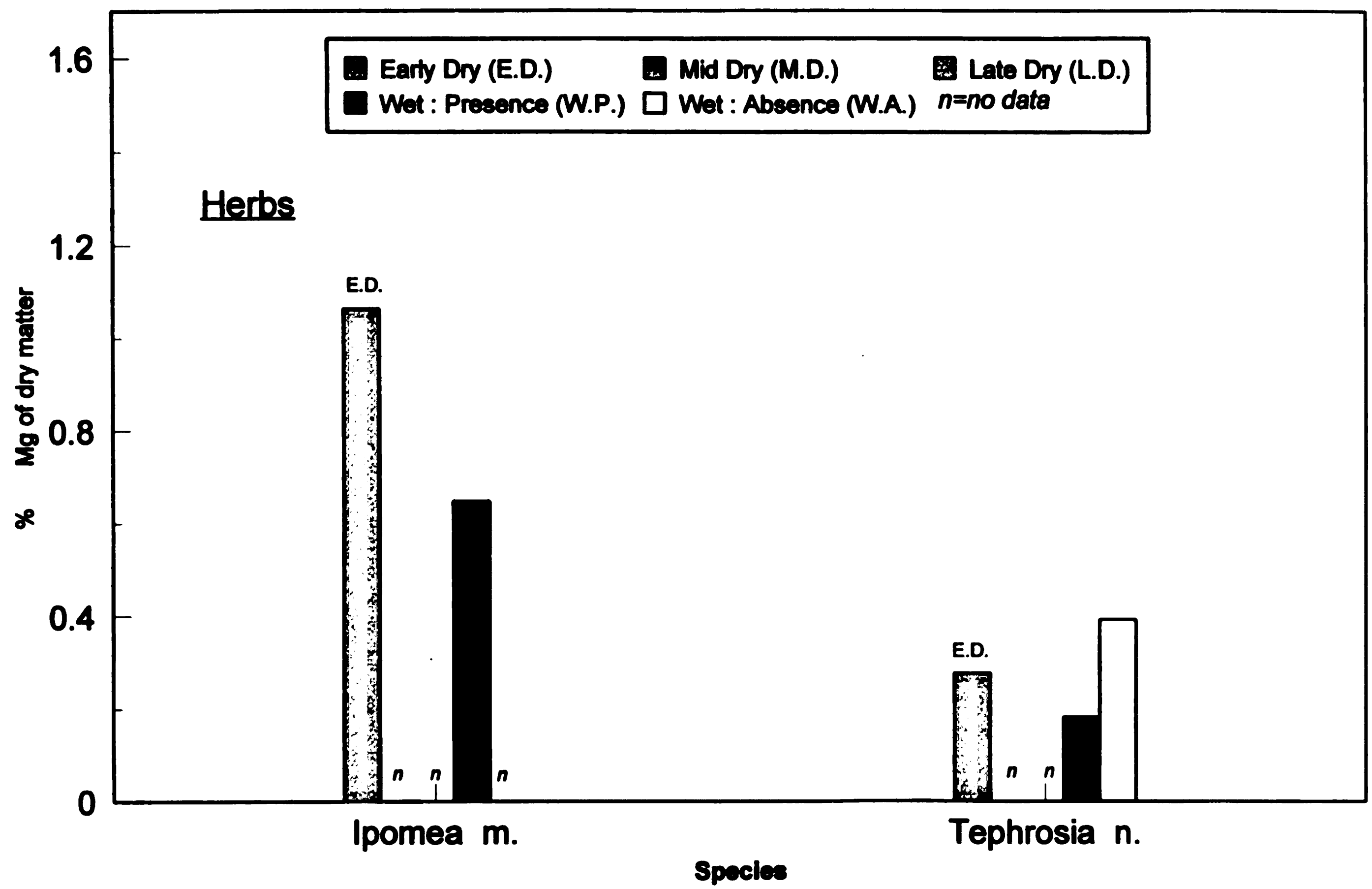


Figure 15-b. (cont'd)

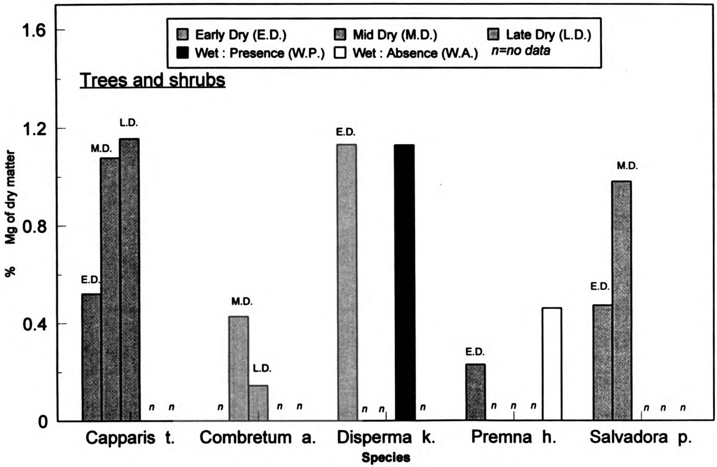


Figure 15-c. (cont'd)

Table 19. Magnesium of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	0.113 ± 0.007	
	(Bushland)					0.201 ± 0.086
Chloris roxburghiana	(Grassland)	0.181 ± 0.025	n.d.	0.216 ± 0.071	0.135 ± 0.018 (a-1)	0.233 ± 0.017
	(Grassland)				0.135 ± 0.015 (a-2)	
Cynodon dactylon	(Forest)	0.225 ± 0.042	0.336 ± 0.003	0.341 ± 0.055 (b-1)	0.332 ± 0.035	n.d.
	(Grassland)			0.210 ± 0.076 (b-2)		
Cynodon plectostachyus	(Grassland)	0.172 ± 0.021	n.d.	n.d.	0.337 ± 0.077	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 0.135% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 0.276% was used for statistical analyses.
3. "n.d." denote no data.

Table 19. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	1.064 ± 0.093	n.d.	n.d.	0.648 ± 0.053	n.d.
Tephrosia noctiflora	(Grassland)	0.276 ± 0.021	n.d.	n.d.	0.181 ± 0.015	0.392 ± 0.028

Note: "n.d." denote no data.

Table 19. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Capparis tomentosa	Leaves	0.648 ± 0.531	1.712 ± 0.108	1.687 ± 0.178		
(Forest)	Stems	0.394 ± 0.145	0.445 ± 0.026	0.626 ± 0.007	n.d.	n.d
	Leaves and stems	0.521 ± 0.338	1.078 ± 0.041	1.156 ± 0.085		
Combretum aculeatum	Leaves		0.750 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	0.306 ± 0.043	0.145 ± 0.018	n.d.	n.d.
(Grassland= Mid dry season)	Leaves and stems		0.427 ± 0.079 (c)	- (d)		
Disperma kilimandscharica	Leaves	1.528 ± 0.291			1.264 ± 0.007	
(Bushland= Early dry season)	Stems	0.686 ± 0.298			0.995 ± 0.085	
(Grassland= Wet season)	Leaves and stems	1.107 ± 0.294 (e-1)			1.129 ± 0.039	
			n.d.	n.d.		n.d.
	Leaves	1.475 ± 0.152				
	Stems	0.835 ± 0.028				
	Leaves and stems	1.115 ± 0.062 (e-2)				
Premna hostii	Leaves	0.698 ± n.a.				0.616 ± 0.326
(Grassland)	Stems	0.077 ± 0.012	n.d.	n.d.	n.d	0.276 ± 0.012
	Leaves and stems	0.229 ± 0.164 (f)				0.460 ± 0.169
Salvadora persica	Leaves	0.501 ± 0.100	1.174 ± 0.302			
(Grassland= Early dry season)	Stems	0.443 ± 0.221	0.789 ± 0.169	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	0.472 ± 0.060	0.981 ± 0.235			

Note for (e): mean of two values averaged (e-1 and e-2), 1.131% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

Within shrub vegetation shown in Table 18, the range for range was 0.172-1.064% on a dry weight basis in the early dry season, and a narrower range, 0.210-0.341% in the mid and late dry season. In the wet season, the range was 0.113-0.648% where elephants were present and 0.201-0.392% where elephants were absent. Aristida adscensionis and Chloris roxburghiana in grassland in the wet season where elephants were present tended to contain lower magnesium among grass-herb vegetation (0.113 ± 0.007%, 0.135 ± 0.018% and 0.135 ± 0.015% respectively; Table 19 and Figure 15a). Ipomea mombassana in grassland in the early dry season tended to contain higher magnesium (1.064 ± 0.093; Table 19 and Figure 15b).

Within shrub vegetation shown in Table 19, the range for the early dry season was 0.077-1.528% (0.501-1.528% for leaves and 0.077-0.835% for stems; Table 19) and the range for the mid and late dry season was 0.145-1.712% (0.750-1.712% for leaves and 0.145-0.789% for stems; Table 19). Leaves of Capparis tomentosa in forest tended to contain higher magnesium in the mid and the late dry season (1.712 ± 0.108% and 1.687 ± 0.177% respectively; Table 19). Leaves of Disperma kilimandscharica in bushland tended to contain higher values in the early dry season (1.528 ± 0.291%, 1.475 ± 0.152%; Table 19). Leaves of Salvadora persica in the mid dry season tended to contain higher magnesium (1.174 ± 0.302%; Table 19). Stems of Premna hostii in the early dry season and stems of Combretum aculeatum in grassland in the late dry season tended to contain lower values (0.077 ± 0.011% and 0.145 ± 0.018% respectively; Table 19).

Manganese

Figure 16 (a, b and c) and Table 20 show the seasonal differences for manganese for each species. The values differed among five seasonal categories for all species ($P < 0.20$), but no differences were detected for ten species when a shrub species, Premna hostii containing the highest values was omitted ($P > 0.20$). The results for seasonal differences in manganese identified by multiple comparisons test were shown in Figure 17.

Manganese in the wet season where elephants were absent was higher than the early dry season ($P < 0.20$) for one species, Premna hostii (Figure 16c) and for one grass species, Chloris roxburgiana (Table 20 and Figure 16a).

Within grass-herb vegetation shown in Table 20, the range was 38-75ppm on a dry weight basis in the early dry season, and 33-60ppm in the mid and late dry season. In the wet season, the range for manganese was 34-77ppm where elephants were present, and 42-92ppm where elephants were absent.

Within shrub vegetation shown in Table 20, the range

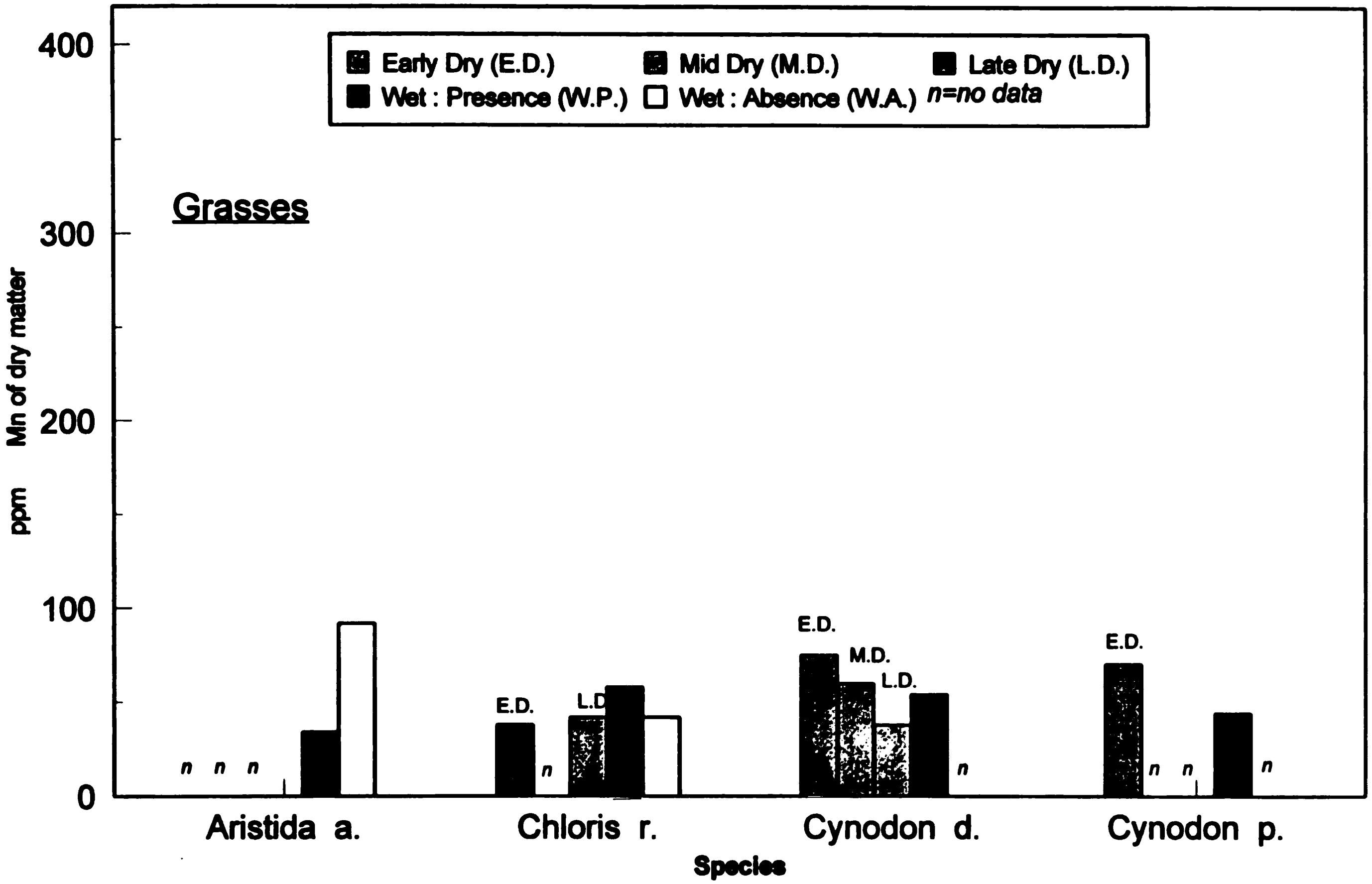


Figure 16-a. Manganese content as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 20.
W.P.=Wet seasons where elephants were present.
W.A.=Wet seasons where elephants were absent.

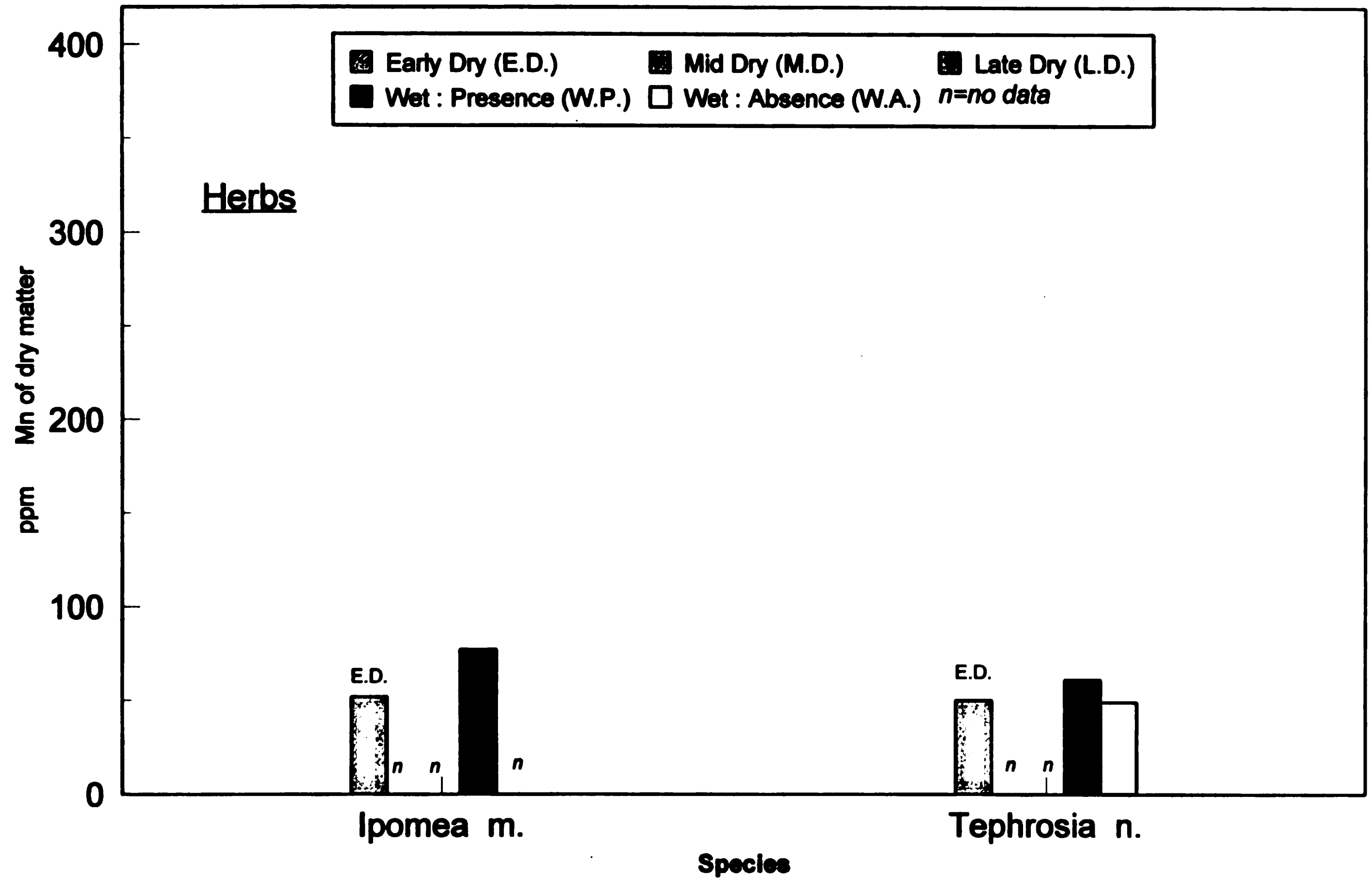


Figure 16-b. (cont'd)

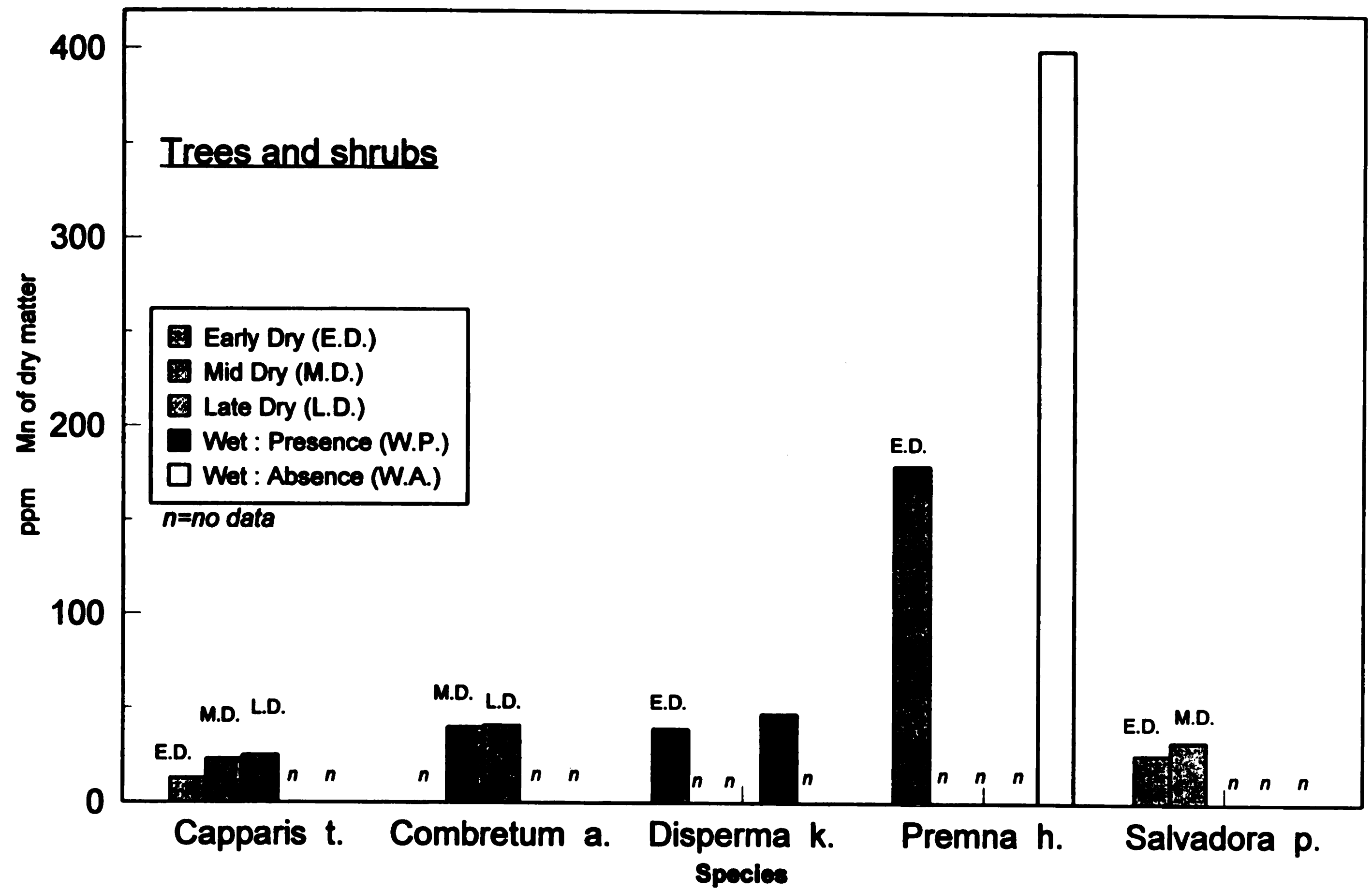


Figure 16-c. (cont'd)

Table 20. Manganese of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (ppm = ug/g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	34 ± 8.4	
	(Bushland)					92 ± 21.7
Chloris roxburghiana	(Grassland)	38 ± 6.2	n.d.	42 ± 1.1	56 ± 1.5 (a-1)	42 ± 12.4
	(Grassland)				60 ± 19.5 (a-2)	
Cynodon dactylon	(Forest)	75 ± 4.6	60 ± 35.8	43 ± 5.7 (b-1)	54 ± 2.3	n.d.
	(Grassland)			33 ± 17.5 (b-2)		
Cynodon plectostachyus	(Grassland)	70 ± 30.8	n.d.	n.d.	44 ± 22.9	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 58ppm was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 38ppm was used for statistical analyses.
3. "n.d." denote no data.

Table 20. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.	ppm Mean ± S.E.
Ipomea mombassana	(Grassland)	52 ± 16.3	n.d.	n.d.	77 ± 31.6	n.d.
Tephrosia noctiflora	(Grassland)	50 ± 20.0	n.d.	n.d.	61 ± 13.8	49 ± 2.8

Note: "n.d." denote no data.

Table 20. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) ppm Mean ± S.E.	Dry season Mid (M.D.) ppm Mean ± S.E.	Dry season Late (L.D.) ppm Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. ppm Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. ppm Mean ± S.E.
Capparis tomentosa	Leaves	18 ± 3.6	40 ± 3.7	41 ± 8.6		
(Forest)	Stems	7 ± 0.3	7 ± 2.9	10 ± 3.2	n.d.	n.d.
	Leaves and stems	13 ± 1.6	23 ± 0.4	25 ± 5.9		
Combretum aculeatum	Leaves		95 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	22 ± 2.4	41 ± 17.9	n.d.	n.d.
(Grassland= Late dry season)	Leaves and stems		40 ± 20.0 (c)	- (d)		
Disperma kilimandscharica	Leaves	49 ± 8.3			48 ± 7.2	
(Bushland= Early dry season)	Stems	56 ± 23.7			47 ± 8.1	
(Grassland= Wet season)	Leaves and stems	52 ± 16.0 (e-1)			47 ± 7.6	
			n.d.	n.d.		n.d.
	Leaves	29 ± 0.6				
	Stems	22 ± 1.3				
	Leaves and stems	26 ± 0.3 (e-2)				
Premna hostii	Leaves	252 ± n.a.				662 ± 55.9
(Grassland)	Stems	132 ± 66.5	n.d.	n.d.	n.d.	139 ± 2.4
	Leaves and stems	179 ± 19.9 (f)				400 ± 29.2
Salvadora persica	Leaves	36 ± 3.2	29 ± 4.8			
(Grassland= Early dry season)	Stems	15 ± 5.5	37 ± 2.9	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	26 ± 4.4	33 ± 3.9			

Note for (e): mean of two values averaged (e-1 and e-2), 39ppm was used for statistical analyses.
See "Note for Trees and shrubs in Tables 14-24".

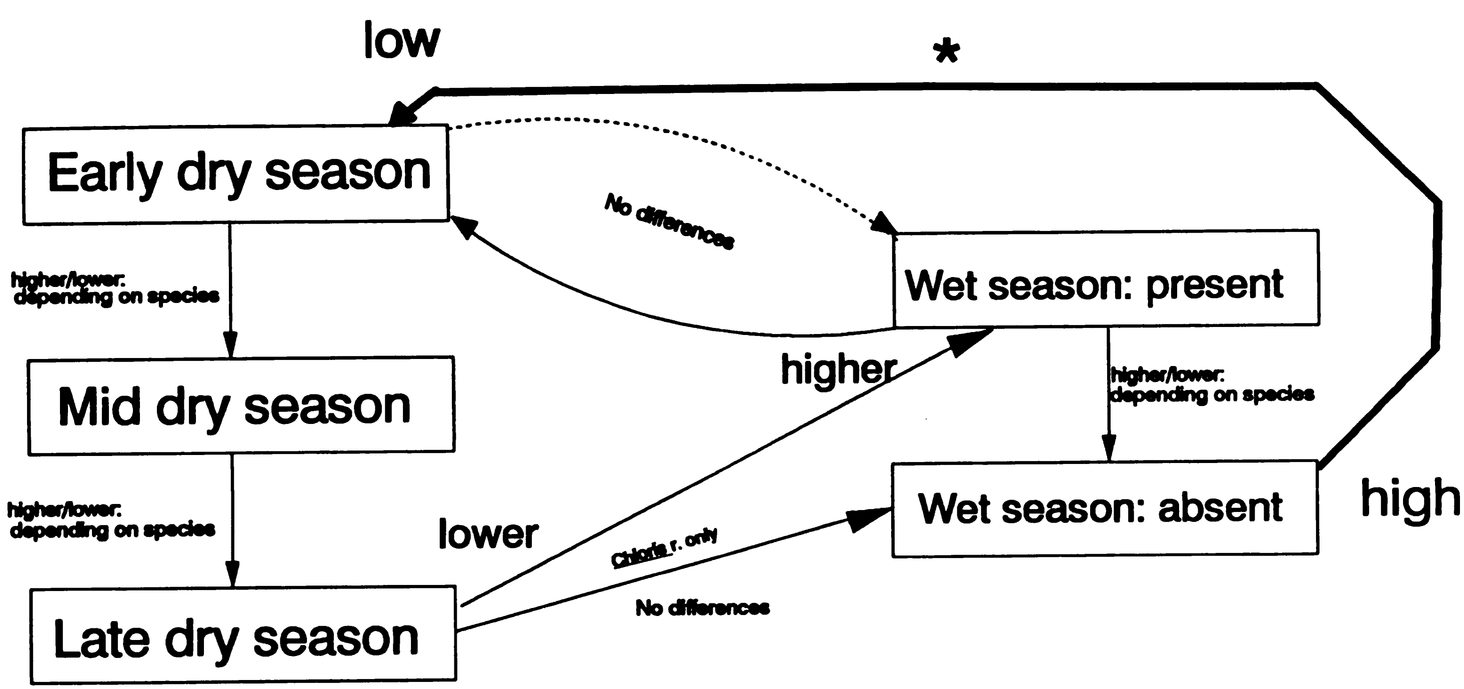


Figure 17. Seasonal patterns or trends of manganese of plants eaten by elephants in the southern part of Tsavo East National Park.

Notes: Directions of arrows show directions of seasons changed from June 1992 to June 1993.
Not differed at P > 0.20 between two seasonal categories.
* Differed at P < 0.20 between two seasonal categories.
Rare pattern (from Feb. to March 1993).
Wet season: present= Wet seasons where elephants were present
Wet season: absent= Wet seasons where elephants were absent due to migration.
Dry seasons= Only where elephants were present.

for the early dry season was 7-252ppm (18-252ppm for leaves and 7-132ppm for stems) and the range for the mid and late dry season was 7-95ppm (29-95ppm for leaves and 7-41ppm for stems). Leaves of Premna hostii in the wet season where elephants were absent and in the early dry season tended to contain highest values (662 ± 55.9ppm, 252ppm respectively; Table 20). Stems of Capparis tomentosa in forest in the dry season tended to contain lower values (7 ± 0.3 ppm in the early dry, 7 ± 2.9 ppm in the mid dry, 10 ± 3.2 ppm in the late dry; Table 20). Stems of Salvadora persica in grassland in the early dry season also tended to have lower values (15 ± 5.5ppm; Table 20).

Lignin

Figure 18 (a, b and c) and Table 21 show the seasonal percentages of lignin for each species. There were no seasonal differences ($P > 0.20$). However, the values in the wet season where elephants were absent tended to be lower than the early dry season for three species (Figures 18a, 18b and 18c), lower than the late dry season for one species (Chloris roxburgiana; Figure 18a), and lower than the wet season where elephants were present for three species (Figures 18a and 18b).

Within grass-herb vegetation shown in Table 21 the range was 8.8-37.5% on a dry weight basis in the early dry

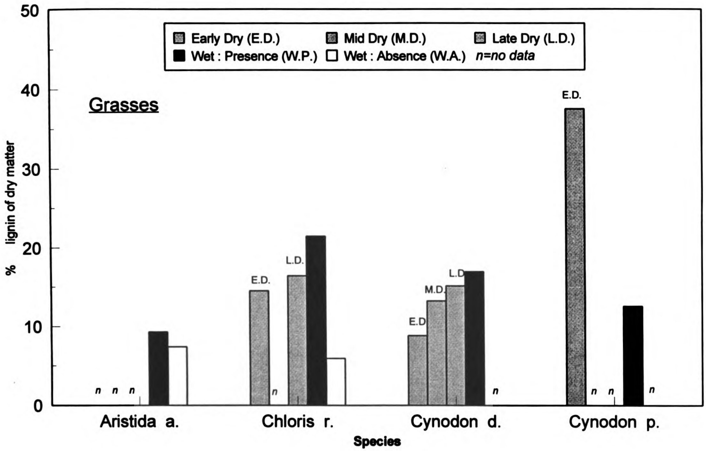


Figure 18-a. Lignin content as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 21. W.P.=Wet seasons where elephants were present. W.A.=wet seasons where elephants were absent.

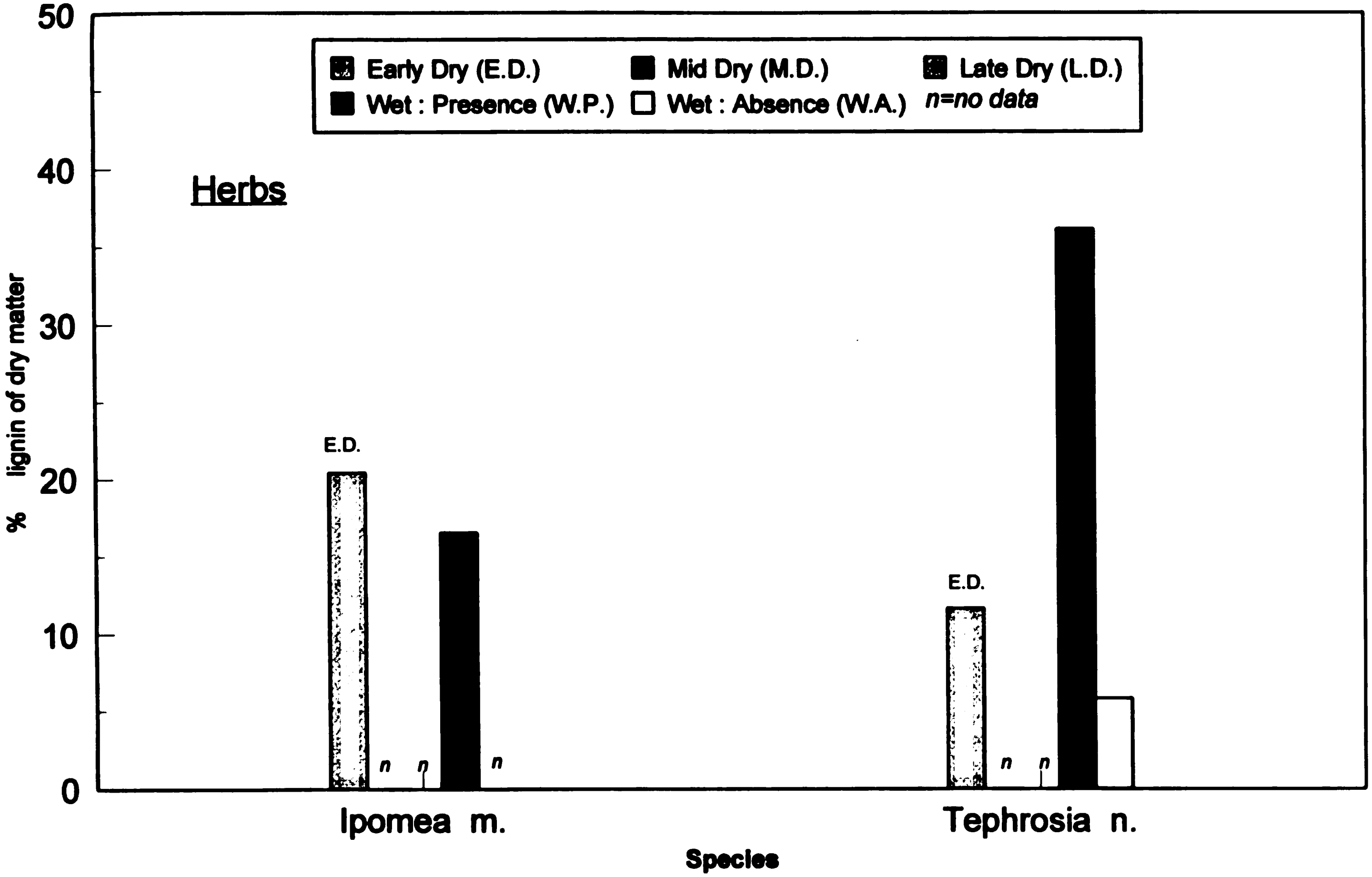


Figure 18-b. (cont'd)

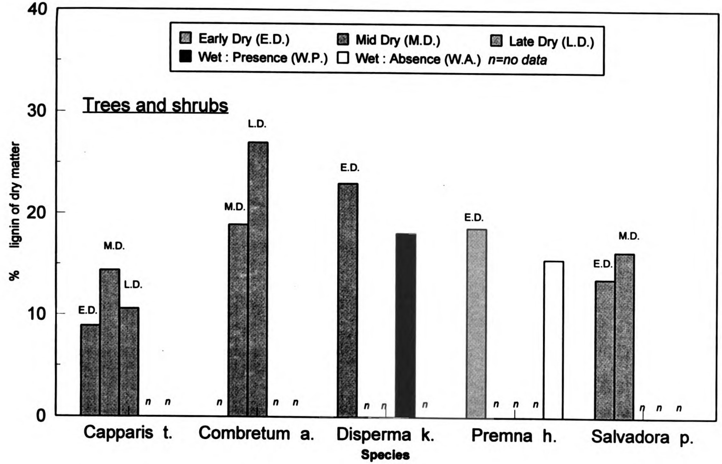


Figure 18-c. (cont'd)

Table 21. Lignin of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	9.3 ± 1.06	
	(Bushland)					8.5 ± 0.69
Chloris roxburghiana	(Grassland)	14.5 ± 1.33	n.d.	16.4 ± 1.13	12.0 ± 0.86 (a-1)	5.9 ± 0.40
	(Grassland)				30.8 ± 16 (a-2)	
Cynodon dactylon	(Forest)	8.8 ± 3.78	13.2 ± 3.82	17.1 ± 3.84 (b-1)	16.9 ± 1.53	n.d.
	(Grassland)			13.1 ± 0.05 (b-2)		
Cynodon plectostachyus	(Grassland)	37.5 ± 1.01	n.d.	n.d.	12.5 ± 0.70	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 21.4% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 15.1% was used for statistical analyses.
3. "n.d." denote no data.

Table 21. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	20.4 ± 11.02	n.d.	n.d.	16.5 ± 11.24	n.d.
Tephrosia noctiflora	(Grassland)	11.6 ± 0.36	n.d.	n.d.	36.1 ± 2.31	5.8 ± 0.18

Note: "n.d." denote no data.

Table 21. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Capparis tomentosa	Leaves	6.9 ± 0.71	14.6 ± 1.31	8.9 ± 1.47		
(Forest)	Stems	11.0 ± 0.18	14.2 ± 0.36	12.4 ± 0.33	n.d.	n.d.
	Leaves and stems	8.9 ± 0.44	14.4 ± 0.48	10.6 ± 0.90		
Combretum aculeatum	Leaves		2.6 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	23.1 ± 1.11	27.0 ± 0.40	n.d.	n.d.
(Grassland= Late dry season)	Leaves and stems		18.9 ± 5.34 (c)	- (d)		
Disperma kilimandscharica	Leaves	17.8 ± 3.58			13.2 ± 0.94	
(Bushland= Early dry season)	Stems	38.4 ± 12.89			22.9 ± 1.13	
(Grassland= Wet season)	Leaves and stems	28.1 ± 8.23 (e-1)			18.1 ± 1.03	
			n.d.	n.d.		n.d.
	Leaves	13.0 ± 0.02				
	Stems	22.6 ± 0.46				
	Leaves and stems	17.8 ± 0.24 (e-2)				
Premna hostii	Leaves	3.1 ± n.a.				9.5 ± 1.84
(Grassland)	Stems	22.7 ± 0.11	n.d.	n.d.	n.d.	21.6 ± 0.83
	Leaves and stems	18.6 ± 4.23 (f)				15.5 ± 1.34
Salvadora persica	Leaves	6.6 ± 0.04	4.9 ± 0.20			
(Grassland= Early dry season)	Stems	20.5 ± 0.51	27.8 ± 18.19	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	13.6 ± 0.28	16.3 ± 9.19			

Note for (e): ı Note for (e): mean of two values averaged (e-1 and e-2), 23.0% was used for statistical analyses.
See "Notes f: See "Notes for trees and shrubs in Table 14-24".

Table 21. (cont'd)

Trees and Shrubs (5 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species (Vegetation type)	parts	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Capparis tomentosa	Leaves	6.9 ± 0.71	14.6 ± 1.31	8.9 ± 1.47		
(Forest)	Stems	11.0 ± 0.18	14.2 ± 0.36	12.4 ± 0.33	n.d.	n.d.
	Leaves and stems	8.9 ± 0.44	14.4 ± 0.48	10.6 ± 0.90		
Combretum aculeatum	Leaves		2.6 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	23.1 ± 1.11	27.0 ± 0.40	n.d.	n.d.
(Grassland= Late dry season)	Leaves and stems		18.9 ± 5.34 (c)	- (d)		
Disperma kilimandscharica	Leaves	17.8 ± 3.58			13.2 ± 0.94	
(Bushland= Early dry season)	Stems	38.4 ± 12.89			22.9 ± 1.13	
(Grassland= Wet season)	Leaves and stems	28.1 ± 8.23 (e-1)			18.1 ± 1.03	
			n.d.	n.d.		n.d.
	Leaves	13.0 ± 0.02				
	Stems	22.6 ± 0.46				
	Leaves and stems	17.8 ± 0.24 (e-2)				
Premna hostii	Leaves	3.1 ± n.a.				9.5 ± 1.84
(Grassland)	Stems	22.7 ± 0.11	n.d.	n.d.	n.d.	21.6 ± 0.83
	Leaves and stems	18.6 ± 4.23 (f)				15.5 ± 1.34
Salvadora persica	Leaves	6.6 ± 0.04	4.9 ± 0.20			
(Grassland= Early dry season)	Stems	20.5 ± 0.51	27.8 ± 18.19	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	13.6 ± 0.28	16.3 ± 9.19			

Note for (e): ı Note for (e): mean of two values averaged (e-1 and e-2), 23.0% was used for statistical analyses.
See "Notes f: See "Notes for trees and shrubs in Table 14-24".

season, and 13.1-17.1% in the mid and late dry season. In the wet season, the range was 9.3-36.1% where elephants were present, and 5.8-8.5% where elephants were absent. Among grass-herb vegetation, Cynodon plectostachyus in grassland tended to contain higher values in the early dry season (37.5 ± 1.10%; Table 21 and Figure 18a). Tephrosia noctiflora in grassland tended to contain higher values in the wet season where elephants were present (36.1 ± 2.31%; Table 21 and Figure 18b), and lower lignin in the wet season where elephants were absent (5.8 ± 0.18%; Table 21 and Figure 18b). Chloris roxburghiana in grassland in the early dry season tended to contain higher lignin (30.8 ± 16.0%; Table 21), and lower lignin in the wet season where elephants were absent (5.9 ± 0.40%; Table 21).

Within shrub vegetation shown in Table 21, the range in the early dry season was 3.1-38.4% (3.1-17.8% for leaves and 11.0-38.4% for stems; Table 21) and the range in the mid and late dry season was 2.6-27.8% (2.6-14.6% for leaves and 12.4-27.8% for stems; Table 21). Stems of Disperma kilimandscharica in bushland tended to contain higher values in the early dry season (38.4 ± 12.89%; Table 21). Leaves of Salvadora persica in bushland in the mid dry season tended to contain lower values (4.9 ± 0.20%; Table 21). Leaves of Premna hostii in grassland in the early dry season and leaves of Combretum aculeatum in forest in the mid dry season tended to contain lower values (3.1 % and 2.6 % respectively; Table 21).

Cellulose

Figure 19 (a, b and c) and Table 22 show the seasonal percentages of cellulose for each species. There were no seasonal differences ($P > 0.20$).

Within grass-herb vegetation, however, the values in the wet season where elephants were absent tended to be lower than in the early dry season for two species, *Chloris roxburghiana* (Figure 19a) and *Tephrosia noctiflora* (Figure 19b), and lower than in the late dry season for one species, *Chloris roxburghiana* (Figure 19a). The range described in Table 22 was 27.7-62.8% on a dry weight basis in the early dry season, and 53.8-64.4% in the mid and late dry season. In the wet season, the range was 21.9-71.8% where elephants were present, and 33.4-49.0% where elephants were absent. *Chloris roxburghiana* in grassland tended to contain higher cellulose (62.8 ± 0.48% in the early dry season, 68.4 ± 2.03% and 71.8 ± 7.23 in the wet season where elephants were present; Table 22). *Aristida adscensionis* in grassland tended to contain higher cellulose in the wet season where elephants were present (65.5 ± 2.90%; Table 22). *Cynodon dactylon* in forest tended to contain higher values in the mid dry season (64.4 ± 1.47%; Table 22). *Ipomea mombassana* and *Tephrosia*

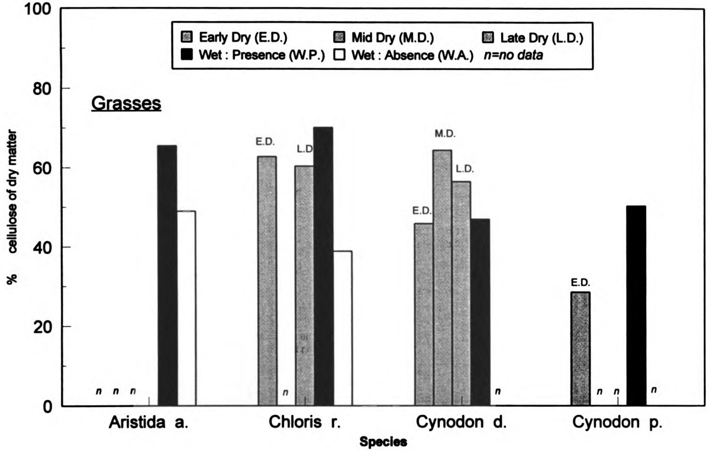


Figure 19-a. Cellulose content as % dry weight of plants eaten by elephants:seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 22.
W.P.=Wet seasons where elephants were present.
W.A.=wet seasons where elephants were absent.

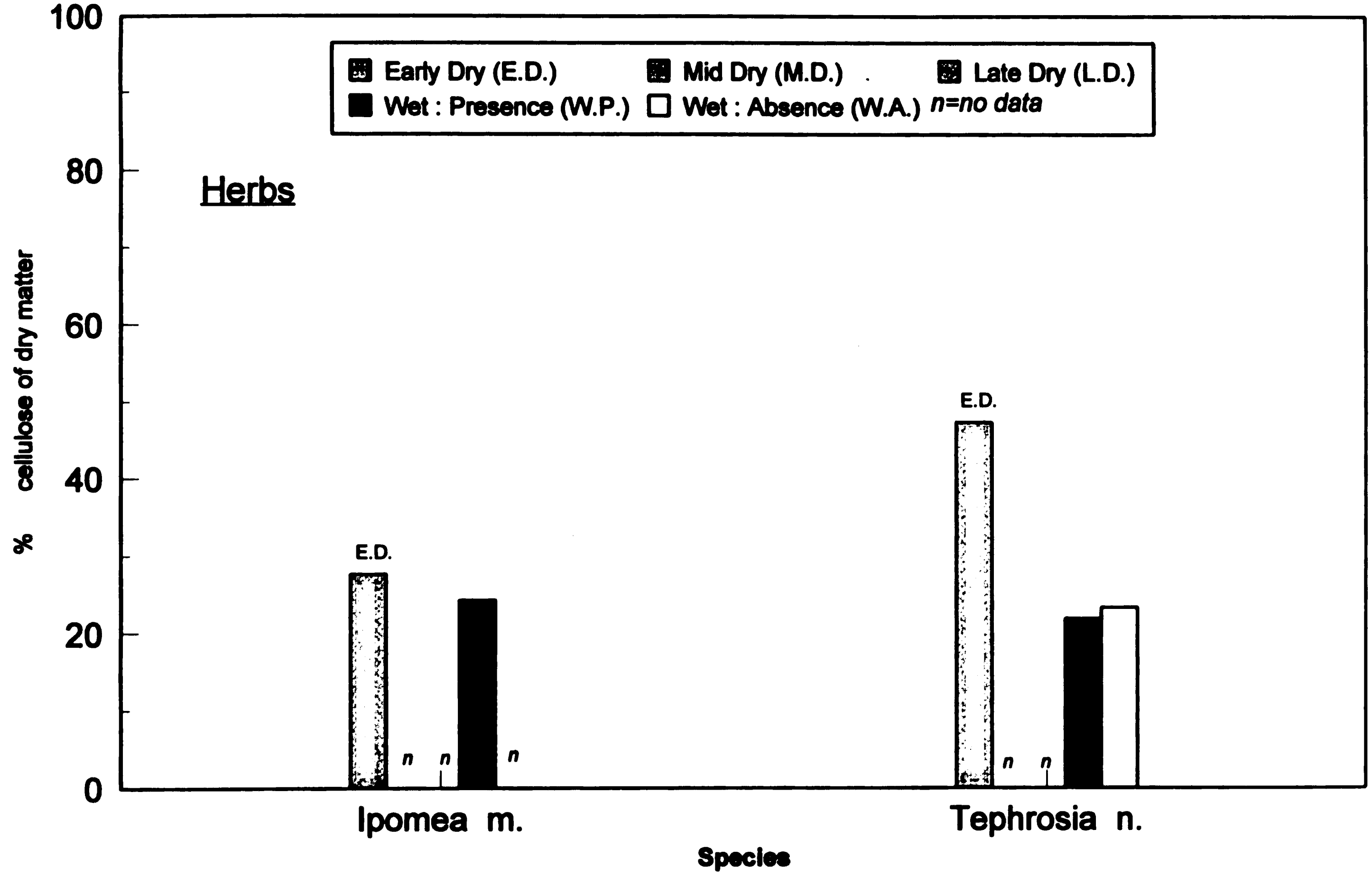


Figure 19-b. (cont'd)

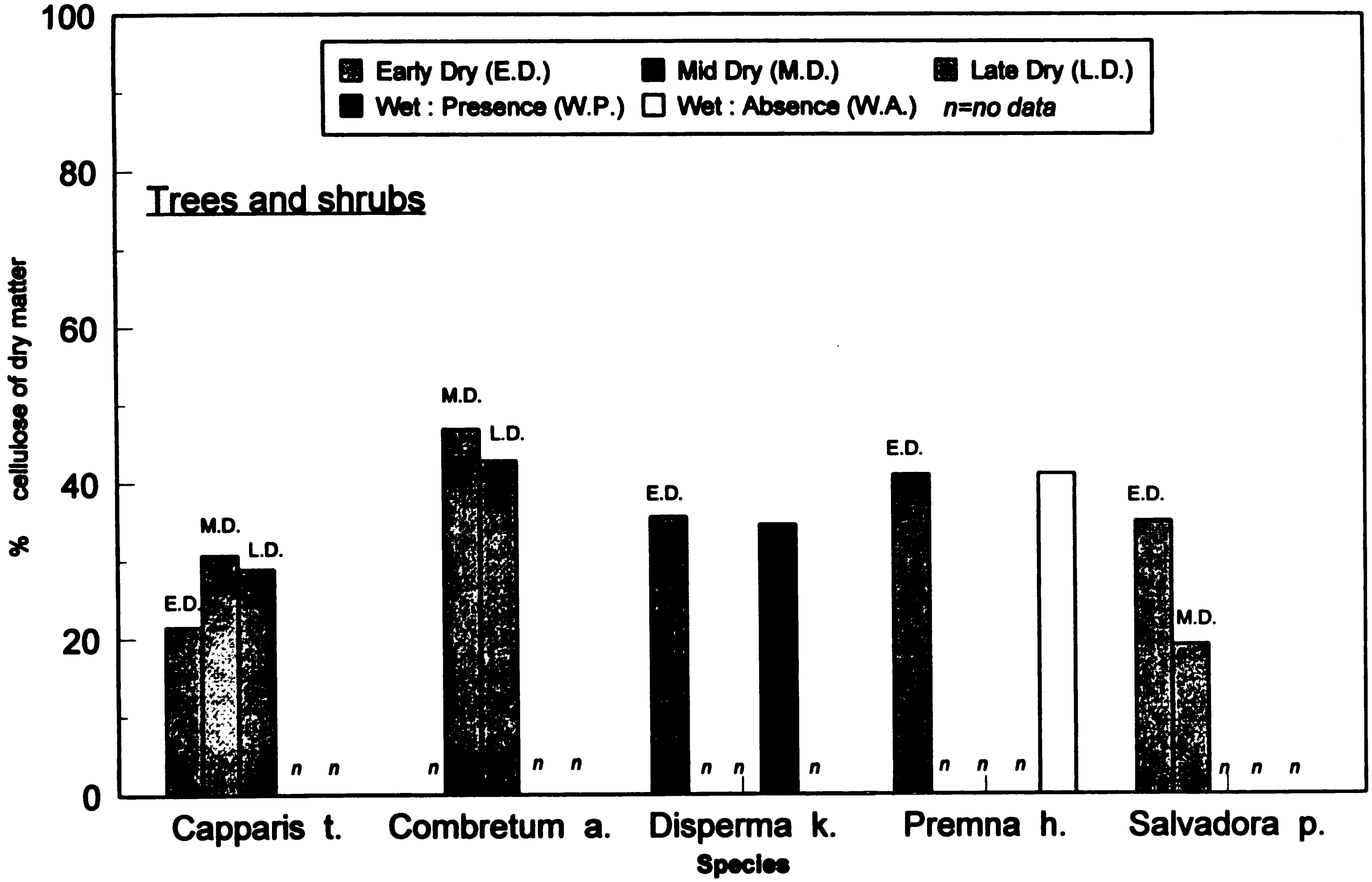


Figure 19-c. (cont'd)

Table 22. Cellulose of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	65.5 ± 2.90	
	(Bushland)					49.0 ± 0.21
Chloris roxburghiana	(Grassland)	62.8 ± 0.48	n.d.	60.4 ± 0.61	68.4 ± 2.03 (a-1)	38.9 ± 0.71
	(Grassland)				71.8 ± 7.23 (a-2)	
Cynodon dactylon	(Forest)	45.9 ± 9.36	64.4 ± 1.47	53.8 ± 1.37 (b-1)	47.0 ± 2.06	n.d.
	(Grassland)			59.2 ± 2.54 (b-2)		
Cynodon plectostachyus	(Grassland)	28.6 ± 1.42	n.d.	n.d.	50.3 ± 4.05	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 70.1% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 56.5% was used for statistical analyses.
3. "n.d." denote no data.

Table 22. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	27.7 ± 9.51	n.d.	n.d.	24.3 ± 4.45	n.d.
Tephrosia noctiflora	(Grassland)	47.4 ± 0.64	n.d.	n.d.	21.9 ± 0.53	33.4 ± 2.02

Note: "n.d." denote no data.

Table 22. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet season Presence (W.P.) =where elephants were present % Mean ± S.E.	Wet season Absence (W.A.) =where elephants were absent % Mean ± S.E.
Capparis tomentosa	Leaves	11.8 ± 2.10	13.5 ± 0.58	14.7 ± 1.46		
(Forest)	Stems	31.2 ± 2.62	47.8 ± 1.02	43.1 ± 2.48	n.d.	n.d.
	Leaves and stems	21.5 ± 2.36	30.7 ± 0.22	28.9 ± 1.97		
Combretum aculeatum	Leaves		17.0 ± n.a.	-		
(Grassland= Wet season)	Stems	n.d.	46.4 ± 1.87	42.8 ± 1.69	n.d.	n.d.
(Forest= Mid dry season)	Leaves and stems		46.9 ± 3.81 (c)	- (d)		
Disperma kilimandscharica	Leaves	24.6 ± 1.51			25.5 ± 0.65	
(Bushland= Early dry season)	Stems	33.7 ± 16.32			43.6 ± 2.76	
(Grassland= Wet season)	Leaves and stems	29.1 ± 7.40 (e-1)			34.6 ± 1.06	
			n.d.	n.d.		n.d.
	Leaves	37.8 ± 0.03				
	Stems	46.4 ± 0.23				
	Leaves and stems	42.1 ± 0.13 (e-2)				
Premna hostii	Leaves	8.5 ± n.a.				23.6 ± 0.62
(Grassland)	Stems	49.4 ± 1.31	n.d.	n.d.	n.d.	58.6 ± 2.41
	Leaves and stems	41.0 ± 7.10 (f)				41.1 ± 0.90
Salvadora persica	Leaves	23.7 ± 0.17	14.8 ± 1.33			
(Grassland= Early dry season)	Stems	46.3 ± 2.46	23.4 ± 15.44	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	35.0 ± 1.32	19.1 ± 7.06			

Note for (e): mean of two values averaged (e-1 and e-2), 35.6% was used for statistical analyses.
See "Notes for trees and shrubs in Tables 14-24".

<u>noctiflora</u> in the wet season where elephants were present tended to contain lower values (24.3 ± 4.45% and 21.9 ± 0.53 % respectively; Table 22).

Within shrub vegetation shown in Table 22, the range in the early dry season was 8.5-49.4% (8.5-37.8% for leaves and 31.2-49.4% for stems; Table 22) and the range in the mid and late dry season was 13.5-47.8% (13.5-17.0% for leaves and 23.4-47.8% for stems; Table 22). Leaves of <u>Combretum</u> <u>aculeatum</u> in forest in the mid dry season tended to contain lower values (17.0 %; Table 22). Leaves of <u>Capparis</u> <u>tomentosa</u> in forest in dry seasons also tended to contain lower values (11.8 ± 2.10% in the early dry season, 13.5 ± 0.58% in the mid dry season, 14.7 ± 1.46% in the late dry season; Table 22). Leaves of <u>Premna</u> <u>hostii</u> in grassland tended to contain higher cellulose in the wet season where elephants were absent (58.6 ± 1.47%; Table 22), and lower cellulose in the early dry season (8.5%; Table 22).

<u>Hemicellulose</u>

Figure 20 (a, b and c) and Table 23 show the seasonal percentages for hemicellulose of each species. The values differed among five seasonal categories ($P < 0.20$). The results for seasonal differences identified by multiple comparisons test are shown in Figure 21. Hemicellulose for the wet season where elephants were

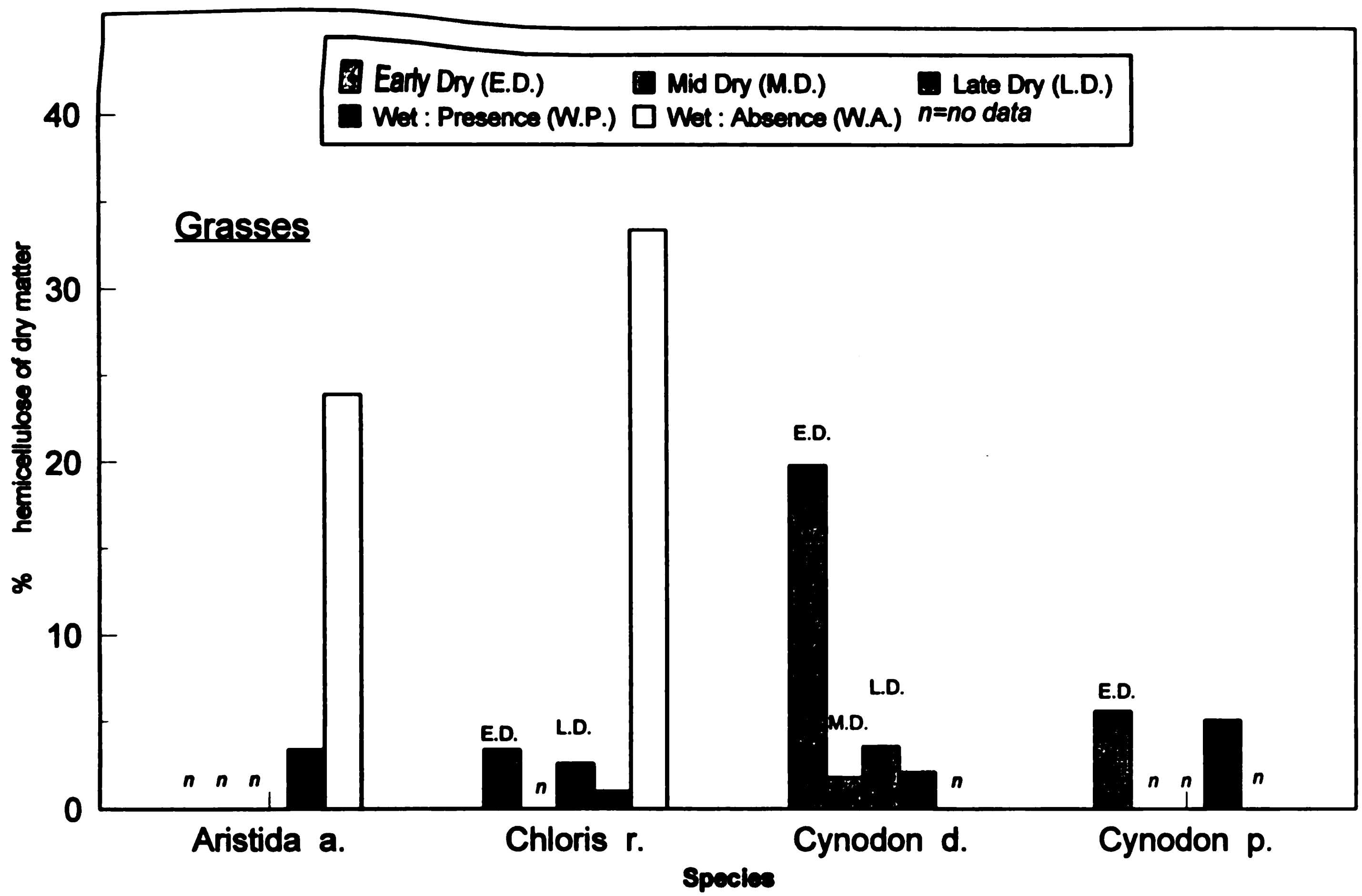


Figure 20-a. Hemicellulose content as % dry weight of plants eaten by elephants: seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 23.
W.P.=Wet seasons where elephants were present.
W.A.=wet seasons where elephants were absent.

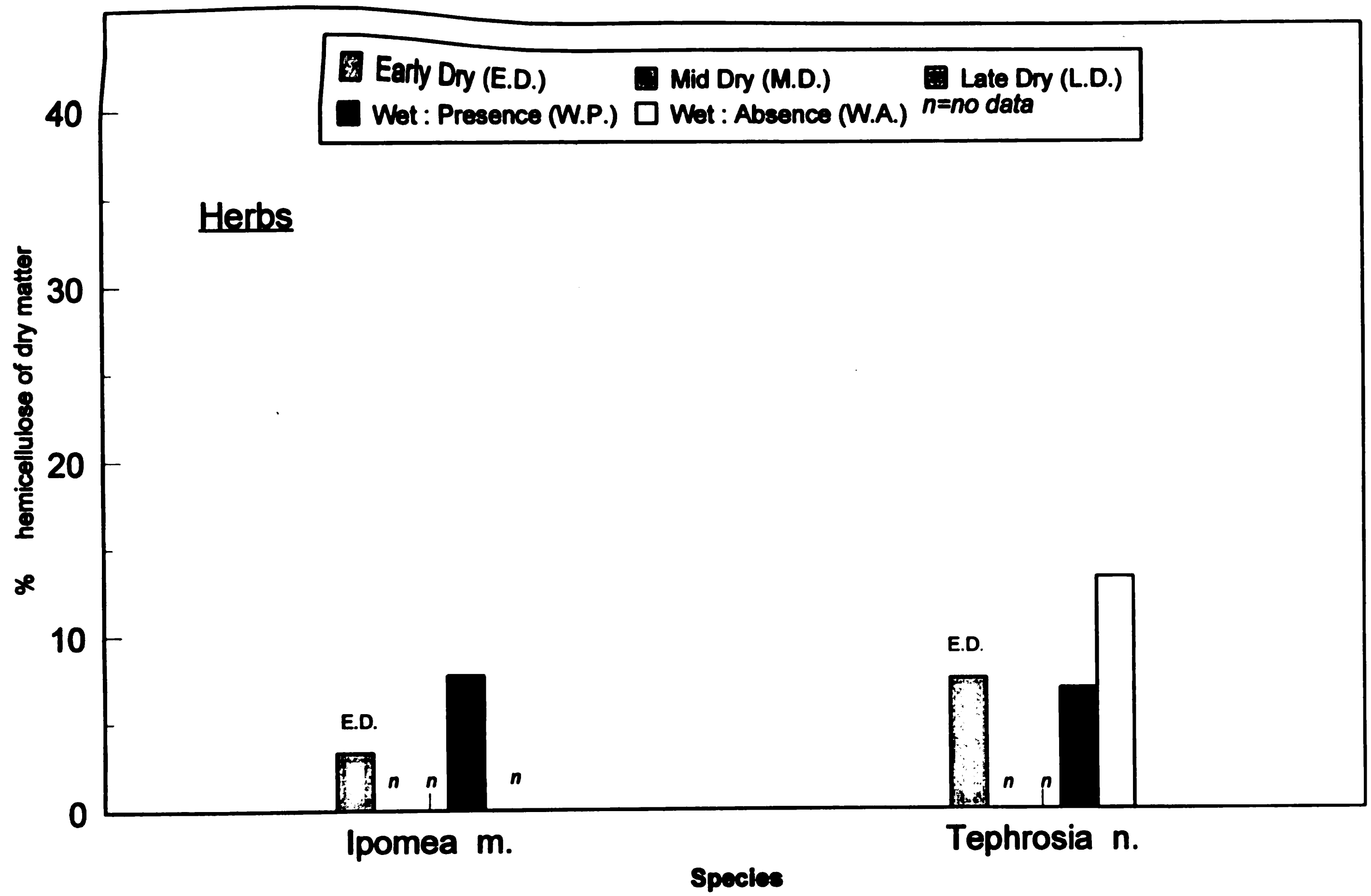


Figure 20-b. (cont'd)

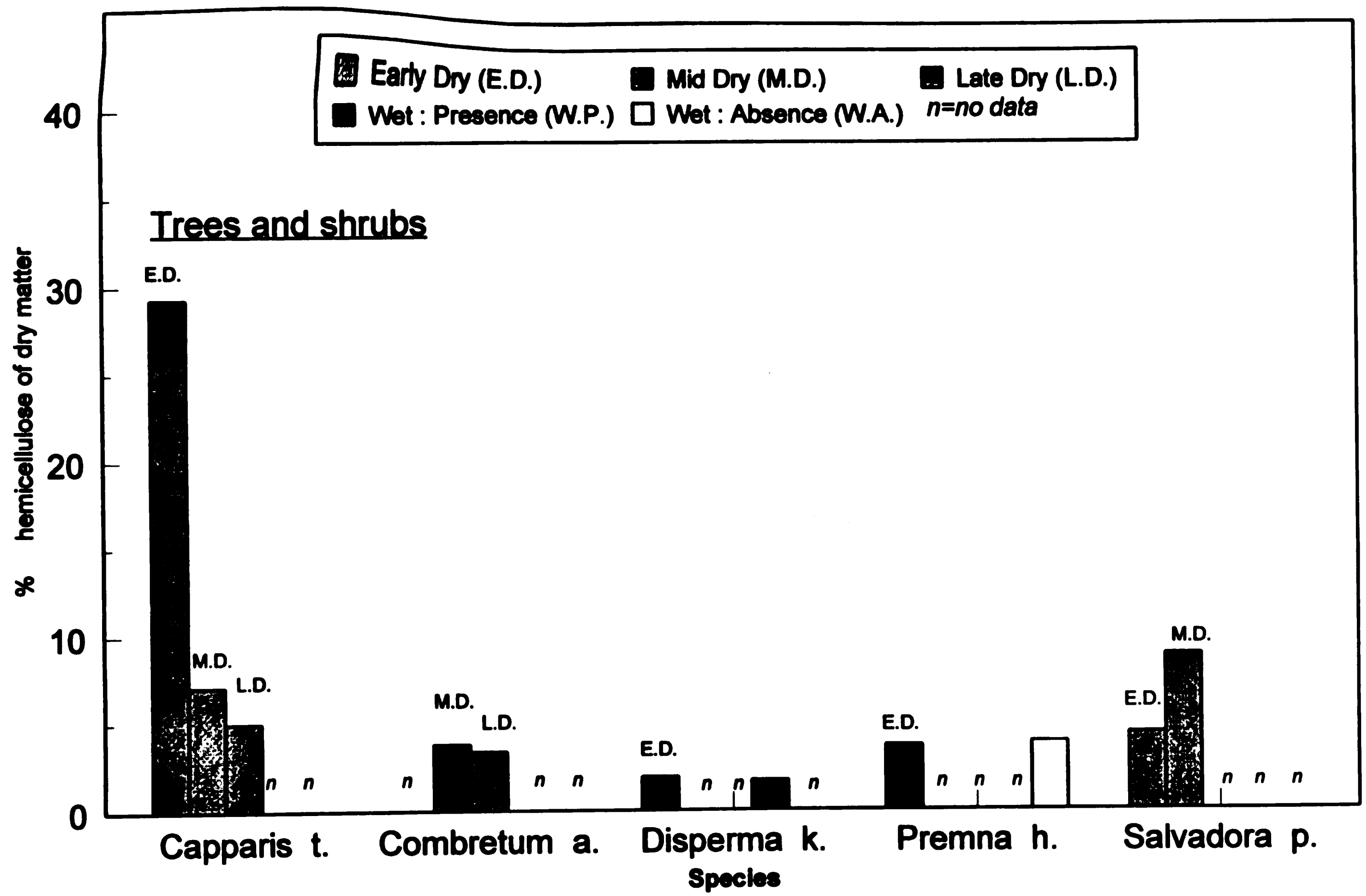


Figure 20-c. (cont'd)

Table 23. Hemicellulose of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d.	n.d.	3.4 ± 1.93	
	(Bushland)					23.9 ± 0.42
Chloris roxburghiana	(Grassland)	3.4 ± 1.19	n.d.	2.6 ± 0.45	0 ± u.a. (a-1)	33.4 ± 0.02
	(Grassland)				2.1 ± 1.37 (a-2)	
Cynodon dactylon	(Forest)	19.8 ± 12.5	1.8 ± 0.58	2.2 ± 0.42 (b-1)	2.1 ± 1.28	n.d.
	(Grassland)			5.0 ± 1.86 (b-2)		
Cynodon plectostachyus	(Grassland)	5.6 ± 0.81	n.d.	n.d.	5.1 ± 0.82	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 1.0% was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 3.6% was used for statistical analyses.
3. "n.d." denote no data.
4. "0" in mean column is an alternative value for "<1" in Appendix 7. "u.a." in S.E. describes that data is unavailable because of use of "<1" for data.

Table 23. (cont'd)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet season Presence (W.P.) =where elephants were present	Wet season Absence (W.A.) =where elephants were absent
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	3.3 ± 2.41	n.d.	n.d.	7.7 ± 7.33	n.d.
Tephrosia noctiflora	(Grassland)	7.5 ± 0.29	n.d.	n.d.	6.9 ± 5.00	13.3 ± 5.50

Note: "n.d." denote no data.

Table 23. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet season Presence (W.P.) =where elephants were present % Mean ± S.E.	Wet season Absence (W.A.) =where elephants were absent % Mean ± S.E.
Capparis tomentosa	Leaves	35.3 ± 10.47	7.5 ± 1.97	5.3 ± 2.63		
(Forest)	Stems	23.3 ± 0.64	6.8 ± 0.09	4.8 ± 0.30	n.d.	n.d.
	Leaves and stems	29.3 ± 4.92	7.1 ± 0.94	5.0 ± 1.47		
Combretum aculeatum	Leaves		2.2 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	3.8 ± 0.69	3.4 ± 0.81	n.d.	n.d.
(Grassland= Late dry season)	Leaves and stems		3.8 ± 0.66 (c)	- (d)		
Disperma kilimandscharica	Leaves	0 ± u.a.			0.1 ± u.a.	
(Bushland= Early dry season)	Stems	3.3 ± 0.77			3.4 ± 0.49	
(Grassland= Wet season)	Leaves and stems	1.7 ± u.a. (e-1)			1.7 ± u.a.	
			n.d.	n.d.		n.d.
	Leaves	0 ± u.a.				
	Stems	4.0 ± 0.91				
	Leaves and stems	2.0 ± u.a. (e-2)				
Premna hostii	Leaves	0.6 ± n.a.				7.5 ± 0.65
(Grassland)	Stems	4.3 ± 1.03	n.d.	n.d.	n.d.	0.3 ± 0.21
	Leaves and stems	3.7 ± 1.55 (f)				3.9 ± 0.43
Salvadora persica	Leaves	7.5 ± 1.80	7.2 ± 0.03			
(Grassland= Early dry season)	Stems	1.2 ± 0.74	10.6 ± 4.58	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	4.4 ± 0.52	8.9 ± 2.31			

Note for (e): mean of two values averaged (e-1 and e-2), 1.9% was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24", and Note 3 in grasses in this Table.

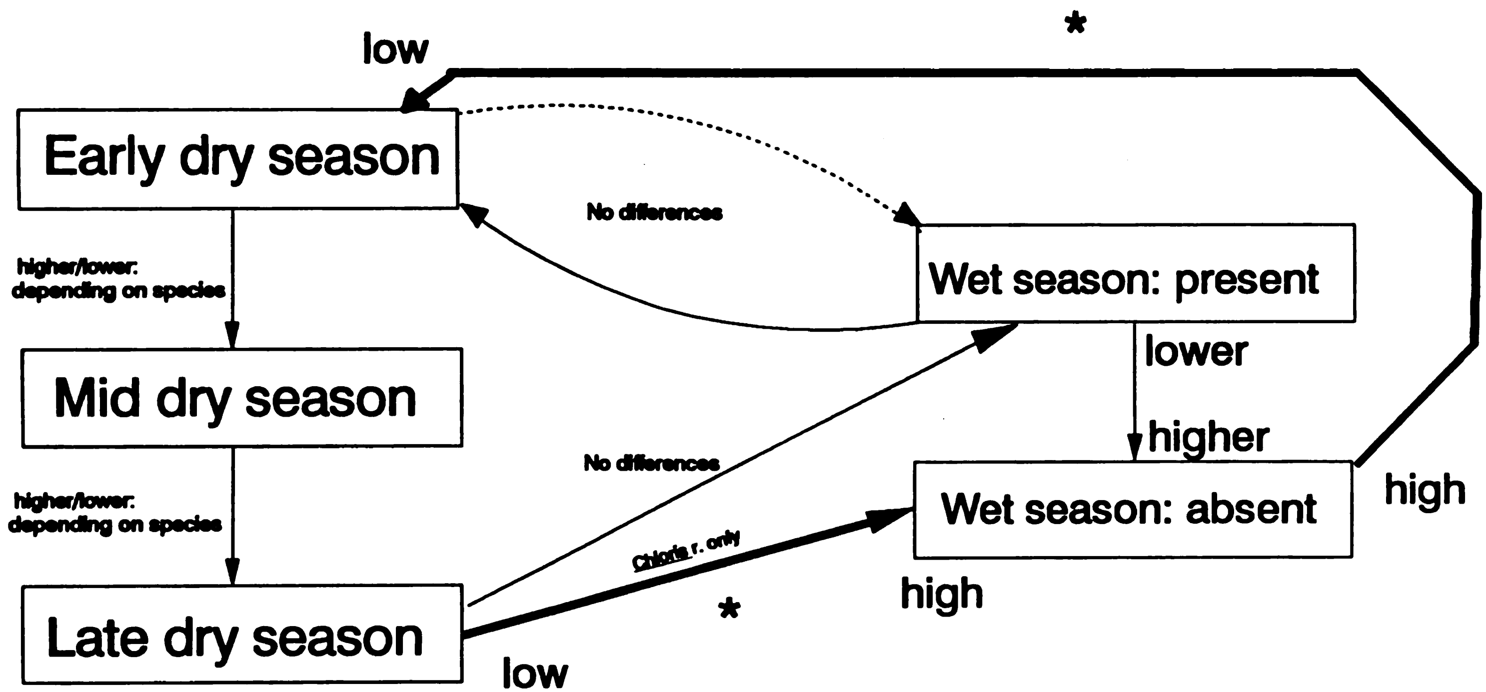


Figure 21. Seasonal patterns or trends of hemicellulose of plants eaten by elephants in the southern part of Tsavo East National Park.

Notes: Directions of arrows show directions of seasons changed from June 1992 to June 1993.
Not differed at P > 0.20 between two seasonal categories.
* Differed at P < 0.20 between two seasonal categories.
Rare pattern (from Feb. to March 1993).
Wet season: present= Wet seasons where elephants were present
Wet season: absent= Wet seasons where elephants were absent due to migration.
Dry seasons = Only where elephants were present.

absent was higher than in the late dry season ($P < 0.20$) for one species (Figure 20a) or in the early dry season ($P < 0.20$) for three species (Figures 20a, 20b and 20c), and tended to be higher than in the wet season where elephants were present for three species (Figures 20a and 20b).

Within grass-herb vegetation shown in Table 23, the range was 3.3-19.8% on a dry weight basis in the early dry season, and 1.8-5.0% in the mid and late dry season. In the wet season, the range was 0-7.7% where elephants were present, and 13.3-33.4% where elephants were absent. <u>Aristida</u> <u>adscensionis</u> in grassland in the wet season where elephants were absent tended to have higher values (23.9 ± 0.42; Table 23 and Figure 20a). <u>Chloris</u> <u>roxburghiana</u> in grassland tended to have higher values in the wet season where elephants were absent (33.4 ± 0.02%; Table 23 and Figure 20a), and lower values in the wet season where elephants were present (0%, 2.1 ± 1.37%; Table 23). <u>Cynodon</u> <u>dactylon</u> in forest in the mid and the late dry season and the wet season where elephant were present tended to contain lower values (1.8 ± 0.58%, 2.2 ± 0.42%, 2.1 ± 1.28% respectively; Table 23).

Within shrub vegetation shown in Table 23, the range in the early dry season was 0-35.3% (0-35.3% for leaves and 1.2-23.3% for stems; Table 23) and the range for the mid and late dry season was 2.2-10.6% (2.2-7.5% for leaves and 3.4-10.6% for stems; Table 23). *Capparis tomentosa* in forest in the early dry season tended to have higher values (35.3 ± 10.47 in leaves, 23.3 ± 0.64 in stems; Table 23). Leaves of *Disperma kilimandscharica* in bushland in the early dry season and the wet season where elephants were present tended to contain the lowest values, 0%. In *Premna hostii* in grassland, lower values appeared in leaves in the early dry seasons (0.6%; Table 23) and in stems in the wet season where elephant were absent (0.3 ± 0.21%).

Crude protein

Figure 22 (a, b and c) and Table 24 show the seasonal values for crude protein by each species. No seasonal differences were identified ($P > 0.20$). However, the values in the wet season where elephants were present tended to be higher than in the early dry season for three species (Figures 22a and 22b).

Within grass-herb vegetation shown in Table 24, the range was 4.8-16.7% on a dry weight basis in the early dry season and 6.4-7.8% in the mid and late dry season. In the wet season, the range was 4.5-19.4% where elephants were present and 7.0-12.8% where elephants were absent. Higher values tended to be in herbs (the range: 12.4-16.8%). Among grasses, crude protein for *Cynodon dactylon* in forest where elephants were present also tended to be

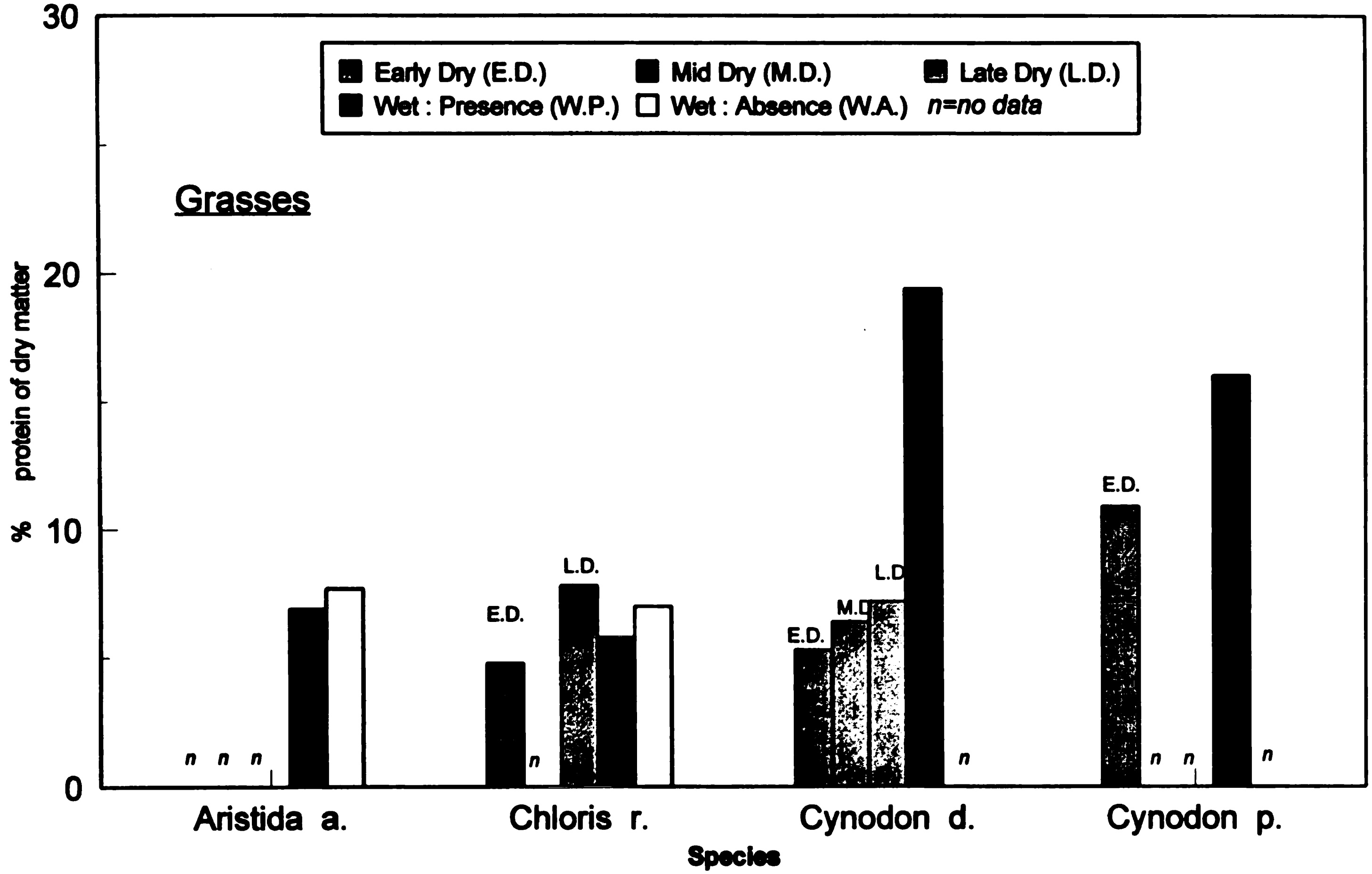
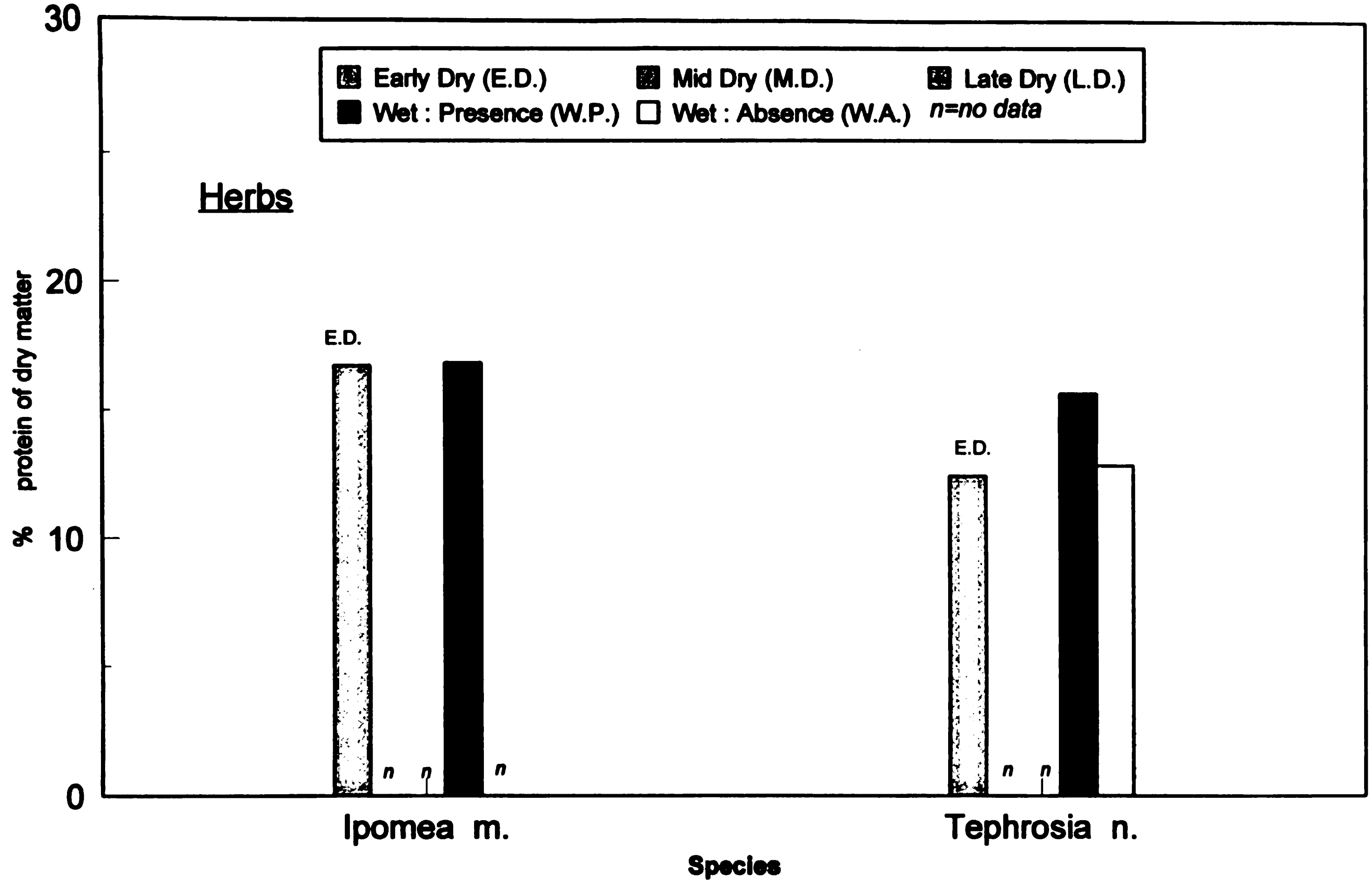


Figure 22-a. Crude protein content as % of plants eaten by elephants: seasonal differences from June 1992 to June 1993. Standard Error (S.E.) is described in Table 24.
W.P.=Wet seasons where elephants were present.
W.A.=Wet seasons where elephants were absent.



Figrue 22-b. (cont'd)

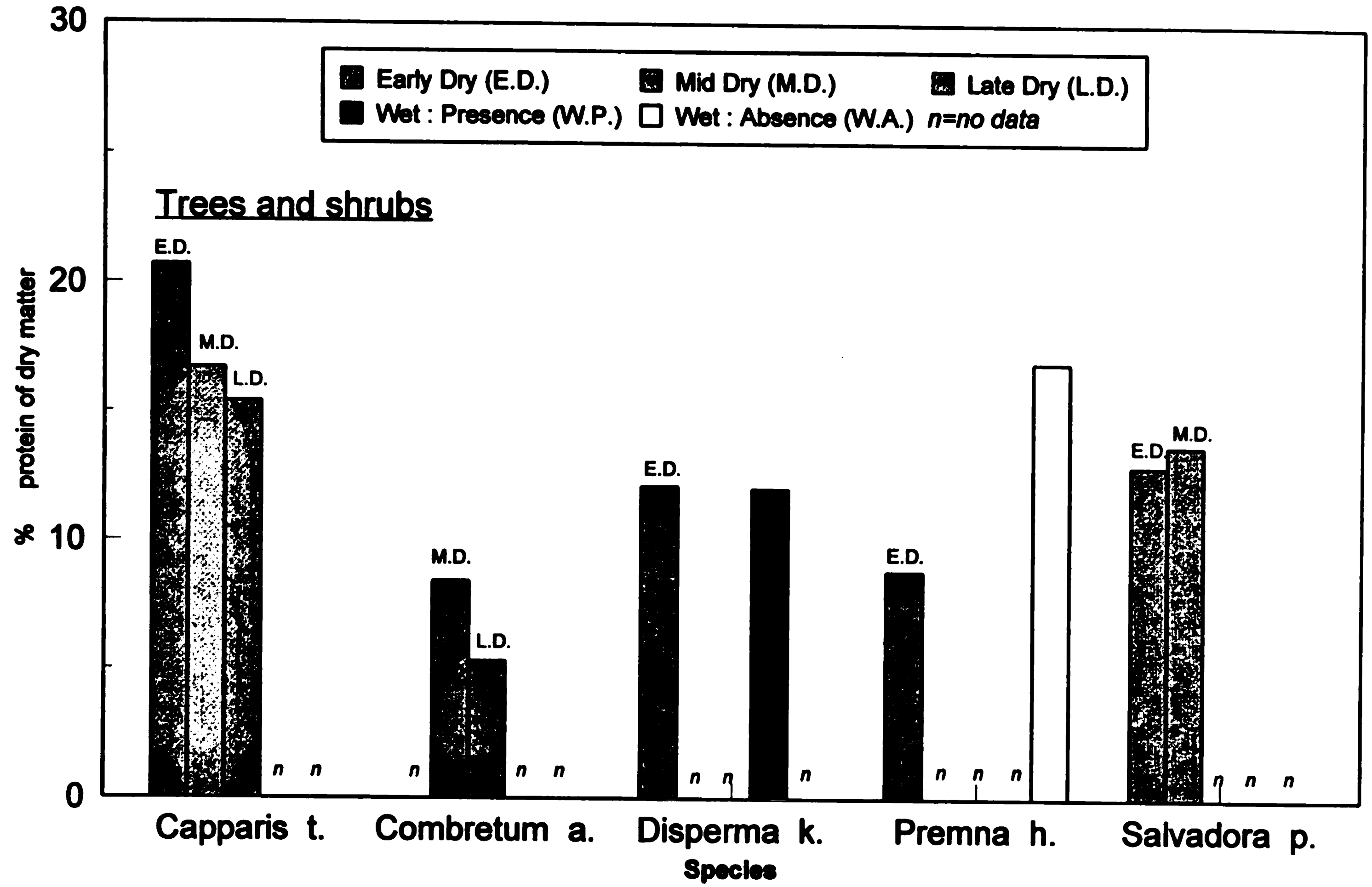


Figure 22-c. (cont'd)

Table 24. Crude protein of eleven species of plants eaten by elephants from June 1992 to June 1993 for seasonal comparisons in the southern part of Tsavo East National Park. (% = g/ 100g dry matter)

Grasses (4 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Aristida adscensionis	(Grassland)	n.d.	n.d	n.d.	6.9 ± 1.00	
	(Bushland)					7.7 ± 1.09
Chloris roxburghiana	(Grassland)	4.8 ± 0.94	n.d.	7.8 ± 1.52	7.0 ± 0.40 (a-1)	7.0 ± 0.84
	(Grassland)				4.5 ± 0.78 (a-2)	
Cynodon dactylon	(Forest)	5.3 ± 0.38	6.4 ± 0.58	7.8 ± 1.52 (b-1)	19.4 ± 1.26	n.d.
	(Grassland)			6.6 ± 1.36 (b-2)		
Cynodon plectostachyus	(Grassland)	10.9 ± 0.45	n.d.	n.d.	16.0 ± 1.57	n.d.

Notes
1. (a): mean of two values averaged (a-1 and a-2), 5.8 % was used for statistical analyses.
2. (b): mean of two values averaged (b-1 and b-2), 7.2 % was used for statistical analyses.
3. "n.d." denote no data.

Table 24. (cont.)

Herbs (2 species)		Dry season Early (E.D.)	Dry season Mid (M.D.)	Dry season Late (L.D.)	Wet Season Presence (W.P.) =where elephants were present.	Wet Season Absence (W.A.) =where elephants were absent.
species	(Vegetation type)	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.	% Mean ± S.E.
Ipomea mombassana	(Grassland)	16.7 ± 1.21	n.d.	n.d.	16.8 ± 1.41	n.d.
Tephrosia noctiflora	(Grassland)	12.4 ± 0.47	n.d.	n.d.	15.6 ± 1.19	12.8 ± 6.54

Note: "n.d." denote no data.

Table 24. (cont'd)

Trees and Shrubs (5 species) species (Vegetation type)	parts	Dry season Early (E.D.) % Mean ± S.E.	Dry season Mid (M.D.) % Mean ± S.E.	Dry season Late (L.D.) % Mean ± S.E.	Wet Season Presence (W.P.) =where elephants were present. % Mean ± S.E.	Wet Season Absence (W.A.) =where elephants were absent. % Mean ± S.E.
Capparis tomentosa	Leaves	26.6 ± 3.91	21.7 ± 0.28	19.8 ± 4.17		
(Forest)	Stems	14.8 ± 2.39	11.8 ± 0.12	11 ± 1.39	n.d.	n.d.
	Leaves and stems	20.7 ± 3.15	16.7 ± 0.08	15.4 ± 2.78		
Combretum aculeatum	Leaves		16.8 ± n.a.	-		
(Forest= Mid dry season)	Stems	n.d.	5.8 ± 0.42	5.3 ± 0.47	n.d.	n.d.
(Grassland= Late dry season)	Leaves and stems		8.4 ± 2.66 (c)	- (d)		
Disperma kilimandscharica	Leaves	19.0 ± 0.11			18.2 ± 2.57	
(Bushland= Early dry season)	Stems	7.2 ± 0.01			5.7 ± 0.82	
(Grassland= Wet season)	Leaves and stems	13.1 ± 0.06 (e-1)			12.0 ± 0.88	
			n.d.	n.d.		n.d.
	Leaves	16.3 ± 0.71				
	Stems	5.8 ± 0.80				
	Leaves and stems	11.0 ± 0.75 (e-2)				
Premna hostii	Leaves	16.2 ± n.a.				14.6 ± 0.71
(Grassland)	Stems	6.4 ± 0.09	n.d.	n.d.	n.d.	19.1 ± 1.66
	Leaves and stems	8.8 ± 2.38 (f)				16.9 ± 1.18
Salvadora persica	Leaves	16.7 ± 1.33	15.5 ± 0.63			
(Grassland= Early dry season)	Stems	9.2 ± 0.26	12 ± 1.62	n.d.	n.d.	n.d.
(Bushland= Mid dry season)	Leaves and stems	12.9 ± 0.54	13.8 ± 1.12			

Note for (e): mean of two values averaged (e-1 and e-2), 12.1 % was used for statistical analyses.
See "Notes for Trees and shrubs in Tables 14-24".

seasons (5.3 ± 0.38% in the early dry season, 6.4 ± 0.58% in the mid dry season, 7.8 ± 1.52% in the late dry season; Table 24). With the exception of Cynodon spp. in the wet season, relatively lower values were reported in grasses (the range: 4.5-10.9%; Table 24).

Within shrub vegetation described in Table 24, the range was 5.8-26.6% in the early dry season (16.2-26.6% for leaves and 5.8-14.8% for stems) and the range for the mid and late dry season was 5.3-21.7% (15.5-21.7% for leaves and 5.3-12.0 % for stems). Higher values tended to be in leaves of shrubs (the range: 14.6-26.6%). Leaves of Capparis tomentosa in forest in the dry season tended to contain higher crude protein (26.6 ± 3.91% in the early dry season, 21.7 ± 0.28% in the mid dry season, 19.8 ± 4.17% in the late dry season; Table 24). With the exception of Capparis tomentosa, stems of shrubs had relatively lower values in the dry season (the range: 5.3-12.0%; Table 24).

Trends of chemical compositions in feces

Seasonal trends for one year

Figure 23 (a, b, c, d and e) and Table 25 show the seasonal differences of chemical composition for elephant

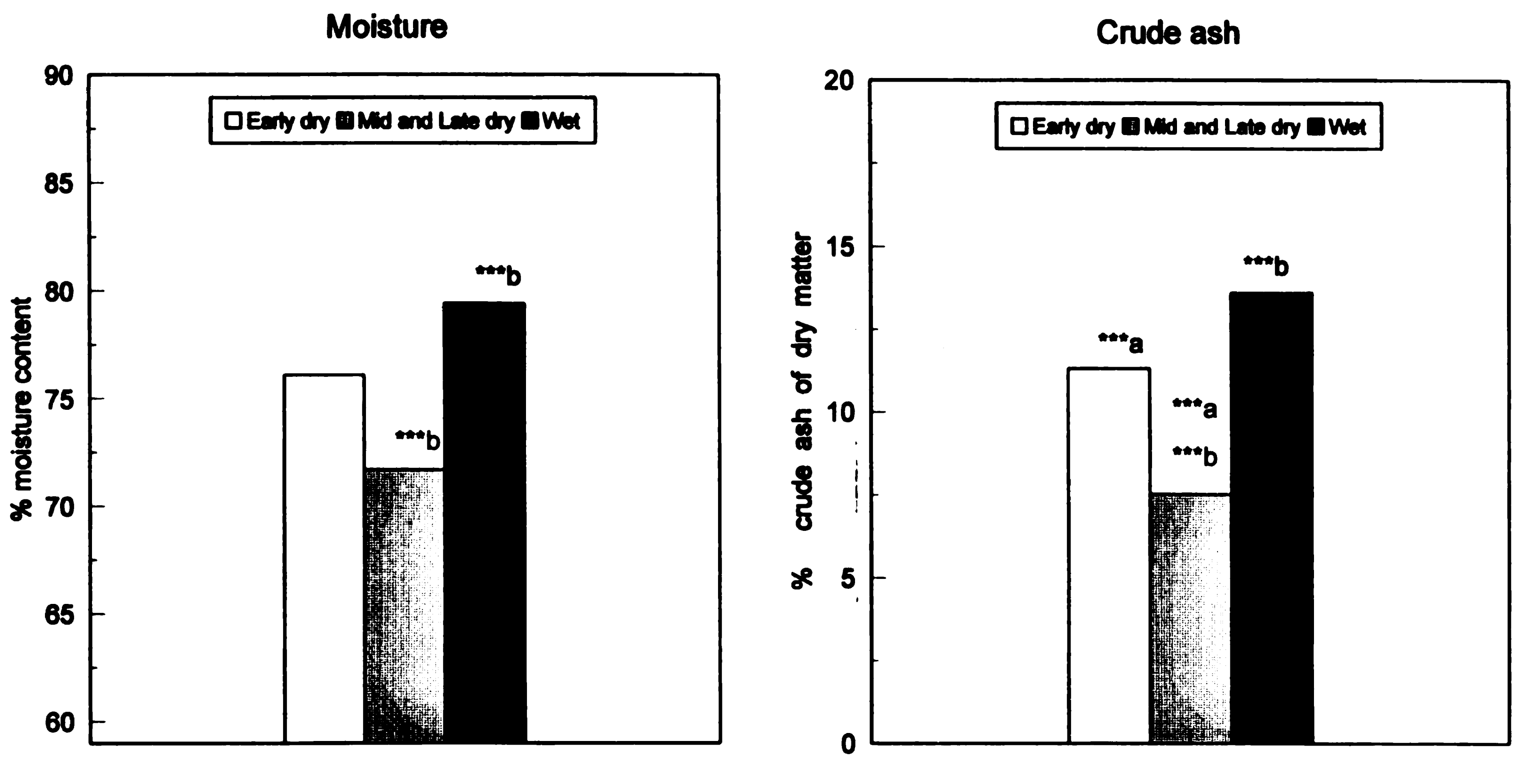


Figure 23-a. Seasonal differences of chemical composition in elephant feces in the southern part of Tsavo East National Park from July 1992 to July 1993. Standard Error (S.E.) is described in Table 25.
*** differed at P < 0.05, ** differed at P < 0.10, * differed at P < 0.20.
a: differed between the early dry season and the mid and late dry season,
b: differed between the mid and late dry season and the wet season.
c: differed between the early dry season and the wet season.

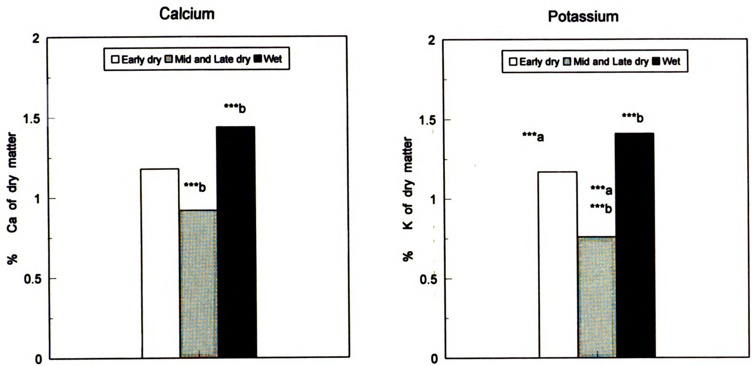


Figure 23-b. (cont'd).

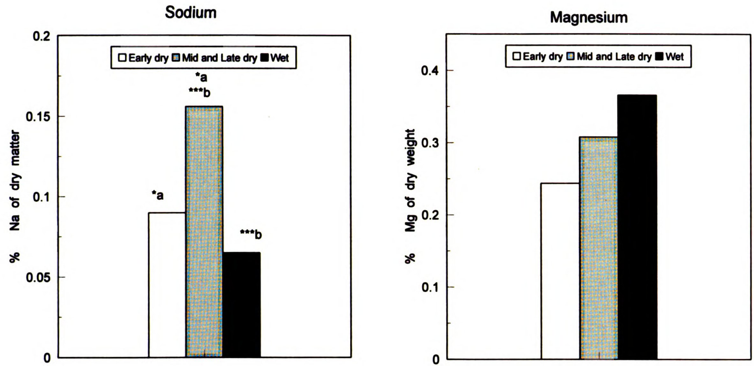
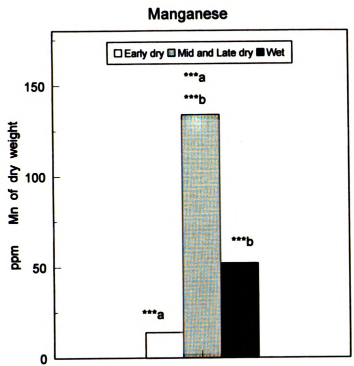


Figure 23-c. (cont'd)



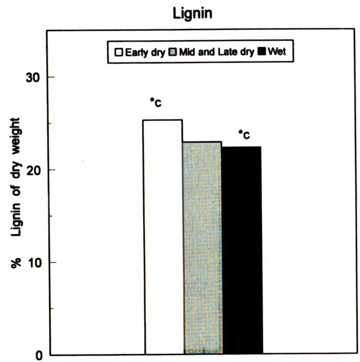


Figure 23-d. (cont'd)

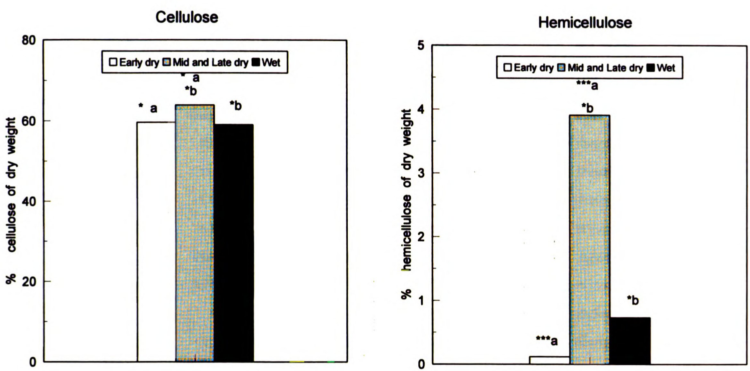


Figure 23-e. (cont'd)

Table 25. Chemical composition of elephant feces in the southern part of Tsavo East National Park from July 1992 to July 1993.

Chemical composition		Early dry season				Mid and Late dry season				Wet season			
		N (n)	Mean	±	S.E.	N(n)	Mean	±	S.E.	N (n)	Mean	±	S.E.
Moisture	% FM	7 (7)	76.1	±	1.41	15 (12)	71.7	±	0.96	17 (10)	79.4	±	0.98
Crude ash	% DM	7 (7)	11.3	±	1.22	15 (12)	7.52	±	0.83	17 (10)	13.6	±	0.83
Calcium	% DM	7 (7)	1.18	±	0.127	13 (12)	0.92	±	0.093	10 (10)	1.44	±	0.107
Potassium	% DM	7 (7)	1.17	±	0.074	13 (12)	0.76	±	0.051	10 (10)	1.41	±	0.058
Sodium	% DM	7 (7)	0.090	±	0.0175	13 (12)	0.156	±	0.0128	10 (10)	0.065	±	0.0146
Magnesium	% DM	7 (7)	0.244	±	0.0447	13 (12)	0.308	±	0.0328	10 (10)	0.366	±	0.0374
Manganese	ppm DM	7 (7)	14	±	21.9	13 (12)	134	±	16.1	10 (10)	52	±	18.3
Lignin	% DM	7 (7)	25.3	±	1.25	10 (10)	22.9	±	1.05	10 (10)	22.3	±	1.05
Cellulose	% DM	7 (7)	59.6	±	1.26	10 (10)	63.9	±	1.05	10 (10)	59.0	±	1.05
Hemicellulose	% DM	7 (7)	0.1	±	0.86	10 (10)	3.9	±	0.72	10 (10)	0.7	±	0.72

%FM= % on a fresh matter basis, %DM= % on a dry matter basis, ppm DM= ppm on a dry matter basis.
N= the number of samples for statistical analyses. n=the number of "paired samples", and a mean value for each "paired sample" was used for statistical analyses. The number of samples for nutrient analyses was N+n.

feces in the southern part of Tsavo East National Park collected from July 1992 to July 1993.

Moisture, crude ash, calcium and potassium had similar seasonal patterns. The values in the mid and late dry seasons were lower than in the wet season (moisture, $P < 0.05$; crude ash, $P < 0.05$; calcium, $P < 0.05$; potassium $P < 0.05$, Figures 23a and 23b), and lower than in the early dry season (crude ash, $P < 0.05$; potassium, $P < 0.05$: Figures 23a and 32b). No differences were observed between the early dry season and the wet season ($P > 0.02$).

Sodium, manganese, cellulose and hemicellulose had similar seasonal patterns. The values in the mid and late dry seasons were higher than in the wet season (sodium, $P < 0.05$; manganese, $P < 0.05$; cellulose, $P < 0.20$; hemicellulose, $P < 0.20$: Figures 23c, 23d and 23e) and higher than in the early dry season (sodium, $P < 0.10$; manganese, $P < 0.05$; cellulose, $P < 0.20$; hemicellulose, $P < 0.05$: Figures 23c, 23d and 23e). No differences were identified between the early dry season and the wet season ($P > 0.20$).

No seasonal differences were detected for magnesium ($P > 0.20$), but the values in the wet season tended to be higher than in the dry season (Figure 23c).

For lignin, the values in the wet season were lower than in the early dry season ($P < 0.20$). No differences were detected between the early dry season and the mid and late dry seasons ($P > 0.20$: Figure 23d).

Seasonal patterns of chemical composition in elephant feces in different geographic areas

Moisture

Figure 24 and Table 26 show the four-year seasonal patterns for moisture in three geographic areas. The values in the mid and late dry seasons were lower than in the wet season within the southern part of Tsavo East National Park ($P < 0.05$), and within the central part of Tsavo East National Park ($P < 0.05$). The values in the mid and late dry seasons were also lower than in the early dry season within the southern part of Tsavo East National Park ($P < 0.20$), and within the central part of Tsavo East National Park ($P < 0.20$). No seasonal differences were detected within the northern part of Tsavo West National Park ($P > 0.20$). However, similar trends for seasonal patterns that were lower in the mid and late dry season appeared among the geographic areas.

Within the mid and late dry season, moisture in the central part of Tsavo East National Park was the lowest among three geographic areas ($P < 0.05$). Within the wet season, the values in the northern part of Tsavo West

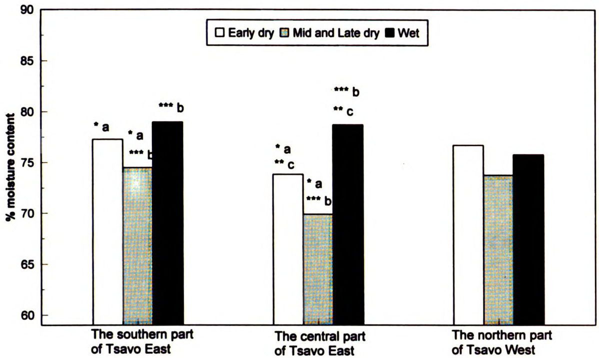


Figure 24. Seasonal differences for moisture in elephant feces in Tsavo National Park from July 1990 to October 1994. Standard Error (S.E.) is described in Table 26. *** differed at $P < 0.05$, ** differed at $P < 0.10$, * differed at $P < 0.20$. a: differed between the early dry season and the mid and late dry seasonal within each geographic area. b: differed between the mid and late dry season and the wet season within each geographic area. c: differed between the early dry season and the wet season within each geographic area.

Table 26. Moisture of elephant feces in Tsavo National Park from July 1990 to October 1994. (% = g/100g fresh matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern part of Tsavo East National Park	18 (9)	77.3 ±	1.12	55 (17)	74.5 ±	0.64	36 (25)	79.0 ±	0.83
The central part of Tsavo East National Park	17 (5)	73.8 ±	1.15	13 (2)	69.9 ±	1.32	15 (6)	78.7 ±	1.28
The northern part of Tsavo West National Park	14 (6)	76.7 ±	1.27	19 (7)	73.8 ±	1.09	16 (6)	75.8 ±	1.24
Significant test among geographic areas		*ns*		*** S-C, *** C-N			** S-N, * C-N		
Total areas	49 (20)	76.0 ±	0.68	87 (26)	75.2 ±	0.75	67 (37)	77.8 ±	0.65

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.

2. Significant test among geographic areas: ns= no differences at $P > 0.20$, *** differed at $P < 0.05$, ** differed at $P < 0.10$, and * differed at $P < 0.20$.
S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).
C-N = differences between the central part of Tsavo East (C) and the northern part of Tsavo West (N).

3. Differences among seasons within each geographic area are shown in Figure 24.

National Park were lower than in the southern part of Tsavo East National Park ($P < 0.10$), and in the central part of Tsavo East National Park ($P < 0.20$).

Seasonal patterns for one year (Figure 23a) tended to be similar to the patterns for four years in the southern part of Tsavo East National Park (Figure 24).

Crude ash

Figure 25 and Table 27 show the four-year seasonal patterns for crude ash in three geographic areas. Crude ash in the mid and late dry seasons was lower than in the wet season and in the early dry season within the southern part of Tsavo East National Park ($P < 0.05$), and within the northern part of Tsavo West National Park ($P < 0.05$). No seasonal differences were detected within the central part of Tsavo East National Park ($P > 0.20$). However, similar trends for seasonal patterns appeared among all geographic areas.

No geographic differences were identified within each season ($P > 0.20$).

Seasonal patterns for one year (Figure 23a) tended to be similar to the patterns for four years in the southern part of Tsavo East National Park (Figure 25).

Calcium

Figure 26 and Table 28 show the three-year seasonal patterns for calcium in three geographic areas. No

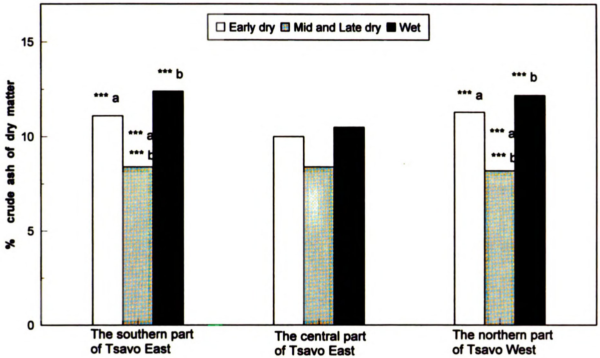


Figure 25. Seasonal differences for crude ash content as % dry weight of elephant feces in Tsavo National Park from July 1990 to October 1994.
Standard Error (S.E.) is described in Table 27.
*** differed at $P < 0.05$. a:differed between the early dry season and the mid dry season within each geographic area. b:differed between the mid and late dry season and the wet season within each geographic area.

Table 27. Crude ash of elephant feces in Tsavo National Park from July 1990 to October 1994. (% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern part of Tsavo East National Park	18 (9)	11.1 ±	0.74	59 (17)	8.4 ±	0.41	36 (25)	12.4 ±	0.56
The central part of Tsavo East National Park	17 (5)	10.0 ±	0.76	15 (3)	8.4 ±	0.81	15 (6)	10.5 ±	0.87
The northern part of Tsavo West National Park	14 (6)	11.3 ±	0.84	19 (7)	8.2 ±	0.72	16 (6)	12.2 ±	0.84
Significant test among geographic areas		*ns*			*ns*			*ns*	
Total areas	49 (20)	10.8 ±	0.45	93 (27)	8.4 ±	0.39	67 (37)	11.7 ±	0.44

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at $P > 0.20$.
3. Differences among seasons within each geographic area are shown in Figure 25.

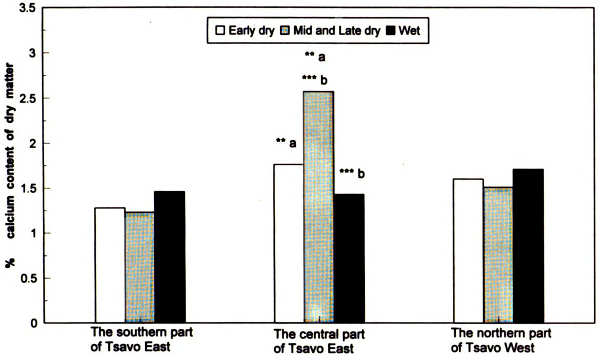


Figure 26. Seasonal differences for calcium content as % dry weight of elephant feces in Tsavo National Park from July 1990 to June 1993. Standard Error (S.E.) is described in Table 28.
*** differed at $P < 0.05$, ** differed at $P < 0.10$. a: differed between the early dry season and the mid and late dry season within a geographic area. b: differed between the mid and late dry season and the wet season within a geographic area.

Table 28. Calcim of elephant feces in Tsavo National Park from July 1990 to June 1993.
(% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern part of Tasvo East National Park	14 (7)	1.28 ±	0.117	37 (14)	1.23 ±	0.072	15 (10)	1.46 ±	0.113
The central part of Tsavo East National Park	11 (4)	1.76 ±	0.132	5 (1)	2.57 ±	0.196	7 (5)	1.43 ±	0.166
The northern part of Tsavo West National Park	10 (5)	1.60 ±	0.139	6 (2)	1.51 ±	0.179	9 (3)	1.71 ±	0.146
Significant test among geographic areas		*** S-C, * S-N			*** S-C, * C-N			*ns*	
Total areas	35 (16)	1.55 ±	0.075	48 (17)	1.77 ±	0.092	31 (18)	1.53 ±	0.083

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples".
A mean value for each "paired sample" (or triple sample) was used for statistical analyses.
The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at $P > 0.20$.
Significant test among geographic areas: ns= no differences at $P > 0.20$, *** differed at $P < 0.05$, * differed at $P < 0.20$.
S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).
C-N = differences between the central part of Tsavo East (C) and the northern part of Tsavo West (N).
3. Differences among seasons within each geographic area are shown in Figure 28.

seasonal differences were detected within the southern part of Tsavo East National Park ($P > 0.20$), or within the northern part of Tsavo West National Park ($P > 0.20$). However, similar trends for seasonal patterns appeared between the southern part of Tsavo East National Park and the northern part of Tsavo West National Park. Within the central part of Tsavo East National Park, calcium in the mid and late dry season was higher than in the early dry season ($P < 0.10$) or the wet season ($P < 0.05$).

Within the early dry season, calcium in the southern part of Tsavo East National Park was lower than in the central part of Tsavo East National Park ($P < 0.05$), and lower than in the northern part of Tsavo West National Park ($P < 0.20$). Within the mid and late dry season, the values in the central part of Tsavo East National Park were higher than in the southern part of Tsavo East National Park ($P < 0.05$) or the northern part of Tsavo West National Park ($P < 0.02$). No geographic differences were identified among three geographic areas within the wet season ($P > 0.20$).

Seasonal patterns for one year (Figure 23b) tended to be similar to the patterns for three years in the southern part of Tsavo East National Park (Figure 26).

<u>Potassium</u>

Figure 27 and Table 29 show the three-year seasonal

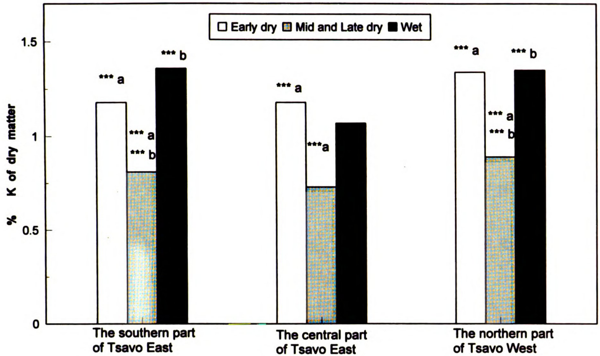


Figure 27. Seasonal differences for potassium content as % dry weight of elephant feces in Tsavo National Park from July 1990 to June 1993.
Standard Error (S.E.) is described in Table 29.
*** differed at $P < 0.05$. a: differed between the early dry season and the mid and late dry season within each geographic area. b: differed between the mid and late dry season and the wet season within each geographic area.

Table 29. Potassium of elephant feces in Tsavo National Park from July 1990 to June 1993.
(% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
		%			%			%	
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.	N (n)	Ave. ±	S.E.
The southern part of Tasvo East National Park	14 (7)	1.18 ±	0.064	37 (13)	0.81 ±	0.030	15 (10)	1.36 ±	0.062
The central part of Tsavo East National Park	11 (4)	1.18 ±	0.072	5 (1)	0.73 ±	0.107	7 (5)	1.07 ±	0.091
The northern part of Tsavo West National Park	10 (4)	1.34 ±	0.076	6 (2)	0.89 ±	0.098	9 (3)	1.35 ±	0.080
Significant test among geographic areas		*ns*			*ns*			* S-C	
Total areas	35 (16)	1.23 ±	0.041	48 (17)	0.81 ±	0.050	31 (18)	1.26 ±	0.045

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples".
A mean value for each "paired sample" (or triple sample) was used for statistical analyses.
The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at $P > 0.20$, * differed at $P < 0.20$.
S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
3. Differences among seasons within each geographic area are shown in Figure 27.

patterns for potassium in three geographic areas. The values in the mid and late dry season were lower than in the early dry season within each geographic area ($P < 0.05$), and lower than in the wet season within the southern part of Tsavo East National Park ($P < 0.05$) and within the northern part of Tsavo West National Park ($P < 0.05$). Similar trends for seasonal patterns that were lower in the mid and late dry season appeared among all geographic areas.

Within the wet season, potassium in the southern part of Tsavo East National Park was higher than in the central part of Tsavo East National Park ($P < 0.20$), but was similar to the northern part of Tsavo West National Park. No geographic differences were identified among the three geographic areas within the dry seasons ($P > 0.20$).

Seasonal patterns for one year (Figure 23b) tended to be similar to the patterns for three years in the southern part of Tsavo East National Park (Figure 27).

Sodium

Figure 28 and Table 30 show the seasonal patterns for sodium in three geographic areas. The values in the mid and late dry season were higher than in the wet season within the southern part of Tsavo East National Park ($P < 0.05$), and within the northern part of Tsavo West National Park ($P < 0.20$), and also higher than in the early dry

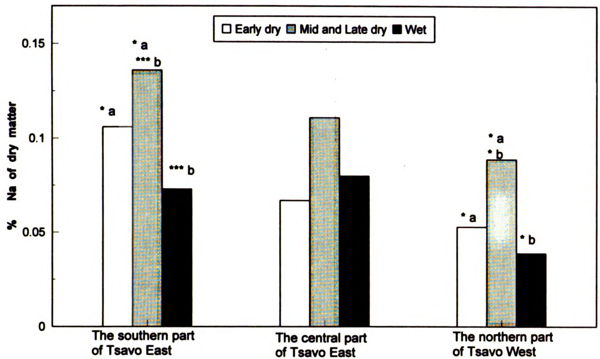


Figure 28. Seasonal differences for sodium content as % dry weight of elephant feces in Tsavo National Park from July 1990 to June 1993.
Standard Error (S.E.) is described in Table 30.
*** differed at $P < 0.05$, * differed at $P < 0.20$. a: differed between the early dry season and the mid and late dry season within each geographic area. b: differed between the mid and late dry season and the wet season within each geographic area.

Table 30. Sodium of elephant feces in Tsavo National Park from July 1990 to June 1993. (% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern part of Tsavo East National Park	14 (7)	0.106 ±	0.0144	37 (13)	0.136 ±	0.0088	15 (10)	0.073 ±	0.0140
The central part of Tsavo East National Park	11 (4)	0.067 ±	0.0163	5 (1)	0.111 ±	0.0242	7 (5)	0.080 ±	0.0204
The northern part of Tsavo West National Park	10 (4)	0.053 ±	0.0171	6 (2)	0.089 ±	0.0221	9 (3)	0.039 ±	0.0180
Significant test among geographic areas		*** S-N			*S-N			*ns*	
Total areas	35 (16)	0.076 ±	0.0092	48 (17)	0.112 ±	0.0113	31 (18)	0.064 ±	0.0102

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.

2. Significant test among geographic areas: *** differed at $P < 0.05$, ** differed at $P < 0.10$, and * differed at $P < 0.20$.
S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).

3. Differences among seasons within each geographic area are shown in Figure 28.

Table 30. Sodium of elephant feces in Tsavo National Park from July 1990 to June 1993. (% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern part of Tsavo East National Park	14 (7)	0.106 ±	0.0144	37 (13)	0.136 ±	0.0088	15 (10)	0.073 ±	0.0140
The central part of Tsavo East National Park	11 (4)	0.067 ±	0.0163	5 (1)	0.111 ±	0.0242	7 (5)	0.080 ±	0.0204
The northern part of Tsavo West National Park	10 (4)	0.053 ±	0.0171	6 (2)	0.089 ±	0.0221	9 (3)	0.039 ±	0.0180
Significant test among geographic areas		*** S-N			*S-N			*ns*	
Total areas	35 (16)	0.076 ±	0.0092	48 (17)	0.112 ±	0.0113	31 (18)	0.064 ±	0.0102

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.

2. Significant test among geographic areas: *** differed at $P < 0.05$, ** differed at $P < 0.10$, and * differed at $P < 0.20$. S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).

3. Differences among seasons within each geographic area are shown in Figure 28.

season within the southern part of Tsavo East National Park ($P < 0.20$) and within the northern part of Tsavo West National Park ($P < 0.20$). Although no seasonal differences were detected within the central part of Tsavo East National Park ($P > 0.20$), similar seasonal patterns that were higher in the mid and late dry season appeared among all three geographic areas.

Sodium in the southern part of Tsavo East National Park was higher than in the northern part of Tsavo West National Park within the early dry season ($P < 0.05$) and within the mid and late dry seasons ($P < 0.20$). No differences within the wet season were detected ($P > 0.20$).

Seasonal patterns for one year (Figure 23c) tended to be similar to the patterns for three years in the southern part of Tsavo East National Park (Figure 28).

Magnesium

Figure 29 and Table 31 show the three-year seasonal patterns for magnesium in three geographic areas. The values in the wet season within the southern part of Tsavo East National Park were higher than in the early dry season ($P < 0.20$) and in the mid and late dry season ($P < 0.20$). No seasonal differences were observed within the central part of Tsavo East National Park ($P > 0.20$), or within the northern part of Tsavo West National Park

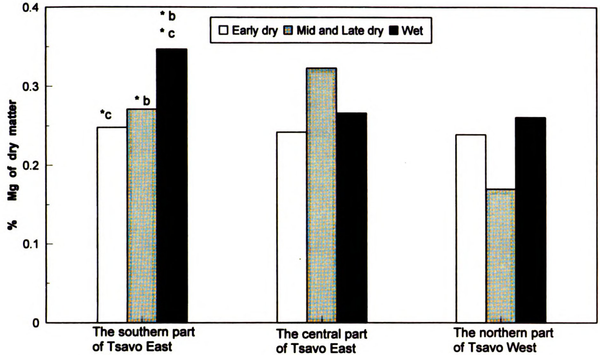


Figure 29. Seasonal differences for magnesium content as % dry weight of elephant feces in Tsavo National Park from July 1990 to June 1993.
Standard Error (S.E.) is described in Table 31.
* differed at $P < 0.20$. b: differed between the mid and late dry season and the wet season within a geographic area.
c: differed between the early dry season and the wet season within a geographic area.

Table 31. Magnesium of elephant feces in Tsavo National Park from July 1990 to June 1993. (% = g/100g dry matter)

	Early dry season			Mid and Late dry season			Wet season		
Geographic areas	N (n)	% Ave. ±	S.E.	N(n)	% Ave. ±	S.E.	N (n)	% Ave. ±	S.E.
The southern parts of Tsavo East National Park	14 (7)	0.248 ±	0.0264	37 (13)	0.271 ±	0.0162	15 (10)	0.347 ±	0.0255
The central parts of Tsavo East National Park	11 (4)	0.242 ±	0.0298	5 (1)	0.323 ±	0.0442	7 (5)	0.266 ±	0.0373
The northern parts of Tsavo West National Park	10 (4)	0.239 ±	0.0312	6 (2)	0.170 ±	0.0403	9 (3)	0.261 ±	0.0329
Significant test among geographic areas		*ns*			* S-N, ***C-N			*ns*	
Total areas	35 (16)	0.243 ±	0.0169	48 (17)	0.255 ±	0.0207	31 (18)	0.291 ±	0.0186

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples".
A mean value for each "paired sample" (or triple sample) was used for statistical analyses.
The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at $P > 0.20$, *** differed at $P < 0.05$, * differed at $P < 0.20$.
C-N = differences between the central parts of Tsavo East (C) and the northern parts of Tsavo West.
S-N = differences between the southern parts of Tsavo East (S) and the northern parts of Tsavo West (N).
3. Differences among seasons within each geographic area are shown in Figure 29.

(P > 0.20). Seasonal patterns seemed to depend on the geographic area.

Within the mid and late dry season, the values in the northern part of Tsavo West National Park were lower than in the southern part of Tsavo East National Park ($P < 0.20$) or in the central part of Tsavo East National Park ($P < 0.05$). There were no geographic differences within the early dry season, or within the wet season ($P > 0.20$).

Seasonal patterns for one year (Figure 23c) tended to be similar to the patterns for three years in the souther part of Tsavo East National Park (Figure 29).

Manganese

Figure 30 and Table 32 show the two-year seasonal patterns for manganese in three geographic areas. The values in the wet season were lower than in the dry season within the southern part of Tsavo East National Park ($P < 0.20$). Similar seasonal trends appeared among all geographic areas although manganese did not significantly differ between two seasons within the central part of Tsavo East National Park ($P > 0.20$), or within the northern part of Tsavo West National Park ($P > 0.20$).

No geographic differences were identified within the dry season ($P > 0.20$), or within the wet season ($P > 0.20$).

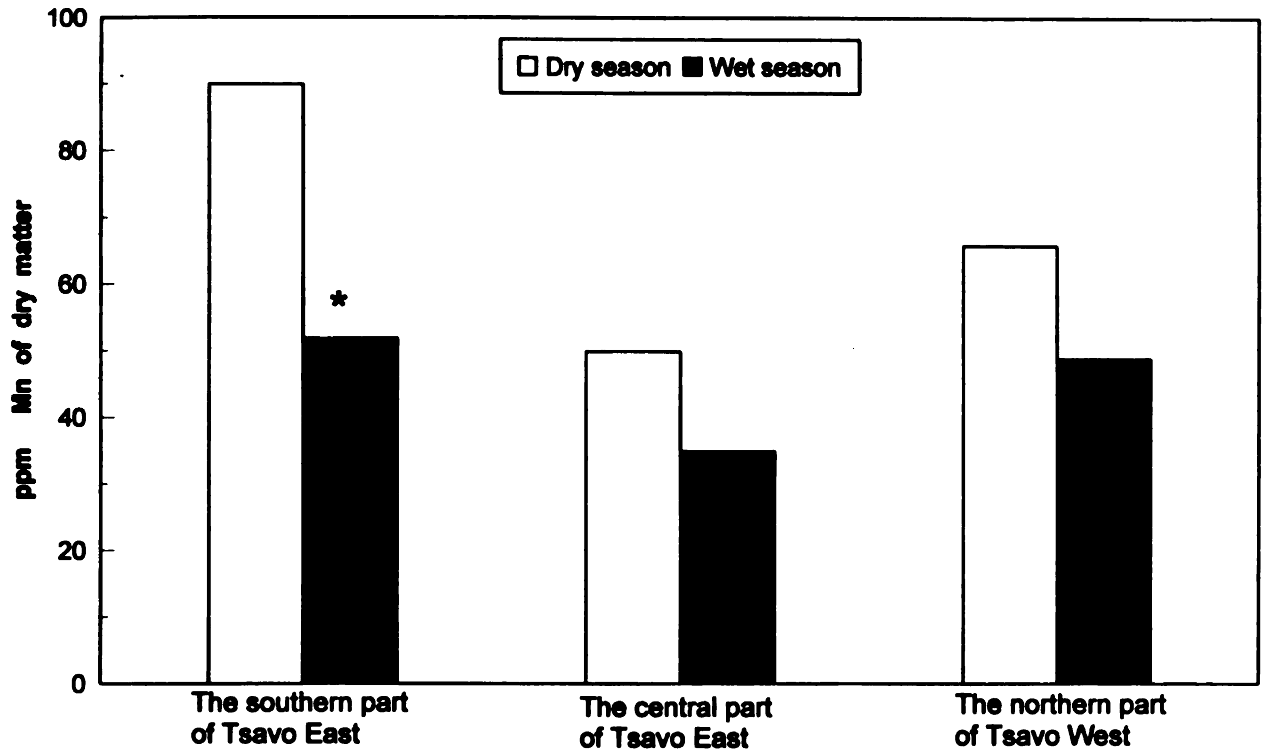


Figure 30. Seasonal differences for manganese content as % dry weight of elephant feces in Tsavo National Park from March 1991 to June 1993.
Standard Error (S.E.) is described in Table 32.
* differed at P < 0.20 between two seasons within a geographic area.

Table 32. Manganese of elephant feces in Tsavo National Park from March 1991 to June 1993. (ppm = ug/g dry matter)

	Dry season			Wet season		
	ppm			ppm		
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.
The southern part of Tsavo East National Park	24 (21)	90 ±	13.4	10 (10)	52 ±	20.7
The central part of Tsavo East National Park	7 (4)	50 ±	24.7	6 (5)	35 ±	26.7
The northern part of Tsavo West National Park	10 (6)	66 ±	20.7	5 (3)	49 ±	29.3
Significant test among geographic areas		*ns*			*ns*	
Total areas	41 (31)	69 ±	11.6	21 (18)	46 ±	14.9

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at P > 0.20.
3. Differences between seasons within each geographic area are shown in Figure 30.

Lignin

Figure 31 and Table 33 show the seasonal patterns for one year for lignin in three geographic areas. The values in the wet season were lower than in the dry season within the northern part of Tsavo West National Park ($P < 0.05$). Similar seasonal trends appeared between the southern part of Tsavo East National Park and the northern part of Tsavo West National Park.

Lignin in the southern part of Tsavo East National Park was lower than in the northern part of Tsavo West National Park within the dry season ($P < 0.05$), and within the wet season ($P < 0.20$). The values within the wet season in the southern part of Tsavo East National Park were also lower than in the central part of Tsavo East National Park ($P < 0.05$).

Cellulose

Figure 32 and Table 34 show the seasonal patterns for one year for cellulose in three geographic areas. The values in the wet season were lower than in the dry season within the southern part of Tsavo East National Park ($P < 0.05$) and similarly within the northern part of Tsavo West National Park ($P < 0.20$). Similar seasonal trends appeared among all three geographic areas.

Within the dry season, cellulose in the southern part of Tsavo East National Park was higher than in the

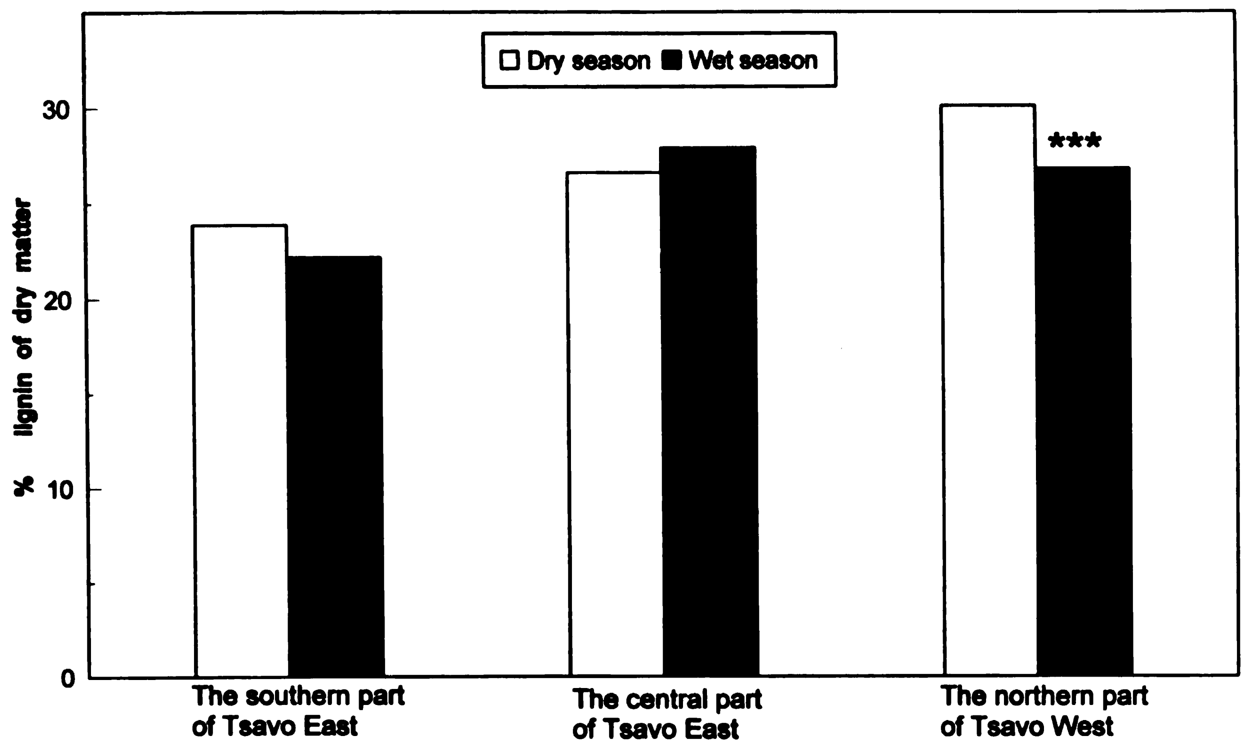


Figure 31. Seasonal differences for lignin content as % dry weight of elephant feces in Tsavo National Park from July 1992 to June 1993. Standard Error (S.E.) is described in Table 33.
*** differed at $P < 0.05$ between two seasons within a geographic area.

Table 33. Lignin of elephant feces in Tsavo National Park from July 1992 to June 1993.
(% = g/100g dry matter)

	Dry season			Wet season		
		%			%	
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.
The southern part of Tasvo East National Park	17 (17)	23.9 ±	0.80	10 (10)	22.3 ±	1.05
The central part of Tsavo East National Park	4 (4)	26.6 ±	1.66	5 (5)	27.9 ±	1.48
The northern part of Tsavo West National Park	6 (6)	30.1 ±	1.35	3 (3)	26.8 ±	1.91
Significant test among geographic areas		*** S-N			*** S-C, * S-N	
Total areas	27 (27)	26.9 ±	0.76	18 (18)	25.7 ±	0.88

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: *** differed at $P < 0.05$, * differed at $P < 0.20$.
S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).
3. Differences between seasons within each geographic area are shown in Figure 31.
4. The values for the southern part of Tsavo East National Park are the same as the ones in lignin on Table 25.

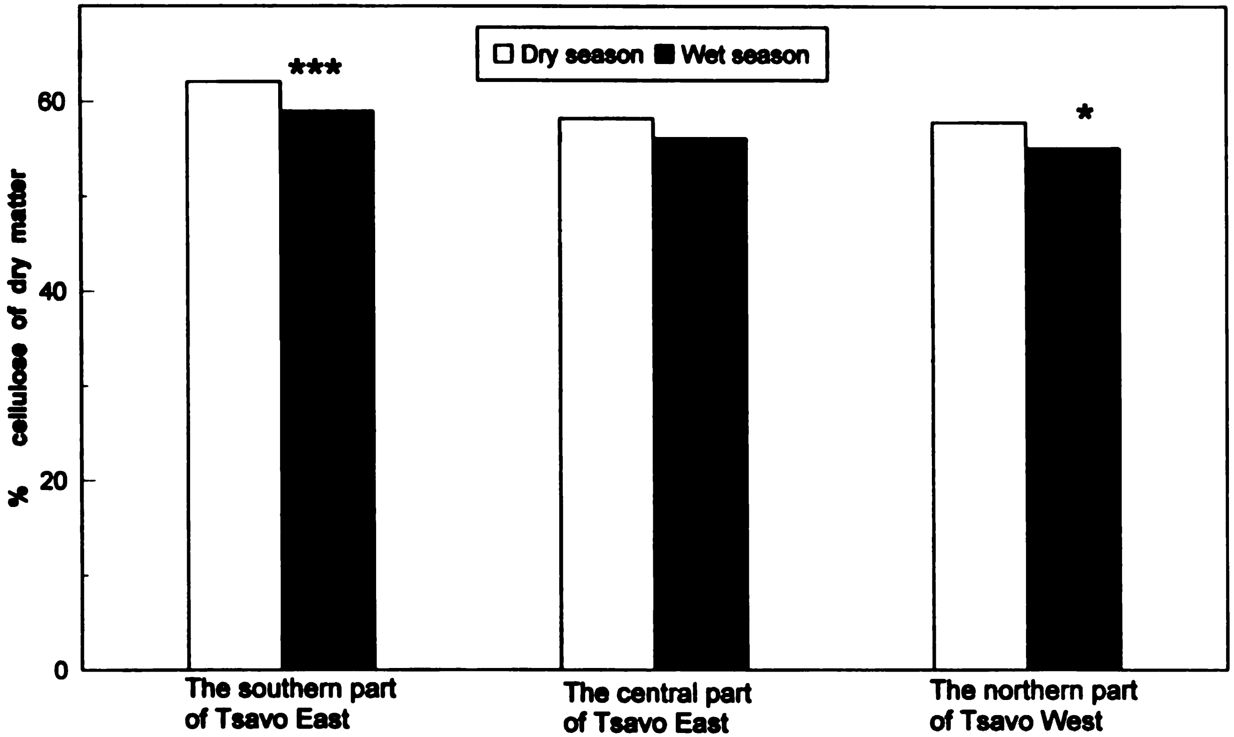


Figure 32. Seasonal differences for cellulose content as % dry weight of elephant feces in Tsavo National Park from July 1992 to June 1993. Standard Error (S.E.) is described in Table 34.
*** differed at $P < 0.05$, * differed at $P < 0.20$ between two seasons within each geographic area.

Table 34. Cellulose of elephant feces in Tsavo National Park from July 1992 to June 1993. (% = g/100g dry matter)

	Dry season			Wet season		
	%			%		
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.
The southern part of Tsavo East National Park	17 (17)	62.1 ±	0.83	10 (10)	59.0 ±	1.05
The central part of Tsavo East National Park	4 (4)	58.2 ±	1.70	5 (5)	56.1 ±	1.52
The northern part of Tsavo West National Park	6 (6)	57.8 ±	1.39	3 (3)	55.1 ±	1.97
Significant test among geographic areas	** S-C, * S-N			*ns*		
Total areas	27 (27)	59.4 ±	0.78	18 (18)	56.7 ±	0.90

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.

2. Significant test among geographic areas: ns= no differences at $P > 0.20$ and ** differed at $P < 0.10$, * differed at $P < 0.20$.
   S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
   S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).
3. Differences between seasons within each geographic area are shown in Figure 32.
4. The values for the southern part of Tsavo East National Park are the same as the ones in cellulose on Table 25.

Table 34. Cellulose of elephant feces in Tsavo National Park from July 1992 to June 1993. (% = g/100g dry matter)

	Dry season			Wet season		
		%			%	
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.
The southern part of Tsavo East National Park	17 (17)	62.1 ±	0.83	10 (10)	59.0 ±	1.05
The central part of Tsavo East National Park	4 (4)	58.2 ±	1.70	5 (5)	56.1 ±	1.52
The northern part of Tsavo West National Park	6 (6)	57.8 ±	1.39	3 (3)	55.1 ±	1.97
Significant test among geographic areas		** S-C, * S-N			*ns*	
Total areas	27 (27)	59.4 ±	0.78	18 (18)	56.7 ±	0.90

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.

2. Significant test among geographic areas: ns= no differences at $P > 0.20$ and ** differed at $P < 0.10$, * differed at $P < 0.20$.
S-C = differences between the southern part (S) and the central part (C) of Tsavo East.
S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).

3. Differences between seasons within each geographic area are shown in Figure 32.

4. The values for the southern part of Tsavo East National Park are the same as the ones in cellulose on Table 25.

central part of Tsavo East National Park ($P < 0.10$) and higher than in the northern part of Tsavo West National Park ($P < 0.20$). Within the wet season, similar patterns tended to appear among all three geographic areas although no significant differences were observed ($P > 0.20$).

Hemicellulose

Figure 33 and Table 35 show the seasonal patterns for hemicellulose in three geographic areas. No seasonal differences were detected within each geographic area ($P > 0.20$).

Within the dry season, the values in the southern part of Tsavo East National Park were higher than in the northern part of Tsavo West National Park ($P < 0.20$). Within the wet season, no geographic differences were observed ($P > 0.20$).

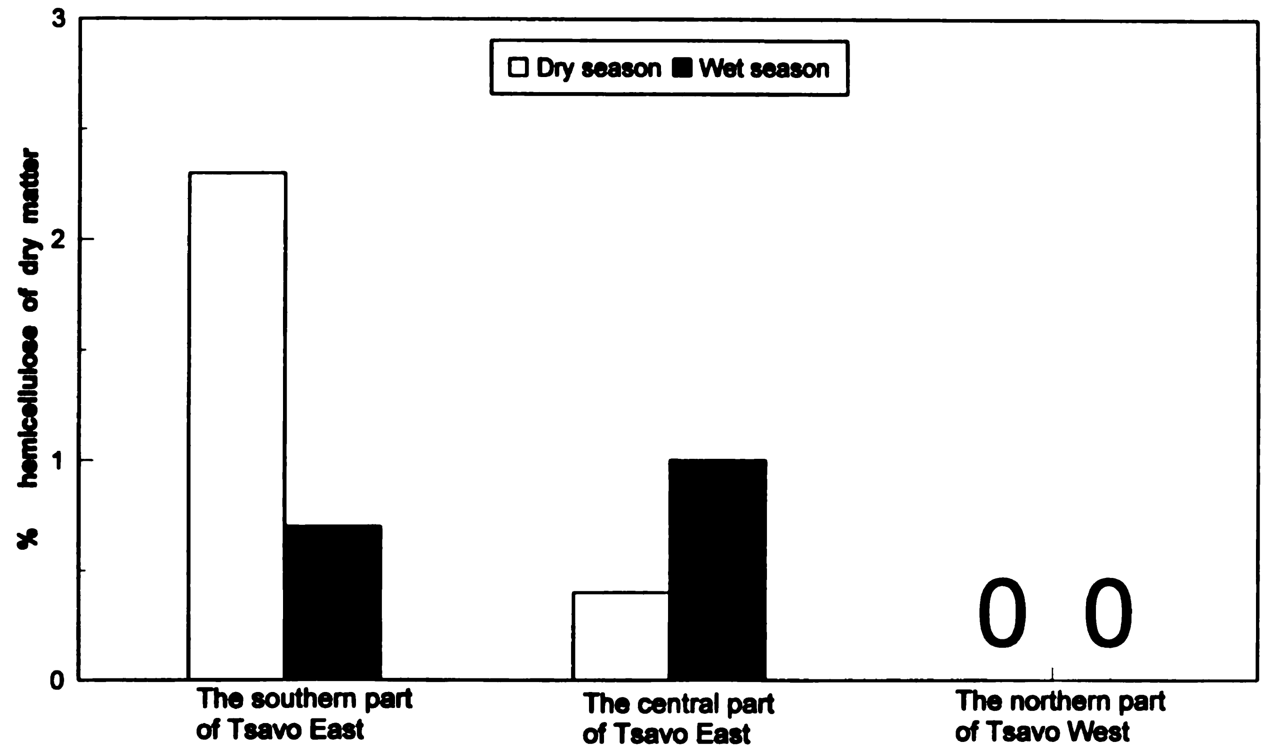


Figure 33. Seasonal differences for hemicellulose content as % dry weight of elephant feces in Tsavo National Park from July 1992 to June 1993. Standard Error (S.E.) is described in Table 35.
"0" in the northern part of Tsavo West denote the chemical values are zero.

Table 35. *Hemicellulose of elephant feces in Tsavo National Park from July 1992 to June 1993.*
(% = g/100g dry matter)

	Dry season			Wet season		
		%			%	
Geographic areas	N (n)	Ave. ±	S.E.	N(n)	Ave. ±	S.E.
The southern part of Tsavo East National Park	17 (17)	2.3 ±	0.54	10 (10)	0.7 ±	0.72
The central part of Tsavo East National Park	4 (4)	0.4 ±	1.12	5 (5)	1.0 ±	1.00
The northern part of Tsavo West National Park	6 (6)	0.0 ±	0.92	3 (3)	0.0 ±	1.29
Significant test among geographic areas		* S-N			*ns*	
Total areas	27 (27)	0.9 ±	0.52	18 (18)	0.6 ±	0.59

Notes; 1. N= The number of samples analyzed for statistical analyses. n= The number of "paired (triple) samples". A mean value for each "paired sample" (or triple sample) was used for statistical analyses. The number of samples for nutrient analyses was N+n.
2. Significant test among geographic areas: ns= no differences at $P > 0.20$ and * differed at $P < 0.20$. S-N = differences between the southern part of Tsavo East (S) and the northern part of Tsavo West (N).
3. Differences between seasons within each geographic area are shown in Figure 33.
4. The values for the southern part of Tsavo East National Park are the same as the ones in hemicellulose on Table25.

DISCUSSION

Feeding patterns of elephants

Elephants in Tsavo National Park spent 48-63% of daylight observation periods in feeding activities (Tables 5 and 6), comparable to that described for other regions (Guy 1976, Wyatt and Eltringham 1974, Kalemera 1987, Barns 1983, Kabigumila 1993a) although previous studies were determined on a daily base. The importance of grasses and herbs for their major diet was suggested in Tsavo East National Park (Bax and Sheldrick 1963), and in other areas (Buss 1961, Tchamba and Seme 1993). The results for grazing in the southern part of Tsavo East National Park (Tables 7, 8 and 9) were consistent with the earlier studies that there was more grazing than browsing throughout the year. Trees and shrubs were argued as important food items for elephants in various habitats (Field 1971, Guy 1976, Kabigumila 1993b, White et al. 1993, Höft and Höft 1995). The results shown for Tsavo West National Park (Table 7) seemed to be consistent with previous speculation for trees and shrubs in other regions. Laws (1970) suggested that an increasing proportion of grass in the diet could be correlated with an increasing degree of habitat change from bush or woodland to grassland. Dissimilar vegetation types within a habitat could influence the differences of elephant feeding patterns between Tsavo East and West.

Seasonal differences of time spent feeding (Tables 5, 6, 7 and 8) seemed to be inconsistent with increasing browsing in the dry season rather than increasing grazing in the wet season previously found for Tsavo East National Park (Bax and Sheldrick 1963) and other areas (Buss 1961, Field 1971, Wayatt and Eltringham 1974, Williamson 1975, Guy 1976, Burns 1982, Kabigurmila 1993a). The characteristic for seasonal feeding patterns in the southern part of Tsavo East National Park (Tables 8 and 9) might be argued as seasonal changes of grazing rather than relatively constant time for browsing. Seasonal patterns might be different in Tsavo West National Park and in the northern part of Tsavo East National Park that were not investigated for this study.

Seasonal changes in time spent feeding could be influenced by combinations of several factors that include food intake regulation, influences by non-feeding activities such as walking or standing, movement to surrounding areas, age classes or sex differences and other related factors. Lower availability of grasses and herbs, withered in the dry season, might cause more time spent grazing and thus less time for browsing than in the wet season. Relatively constant time spent browsing may relate to uniform availability of woody browse and evergreen species. Food quality was previously thought to be the reason for seasonal changes for feeding, this occurred to acquire higher protein in grasses in the wet season (Bax and Sheldrick 1963, Field 1971). Lower nutrient quality in grasses and herbs might force elephants to spend more time feeding in the dry season. Palatability also could be one of the determining factors for time spent feeding. Elephants might spend extra time eating more palatable grasses and herbs in the early dry season or the mid dry season than they were likely to spend eating less palatable trees and shrubs. Some evergreen trees and shrubs were unlikely to be eaten in the wet season; however, slightly more time was spent browsing those species in the dry season.

Heat stress might result in less time spent feeding because of a need to seek shade (expressed as standing for this study). Barnes (1983) inferred that time spent feeding might depend on energy costs for metabolic needs related to heat stress as well as food quality. Roehrs et al. (1989) discussed seasonal changes of digestibility caused by temperature differences in captive conditions.

Heat stress might influence daily feeding activities, and consequently could influence seasonal variations.

Other activities related to seasonal changes seemed to reduce feeding time. During the wet season, elephants (migratory groups) in the southern part of Tsavo East National Park start to migrate to the northern part of Tsavo East National Park (Figure 7). More time spent walking in the early wet season could be related to an increase of movement in residential groups and migration for migratory groups, and thus result in less time available for feeding activities. Standing and walking could be related to migration for a long distance and to movement to expand the residential areas.

Time spent drinking in dry seasons was higher, particularly in mid dry seasons (Tables 6 and 9) and might explain less time spent grazing and browsing. Assumption for time spent drinking is that there is a positive relation between the amount for consumption of water and time spent drinking throughout the year. After the early dry season, the number of water sources decreased, and the observation of elephants drinking tended to increase. This may be the reason more time spent drinking was recorded in the mid dry season. However, in the late dry season less time drinking was recorded as elephants searched for water in the surrounding areas of Tsavo

National Park because the majority of water sources in the Parks were dried and the permanent water sources were limited. Some of the permanent water sources in the National Park such as the Galana River might not be preferable habitat for elephants during the study period, possibly because of heavy poaching pressure.

Seasonal trend for females (Tables 12 and 13) could be related to reproduction status and caring for infants, although only 8% of the samples were infants (Appendix 3), and the stress of their social status as leaders in the dry season. Elephant breeding season in Tsavo National Park seemed to be throughout the year. Seasonal trends for subadults and infants (Table 11) could be related to growth, physiological development and learning feeding behavior in their society.

Nutritional qualities of plants

The mid and late dry season might be the most difficult seasons for nutrient acquisition for a majority of wildlife, as well as elephants, while the wet season and the early dry season could be better seasons to meet nutrient requirements in Tsavo National Park. Rainfall is the significant factor in altering the nutritional quality and quantity of seasonal vegetation through moisture inputs. Available moisture produces higher nutrient concentration in grass-herb vegetation and also produces a higher digestibility in the early wet season compared to the mid and late dry season. Trees and shrubs with deeper root systems appear to fluctuate less with surface moisture (Boutton et al. 1988a, 1988b).

Higher concentrations of moisture in grasses in the early wet season than in the dry season were reported in Tsavo National Park (Wijngaarden 1985). Seasonal differences in moisture intake with vegetation (Figure 9) may influence the water intake requirements of elephants. In addition to the reduced water sources in the mid and late dry season in Tsavo area, the reason why elephants searched for water in the surrounding areas of the National Park may be compounded by the reduced moisture in grasses in grasslands, bushlands or woodlands, the decline of moisture due to a higher proportion of deciduous trees for elephant foods in the habitat, and less proportion of forest as vegetation cover for elephant foods that may maintain constant moisture throughout the year. Herbs are likely to be better moisture sources for elephants in the wet season and the early dry season (Figure 8b). Elephants frequently ate *Ipomea mombassana*, the non-leguminous creeper containing the highest moisture among the eleven species that could help meet their water requirement. *Cynodon dactylon*, a grass species, in forest vegetation cover (Table 14) had constant moisture values as did shrubs in forest such as Capparis tomentosa (Table 14) that were frequently eaten during the wet and early dry season, possibly because of supplying moisture needs. At the same time, elephants did not seem to select higher moisture content species such as Salvadora persica, Capparis tomentosa and Combretum aculeatum (Table 14) in the mid or late dry season, possibly because moisture was not the only requirement related to those species. Or seasonal changes might occur because of a decline in palatability due to tannins or toxic compounds. Lower quantity of tannins influenced the intake of the preferred species by giraffes (Giraffa camelopardalis) in Krugar National Park, South Africa, and seasonal changes in food availability were speculated in relation to quantity of tannins in foliage (Furstenburg and Van Hoven, 1994). However, impact of tannins on seasonal palatability on elephant food was not yet found.

The crude protein content of all vegetation (Table 24) was over the 5% recommended as minimum values for the food supply of ruminants (Agric. Res. Council 1965: *In* Boutton et al. 1988b). Although the elephant is monogastric and fermentation occurs in the caecum and colon (Van Hoven et al. 1981, Clemens and Maloiy 1982), Tsavo elephants appear to meet their minimum protein requirements throughout the year. Bax and Sheldrick (1963) reported herbs to have a higher protein content than grasses among elephant foods in Tsavo National Park during the wet season, relatively lower values in the grasses in the dry season and higher constant protein in legumes, some herbs and leaves of trees and shrubs throughout the year. Williamson (1975) reported a similar trend for elephant foods in Wankie National Park in Zimbabwe. A different trend shown for this study (Figure 22) was that the protein in some grasses such as <u>Cynodon</u> sp. (Figure 22a) in the wet season seemed to be higher than in herbs. The values for <u>Cynodon</u> <u>dactylon</u> (Figure 22a) in the wet season were higher than the range previously reported (Dougall et al. 1964, Field 1971, Williamson 1975) while the values in the dry season were within the range. Lower protein in grasses in the dry season may cause elephants to spend more time grazing to meet their protein or energy needs. Thus seasonal differences for time spent grazing more than browsing can be argued on the basis of the qualitative differences for protein.

Seasonal trends for potassium and magnesium were similar to each other in seven species (Figure 12 and 15) and could be related to seasonal physiological requirements, such as enzyme activity for elephants.

Possible reasons for higher sodium in plants eaten in the mid or late dry seasons are that the southern part of Tsavo East National Park could have higher environmental sodium in the mid and late dry season, or elephants could select plants containing higher sodium as their foods despite lower sodium availability in their habitat in the mid or late dry season than in the wet season, or this trend might only be specific for this study period due to a relatively prolonged wet season (Figure 4).

The southern part of Tsavo East National Park located within 160km from the coast of the Indian Ocean, continue a habitat of plains such as grasslands, bushlands or woodlands without geological interruption by mountains or highlands. Similar situations for sodium may be found in coastal and desert areas referred to high-sodium areas. The depletion of water in the area in the mid and late dry season might affect sodium concentrations of plants for elephants. Higher sodium in soils from waterhole areas was reported in the dry season, south of the Voi River in Tsavo East National Park (Ayeni 1977). Elephants tended to feed intensively from areas close to water sources. Sodium in natural water sources in the dry season in the southern part of Tsavo East National Park tended to be relatively higher than in the wet season (Ayeni 1977). Wijngaarden (1987) concluded that no relationship existed between the mineral content of the soil and vegetation structure and grass cover in the Tsavo areas. However, his conclusion seemed to be limited to the wet season, and the relationships might be different in the dry season particularly in the southern part of Tsavo East National Park.

Higher concentration of sodium in Cynodon dactylon could be related to differences in the vegetation cover type (Table 18). Forest in Tsavo might be good reservoirs for sodium in plants eaten by elephants while elephants in Tsavo seemed to select food for sodium from grasses, herbs and shrubs in various vegetation cover types during the dry season. Elephants might depend on forest because vegetative components might meet sodium requirement in the dry season, although there is a lower proportion of forest vegetation cover in Tsavo National Park. Cynodon dactylon in forest seemed to be one species selected by elephants in the dry season although shrubs and trees dominated in the riverine forest of the Voi River. Stems of shrubs contained higher sodium than leaves in Combretum aculeatum and Salvadora persica in the dry season (Table 18). This may have been one of the most important reasons for debarking of tress by elephants in Tsavo National Park during the early 1960's.

Elephant debarking in search of calcium in Tsavo National Park was suggested by Bax and Sheldrick (1963) particularly in the drought of 1961 when there was very little green vegetation available. It is difficult to compare to the conditions for this study since there was no drought during this period. However, the search for calcium might not be the reason for debarking because leaves of evergreen species had usually more calcium content than stems (Salvadora persica and Capparis tomentosa: Table 18). Selectively forage on leaves in Salvadora persica, for example, had the highest calcium in the mid dry season (no data available for the late dry season: Table 18). Elephants generally eat leaves and twigs together of this species, although the proportion of amounts for leaves and twigs are not determined. Bax and Sheldrick (1963) reported leaves of Salvadora persica, an evergreen species were eaten during the drought of 1961, while this species appeared to be untouched during the normal dry season for their study period. Calcium might be obtained from leaves of Salvadora persica, and thus was not strongly related to debarking. Debarking related to calcium increase in plant species age is further consideration although this study was not conducted to find differences of calcium depending on plant species age.

The heterogeneous mixture of minerals combined as crude ash did not reveal that some minerals might be higher and some lower in the wet season and some might be the opposite in the dry season, thus revealing no seasonal differences.

Manganese could be one of the important elements for elephants since bone formation is one of the important functions for manganese (Maynard et al. 1979, Robbins 1993). Premna hostii is the species that had the highest manganese concentration among the eleven species investigated (Figure 16c). Premna hostii tended to be frequently eaten in the early and mid dry season, more so than in the other seasons. Dougall et al. (1964) reported that some Kenya browse species had high values of manganese. Some other plants during this study period also had higher values than Premna hostii (Appendix 15). Elephants might meet their manganese requirements in the early and mid dry seasons by eating such plants. Ayeni (1977) inferred that manganese may be needed by animals more than sodium, particularly during the dry season in Tsavo East National Park.

Patterns appearing within the wet season between plants eaten by elephants and plants collected from elephant-absent areas, due to migration, could be influenced by an unusually long rain during this study period. Elephants might avoid eating plants containing extreme concentrations (too high or too low), and consequently obtain optimum nutritional needs from the environment. Additionally, physiological seasonal requirements may change, depending on seasonal changes. Lower sodium observed in the wet season where elephants were absent (Figure 13) might be too low to maintain sodium requirements for elephants and thus explain their absence. Although sufficient sodium for nutrient needs might be available from water or soils, excess intake of water or soils to meet only sodium requirements would be an unfeasible supplement for elephants. Robbins (1993) discussed animal distribution restricted by limited availability of sodium in some areas. Weir (1972) found a close relationship between the sodium content of water for drinking and elephant distribution in Zimbabwe, but Ayeni (1977) denied this for Tsavo animals and insisted more distributing relations to water rather than sodium in the dry season. However, limited availability of sodium in the wet season in the southern part of Tsavo East National Park may influence elephant distribution, and it might be argued that Tsavo elephant migration could result from the balance of sodium availability between the southern part and the northern part of Tsavo East National Park.

However, sodium might not be the only nutrient influencing the migration mechanism.

Hemicellulose in plants collected from the area where elephants were absent due to migration in the wet season (Figure 20) might be too high to be digested. Optimally, elephants might desire the plants as their food, but possible seasonal changes in digestibility might reduce the food palatability. Higher manganese (Figure 16) in some shrub and herb species that might otherwise be preferable, or more selected as elephant foods, might have negative effects (e.g. toxins) and could introduce more risk for infants since their browsing and grazing time seemed to increase in the wet season (Table 11). Some protective mechanisms for nutritional acquisition for young animals might also involve avoidance of some nutrient high areas, and thus stimulate migration.

Trends of chemical composition in feces

Seasonal differences in the chemical composition of elephant feces in Tsavo National Park is related to the quality of plants ingested, physiological seasonal effects, particularly in digestibility, chemicals obtained by geophosia (eating soil) or acquired from soils attached to vegetation eaten by elephants, chemical composition of drinking water, insect activities, chemical complexity reflected within chemicals and a combination of other related factors.

Relationships between diet quality and fecal chemicals were found in free-ranging ruminants for potassium and calcium, and for lignin in a monogastric animal (horse) (Putman and Hemmings 1986). Although the monogastric digestive tract of the elephant resembles that of the horse (Clemens and Maloiy 1983, Roehs et al. 1989), nutrient content of ingesta could be a major influence on the chemical composition of elephant feces. The quantity of each chemical in plants ingested would seem to influence the quantitative chemical composition of the elephant feces. However, under water limited conditions in the mid and late dry season, the quality and quantity of nutrients in plants could differ compared to the early dry season and the wet season as discussed earlier. Although supplemental ingestion from non-plant dietary sources (e.g. water) seemed to increase in the mid and late dry season, seasonal differences in feces were likely to reflect plants eaten by elephants with the possible exception of minerals such as sodium or manganese obtained from non-plant dietary sources.

Similar patterns between single year data (Figure 23) and data collected over a few years for moisture (Figure 24), crude ash (Figure 25), calcium (Figure 26), potassium

(Figure 27), sodium (Figure 28), magnesium (Figure 29) and manganese (Figure 30) might be obtained by constant nutritional ingesta within seasons with similar physiological changes among seasons. Thus, a small number of fecal samples might be sufficient and useful to indicate elephant nutritional dietary quality through fecal chemical composition as opposed to collecting multiple samples of various plant species.

Seasonal contrary patterns for feces between sodium (Figures 23c and 28) and potassium (Figures 23b and 27) in the mid and late dry season might occur in response to seasonal depletion of water, seasonally chemical differences in foods related to moisture, and combinations of chemical complexity. Dehydrated body conditions could influence chemical composition of feces in the mid and late dry season. For example, sodium absorption in the intestinal tract occurs concurrent with water absorption (Robbins 1993). Although the major cations, sodium (Na) and potassium (K) generally respond in opposition to one another, the elephant demonstrated little net flux of either sodium or potassium ions (Clemens and Maloiy 1983). Water balance and Na/K balance in osmo-regulation could be unbalanced during the mid and late dry season, and consequently higher sodium and lower potassium might be excreted.

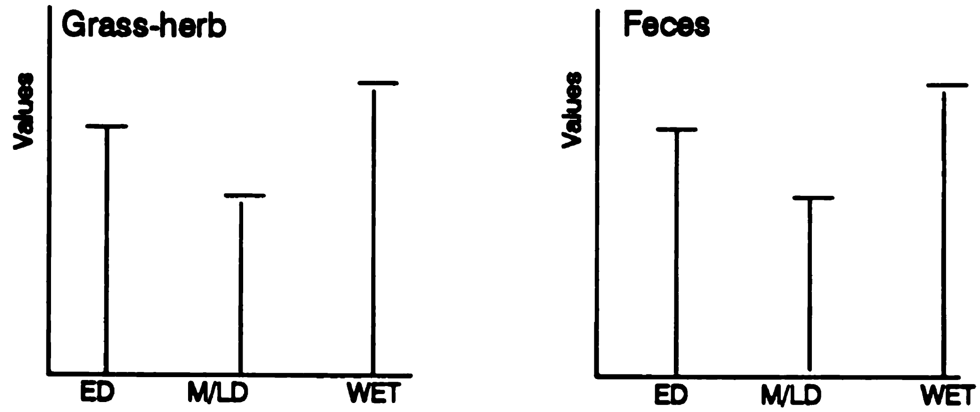
The elephant does not seem to be a good digester of plants and leaves, seeds, stems or bark as these were frequently observed in feces. The components in feces play ecological roles in the spread of plants from seeds (Liebeman and Liebeman 1987, Brahmachary 1980) and in providing food activities for termites (Coe 1977), dung beetles and butterflies. Elephants appeared to digest cellulose more effectively than hemicellulose as compared with browsers such as black rhinos (Clemens and Maloiy 1983). Higher fecal manganese (Figure 23-d) and hemicellulose (Figure 23-e) in the mid and late dry season might reflect the increase of food eaten containing higher values of manganese (e.g. *Premna hostii*) and hemicellulose content and possibly relate to a lower digestibility in the mid and late dry season.

Geophosia was reported in elephants in other regions (Weir 1972, Ruggiero and Fay 1994), but no intentional geophosia was observed during this study period in Tsavo National Park. Higher sodium and magnesium content in water and soils in waterholes or the surrounding areas in the late dry season (Ayeni 1977) could account for higher sodium in feces, and possibly for magnesium in the dry season. For Tsavo elephants, ingesting soils attached to vegetation rather than geophosia might be good for mineral supplementation.

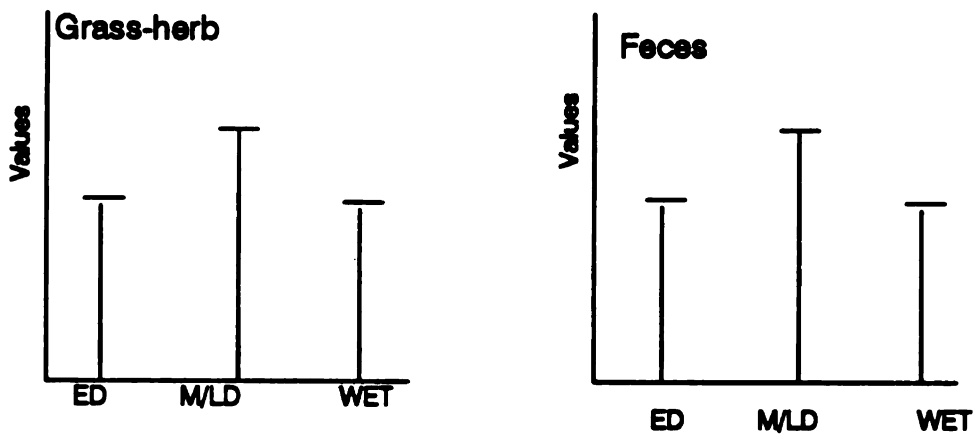
Geographic differences in feces shown in Figures 24-33 could be mainly due to vegetative differences in ingesta and physiological factors that might be reflected by geographic distribution and seasonal differences in chemical composition of elephant forage. Geographic differences in feces strongly appeared within the mid and late dry season (Tables 26, 28, 30 and 31) because possible dietary sources could vary with geographic areas. Compared to the mid and late dry seasons, there appeared to be less geographic differences in feces in the early dry season (Tables 28 and 30) and in the wet season (Tables 26 and 29). This could be possibly related to the uniform nutritional quantity obtained from vegetation and similar digestibility among geographic areas within the early dry and the wet seasons.

Nutritional relations

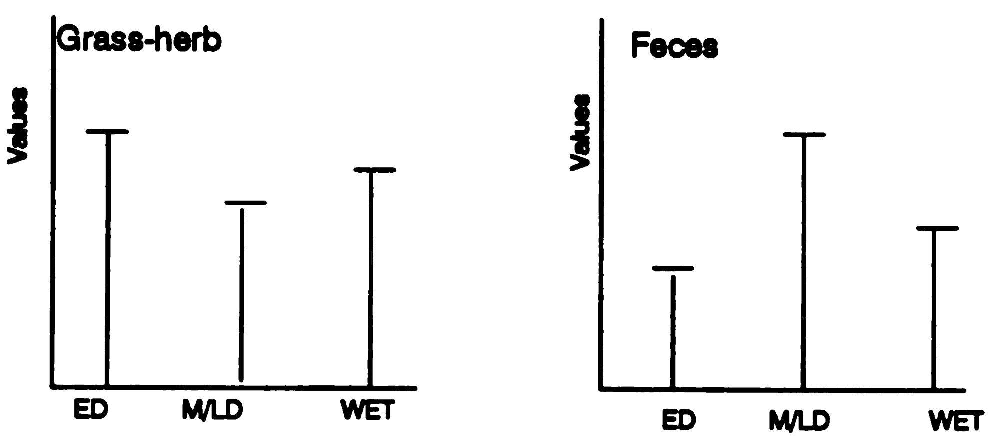
Mean values for grass-herb vegetation (six species) grazed by elephants for three seasonal categories (the early dry, the mid and late dry, and the wet season) were compared to seasonal patterns of chemical composition of feces (Figure 34). Grazing, the main feeding activity, was thought to have a main influence on seasonal fecal patterns. Seasonal patterns between grass-herb vegetation eaten and feces coincided for moisture, crude ash,



a. Moisture, crude ash, calcium and potassium.



b. Sodium and cellulose.



c. Hemicellulose and manganese

Figure 34. Relations of seasonal patterns for chemical composition between grass-herb vegetation grazed by elephants and elephant feces from June 1992 to July 1993 in the southern part of Tsavo East National Park. ED=Early dry season, M/LD=Mid and late dry season, Wet=Wet season.

calcium, potassium (Figure 34a), sodium and cellulose (Figure 34b). Manganese and hemicellulose (Figure 34c) were inversely related between plants and feces. Seasonal relations between grass herb-vegetation grazed by elephants and feces for lignin and magnesium were not observed. Nutrients in shrubs seemed to be more constant and were not consistent with patterns for feces with the exception of sodium. Sodium for shrubs in the dry season showed a pattern similar to that in Figure 34b. Although the seasonal patterns of the chemical composition of feces largely reflected that of the plants eaten, at the same time, coincidental patterns for some chemicals seemed to represent food intake and food quality as related to the time spent for grazing. Further investigation would be required to determine the more subtle relations between the chemical composition of feces as influenced by seasonal nutrition changes in Tsavo elephant diets.

CONCLUSIONS

Elephants spent more time grazing and drinking in the dry season than in the wet season and relatively constant time browsing throughout dry and wet seasons in the southern part of Tsavo East National Park. Elephants in Tsavo West tended to browse more than in Tsavo East National Park. Since water is a limiting factor for elephants and Tsavo National Park is a water limited region particularly in the mid and late dry season, seasonal moisture and water availability was likely to influence nutritional conditions for elephants as reflected by seasonal differences in feeding patterns, plants eaten by elephants and elephant feces.

Seasonal feeding patterns of elephants seemed to be influenced by seasonal changes of nutritional quality, food availability, palatability, other activities such as walking for migration in the early wet season, physiological regulations, age or sex differences, human pressure and other related factors. Additionally, geographic differences or dissimilar vegetation types within a habitat also could be considered factors producing the seasonal feeding patterns.

Nutrients in plants eaten by elephants tended to have seasonal differences. Lowest concentrations of nutrients in the mid or late dry season appeared strongly for moisture, manganese and hemicellulose, and weakly for crude protein, potassium, magnesium and cellulose. Within grass-herb vegetation, crude ash, calcium and lignin also showed the same patterns. Sodium showed highest concentrations in the mid or late dry season and was a trend contrary to a majority of nutrients. Trends that were similar to sodium appeared weakly for cellulose. Sodium in shrub vegetation also appeared to be highest in the mid or the late dry season. Higher sodium concentration in plants of the southern part of Tsavo East National Park in the mid and late dry season in elephant foods might relate to geographic location, climatic conditions during the study period, or elephant requirements influencing selection of plants eaten.

Elephants might migrate to select optimum moisture, sodium, manganese or hemicellulose concentrations. Thus elephants might find the area of optimal nutritional quality in the northern part of Tsavo East National Park in the wet season. As previously described elsewhere for mammals, sodium in Tsavo might regulate elephant distribution. While sodium availability in Tsavo might influence elephant migration, water and moisture availability are still major considerations for their movement or migration.

Seasonal patterns appeared in the chemical composition of elephant feces. Lower values in the mid and late dry season, compared to the wet season and the early dry season, appeared for moisture, crude ash, calcium and potassium for one year collections in the southern part of Tsavo East National Park. Contrarily, higher values in the mid and late dry season appeared for sodium, manganese, cellulose and hemicellulose for the same collection period. The seasonal patterns for the one-year collections tended to be similar to patterns for collections over three or four years. Differences in chemical composition of elephant feces seemed to be introduced by seasonal changes in nutritional quality of plants ingested, physiological seasonal effects, seasonal differences in soil ingested with plants and drinking water, chemical complexity related to seasons and other related factors. Geographic differences seemed to appear strongly in the mid and late dry season possibly because of higher variations of ingesta caused by water limited conditions.

Seasonal patterns of some chemicals in feces seemed related to patterns of the chemical composition of the grass-herb vegetation grazed by elephants. Some chemicals in feces in Tsavo area could be subsequently useful to determine seasonal nutritional variations in food quality.

Plant and habitat management for elephant nutrition should focus on the mid and late dry season when water and moisture are limited. Vegetation differences in nutritional quality should be investigated, and related to seasonal differences and geographic differences within ecosystems. Protection against poaching and hunting pressure should be considered to ensure access to appropriate habitat for elephants. Another consideration is minimizing human-elephant conflicts through managing elephant seasonal movement patterns related to food or nutritional requirements and by avoiding the creation of inadequate habitat for elephants. Community and education programs are necessary to complement elephant management focused on nutrition because human-elephant conflicts are also likely to reflect elephant seasonal movement patterns related to food or nutrition requirements.

RECOMMENDATIONS

Habitat management for elephant nutrition should be focused on the mid and late dry season since water is limited and moisture in foods for elephants is low. Managing water supplies in appropriate areas is most important while maintaining vegetation having high moisture content in the mid and late dry season should be considered.

Creating waterholes to provide water for elephants inside the National Park is essential to avoid elephant-human conflict in the mid and late dry season. During the study period, the riverine forest along the Voi River, a seasonal river in the southern part of Tsavo East National Park seemed to be the most important habitat for elephants in the mid or late dry season. Waterholes in bushland, grassland or wooded-grassland next to the riverine forest along the Voi River would be appropriate locations if supplying water is feasible during the mid and late dry season.

The habitat along the Galana River, a permanent water source in the central part of Tsavo East National Park is expected to recover for elephant habitat. Elephant habitat use in the area along the Voi River during the study period seemed to relate to low poaching activity while avoidance of habitat use seemed to occur in the area along the Galana River under previously higher poaching activity. Assuming low poaching activity continues in the future, waterholes could be located in bushland or wooded-grassland next to the riverine forest along the Galana River. Supplying water to waterholes created is more feasible in this habitat, compared to the habitat along the Voi River, because the Galana River is a permanent river. However, it is also considered that the water supplies along the Galana River might produce easily accessible areas for poachers in the mid and late dry season since elephant herds tend to concentrate on the waterhole areas. Presently low poaching activity supported by the international ban for ivory trade decided by the CITES seems to continue. To sustain low poaching activity in Tsavo for elephant habitat, the international ban for ivory trade should continue.

Location of waterholes in the northern part of Tsavo East National Park is presently not recommended because a few years are required for recovery of elephant habitat after stable security against poachers is established.

The importance of tropical forests has been described earlier (Lugo and Brown 1991). To protect riverine forest in Tsavo also should be emphasized. Riverine forest could be one of the important habitat types for elephants to have overall optimal habitat. Further nutritional investigation focused on riverine forest compared to other habitat types is recommended with protection provided for riverine forest.

Plants in areas surrounding natural water sources would be good vegetation types to provide moisture for elephants and possibly other nutrients such as sodium to meet elephant requirements. Managing seasonal water sources and vegetation cover in the mid and late dry season is recommended. Vegetation maps showing distribution of specific vegetation types would be helpful. For example, a distribution map for some grass species selected by elephants is recommended for each vegetation cover type: e.g. *Cynodon dactylon* in forest, grassland or swamp areas, *Cenchrus ciliaris* in grassland or bushland, or *Chloris roxburghiana* in grassland, and also in human settlement areas. A map showing seasonal changes of vegetation distribution is also recommended: e.g. *Ipomea mombassana* or *Commelina* sp. succulent herbs in the wet season and in the early dry season. A map showing specific vegetative components in riverine forest and associated bushland, grassland or swamp areas may be necessary: e.g. Capparis tomentosa (shrub) or Panicum sp. (grass) in forest, or Disperma kilimandscharica in bushland. The information from vegetation maps would be useful to set up appropriate corridors between Tsavo East and West or other areas identified as elephant habitat.

Fire presently is not necessary for vegetation regrowth in the southern part of Tsavo East National Park. When fire might be used as a management technique, a careful plan should be recommended, considering climatic prediction for the coming wet season, and the event of drought and accidental fires. Soil chemical amendment may be unfeasible in the field in the mid and dry season when soils are too hard for ploughing or in the wet season when a majority of the area is inaccessible.

Plant diversity must be maintained since elephants seemed to obtain a variety of nutrients from a variety of plant species depending on the vegetative state, season or year or other conditions. Although evergreen shrubs did not seem to be frequently eaten in the early dry season or in the wet season, those plants should not be neglected for vegetation cover. Plants that seem to be lower in known nutrient quality might have high concentrations of some minor uninvestigated nutritional components that elephants might need.

Elephants and their habitat in Tsavo should be managed within the entire Tsavo ecosystem. Seasonal nutritional needs for elephants might be influenced by geographic areas because the component of vegetation cover types is different among geographic areas. Considering the entire Tsavo ecosystem, nutritional differences in vegetation types among geographic areas (e.g. Tsavo East and West, north of Tsavo East) should be investigated in more detail.

Poaching should be strictly controlled and hunting pressure from Tanzania should be minimized to allow elephants to access all areas. Managing poaching and hunting allows better determination of elephant habitat preference.

Crop damage is frequently reported at night. Night observations should be involved to find one of the resolution for elephant-human conflict. Crop damage might be investigated as related to nutritional requirements for elephants. For example, when elephant sodium requirements are quantitatively determined, crops containing higher concentrations of sodium might be protected by compound fencing to avoid elephant invasion. Alternative techniques can be used for habitat manipulation including using indigenous vegetation, or growing crops that are low in sodium. Some adequate changes in traditional food culture of indigenous people may be necessary with an appropriate direction of community education program.

Some vegetation favored or often selected by elephants may be removed from human settlements to protect local people. Cynodon plectostachyus or Chloris roxburghiana often was seen in human settlements where elephants seemed to visit frequently. At the same time, those desired plant species might be supplemented in corridors for elephants, if the species component of vegetation in the area determined for corridors did not meet elephant life requisites. Plantings or supplemental plantings should be carefully planned and conducted based on long term research information in human settlement areas as well as in the National Park. Artificial manipulation might change elephant palatability or food selection or their habitat itself, and consequently increase human-elephant conflict. Another consideration for habitat manipulation would be maintaining balanced populations of a variety of invertebrates depending on various vegetation types. Simplifying vegetation cover types may produce a preferable habitat for only a few invertebrate species, and as a result, the entire ecosystem could be damaged.

Quantitative nutrition research is urgently needed to determine the area for corridors and to manage the buffer zones as one of the important solutions for human-elephant conflicts. The size and location of corridors between Tsavo West and Tsavo East may be determined by agreements with ranch owners who are enthusiastic with establishing tourism. The area of corridors could be justified according to further investigation of historical migration route of elephant. Elephants seemed to migrate due to water and sodium requirements, and possibly some other nutrient requirements related to moisture availability. For example, it is important to determine minimum and optimum amounts of water and moisture required to manage elephants in the mid and late dry season. Further investigation of sodium requirements, possibly regulating elephant migration in Tsavo, will contribute to determining appropriate areas for human settlements and for elephant migration in the buffer zones.

Providing research knowledge about elephant nutrition to local people and wildlife managers is necessary through wildlife community and education programs. Future management for Tsavo elephants can be the product of good relationships among wildlife managers, local people and researchers supported by government and international agencies.

APPENDICES

APPENDIX 1

Table 36. The number (N) and actual minutes (Min.) for feeding and other activities collected by "5" minute interval method.

Period	less than 3 minutes		3 -4 minutes		4 -5 minutes		Total	
	N	Min.	N	Min.	N	Min.	N	Min.
Sep.90-Feb.92	3	9.73	8	35.60	76	380.00	87	425.33
Jun.92-Aug.93	4	14.58	8	33.85	83	415.00	95	463.43
Dec.93-Dec.94	6	19.63	9	40.23	90	450.00	105	509.87
Total	13	43.95	25	109.68	249	1245.00	287	1398.63

APPENDIX 2

Table 37. The number of samples for feeding and other activities under categories (287 observation periods): for Tables 5,6 and 7.

	Total		Geog. area		Age classes				Sexes		
			East	West	A	SA	I	?	M	F	?
Dry season	ED	93	90	3	45	23	24	1	36	38	19
N= 232	MD	36	29	7	14	14	8	0	20	13	3
	LD	103	92	11	62	21	20	0	41	45	17
Wet season	EW	30	26	4	18	10	2	0	14	13	3
N=55	LW	25	24	1	13	7	5	0	17	5	3

Seasons = ED:early dry season, MD:mid dry season, LD:late dry season, EW:early wet season, LW:late wet season. Geog. area = Geographic area: East is Tsavo East National Park, West is Tsavo West National Park. Age classes = A:adults, SA:subadults, I:infants, ?:unknown. Sexes = M:males, F:females, ?:unknown.

APPENDIX 3

Table 38. The number of samples for feeding and other activities under categories(247 observation periods) in the southern part of Tsavo East National Park: for Tables 8-13.

Dry seasons (N= 208)

		Adults (N=111)			Subadults (N=48)			Infants (N=48)			?
		M*	F	?	M	F	?	M	F	?	?
Early	90	17	25	2	10	6	6	8	5	10	1
Mid	29	5	7	0	7	3	0	5	1	1	0
Late	89	19	36	0	5	5	6	8	2	8	0
Total	208	41	68	2	22	14	12	21	8	19	1

* M:males, F:females, ?:unknown.

Wet seasons (N= 39)

		Adults (N=21)			Subadults (N=11)			Infants (N=7)		
		M*	F	?	M	F	?	M	F	?
Early	17	5	5	0	1	2	2	1	0	1
Late	22	7	3	1	3	2	1	4	0	1
Total	39	12	8	1	4	4	3	5	0	2

* M:males, F:females, ?:unknown.

APPENDIX 4

Table 39. Plants eaten by elephants and plants uneaten: the period for each seasonal category from June 1992 to June 1993 (35 species).

Early dry seasons

	Species	Period	Form	Vegetation type
	Cenchrus ciliaris	June-July 1992	Grass	Grassland
*	Chloris roxburghiana	"	"	"
	Boscia coriacea	"	Shrub	"
	Thylachium thomasii	"	"	"
	Enteropogon macrostachyus	"	Grass	Bushland
	Cordia gharaf	"	Shrub	"
	Echnochloa haploclada	March 1993	Grass	Bushland
*	Disperma kilimandscharica	"	Shrub	"
	Panicum coloratum	"	Grass	Forest
	Dobera glabra	"	Tree	"
*	Cynodon plectostachyus	May-June 1993	Grass	Grassland
	Echnochloa haploclada	"	"	"
*	Ipomea mombassana	"	Herb	"
*	Tephrosia noctiflora	"	"	"
*	Premna hostii	"	Shrub	"
*	Salvadora persica	"	"	"
	Sporobolus gemiratus	"	Grass	Bushland
*	Disperma kilimandscharica	"	Shrub	"
	Barleria argentea	"	"	"
*	Cynodon dactylon	"	Grass	Forest
	Panicum coloratum	"	"	"
*	Capparis tomentosa	"	Shrub	"

Table 39. (cont'd)

Mid dry seasons

Species	Period	Form	Vegetation type
* Salvadora persica	July 1992	Shrub	Bushland
* Cynodon dactylon	"	Grass	Forest
* Capparis tomentosa	"	Shrub	"
* Combretum aculeatum	"	"	"

Late dry seasons

Species	Period	Form	Vegetation type
* Chloris roxburghiana	September-October 1992	Grass	Grassland
* Cynodon dactylon	"	"	"
* Combretum aculeatum	"	Shrub	"
Cyperus articulatus	"	Herb	Grassland (Swamp)
* Cynodon dactylon	"	Grass	Forest
Panicum repens	"	"	"
* Capparis tomentosa	"	Shrub	"

Presence: Wet seasons

Species	Period	Form	Vegetation type
* Cynodon dactylon	November 1992	Grass	Forest
* Chloris roxburghiana	December 1992	Grass	Grassland
* Cynodon plectostachyus	"	"	"
Digera mucronata	"	Herb	"
* Aristida adscensionis	February 1993	Grass	Grassland
* Chloris roxburghiana	"	"	"

Table 39. (cont'd)

	Digera mucronata	February 1993	Herb	Grassland
*	Disperm kilimandscharica	"	Shrub	"
	Anisotes parrifolius	"	"	Bushland
	Commelina erecta	April 1993	Herb	Grassland
*	Ipomea mombassana	"	"	"
*	Tephrosia noctiflora	"	"	"

Absence: Wet seasons

	Species	Period	Form	Vegetation type
X	Brachiaria serrifolia	December 1992 -January 1993	Grass	Grassland
*	Chloris roxburghiana	"	"	"
	Dactyloctenium giganteum	"	"	"
	Panicum maximum	"	"	"
	Commelina benghalensis	"	Herb	"
*	Tephrosia noctiflora	"	"	"
*	Premna hostii	"	"	"
X	Strychnos decussata	"	"	"
*	Aristida adscensionis	"	Grass	Bushland
X	Cleome hirta	"	Herb	"
	Grewia nematopus	"	Shrub	"
	Dactyloctenium giganteum	"	Grass	Woodland (Tsavo West)
	Indigofera arrecta	"	Herb	"
	Tephrosia noctiflora	"	"	"
	Preman resinosa	"	Shrub	"

1. Asterisk show the plants that were analyzed and described in the results in Figures 8-22 and Tables 14-24 (11 species).
2. Cross mark (X) denote the plants were never observed as elephant foods (3 species).
3. All samples were collected from the southern parts of Tsavo East National Park with the exception of the samples collected from woodland in Tsavo West (Absence: Wet seasons).

APPENDIX 5

Table 40a. Chemical composition of elephant feces in age classes and in sexes in the southern parts of Tsavo East National Park in the mid and late dry season from October 1990 to August 1992 (21 cases).

Chemical composition	Adults (N=9) Mean ± S.E.	Subadults (N=6) Mean ± S.E.	Infants (N=6) Mean ± S.E.
Moisture	77.3 ± 1.14	76.7 ± 1.39	79.2 ± 1.48
Crude ash	7.6 ± 0.49	8.0 ± 0.59	8.9 ± 0.63
Calcium	1.36 ± 0.130	1.60 ± 0.158	1.32 ± 0.168
Potassium	0.92 ± 0.066	0.79 ± 0.080	0.96 ± 0.085
Sodium	0.140± 0.016	0.122± 0.019	0.105± 0.021
Magnesium	0.273± 0.033	0.301± 0.041	0.265± 0.043

Moisture was determined by % on a fresh matter base. Other chemical compositions were determined by % on a dry matter base. There were no significant differences among three age classes within each chemical at $P > 0.20$.

Table 40b. (cont'd)

Chemical composition	Males (N=11) Mean ± S.E.	Females (N=10) Mean ± S.E.
Moisture	75.7 ± 1.04	79.8 ± 1.16
Crude ash	7.9 ± 0.44	8.5 ± 0.49
Calcium	1.41 ± 0.118	1.44 ± 0.131
Potassium	0.92 ± 0.060	0.86 ± 0.066
Sodium	0.119± 0.014	0.126± 0.016
Magnesium	0.295± 0.030	0.264± 0.034

Moisture was determined by % on a fresh matter base. Other chemical compositions were determined by % on a dry matter base. There were no significant differences between sexes within each chemical with the exception of moisture at $P > 0.20$. Moisture was significantly different between sexes at $P < 0.05$.

APPENDIX 6

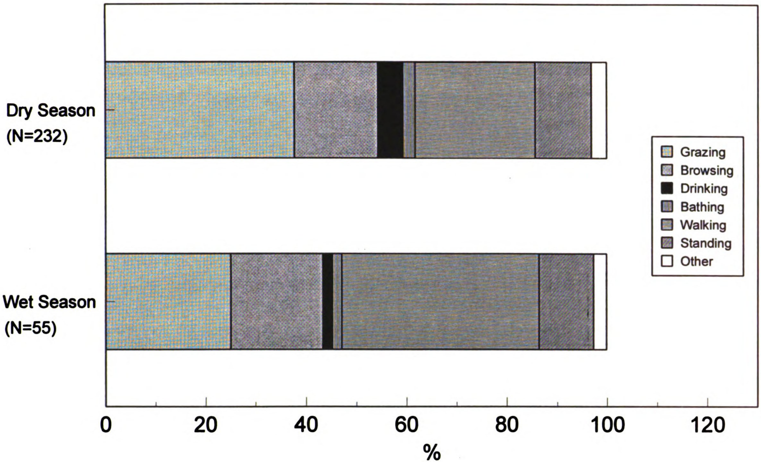


Figure 35. Percentage of time elephants spent feeding and other activities from September 1990 to October 1994 in Tsavo National Park (East and West):differences for two seasons (287 observation periods) for Table5.

APPENDIX 7

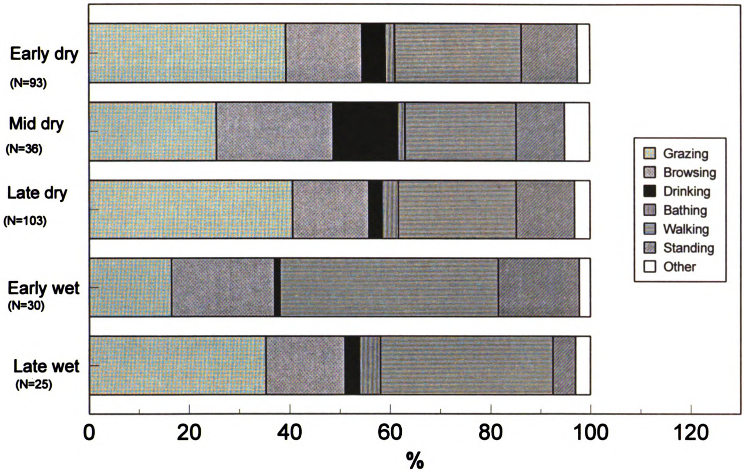


Figure 36. Percentage of time elephants spent feeding and other activities from September 1990 to October 1994 in Tsavo National Park (East and West): differences for five seasonal categories (287 observation periods) for Table 6.

APPENDIX 8

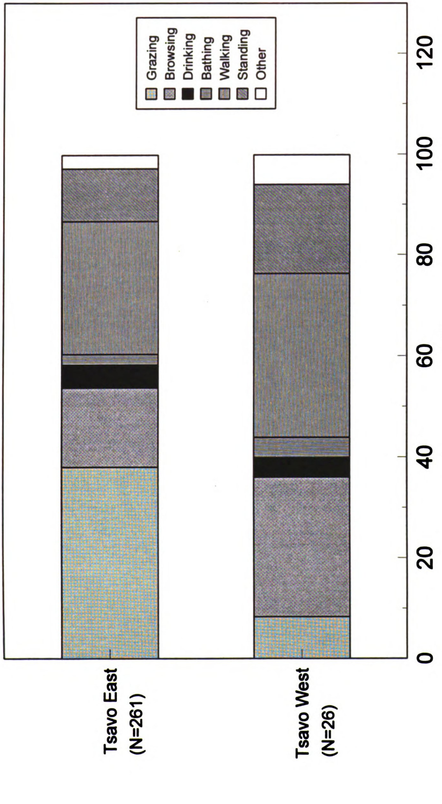


Figure 37. Percentage of time elephants spent feeding and other activities from September 1990 to October 1994. Tsavo National Park (East and West): differences in geographic areas (287 observation periods) for Table 7.

APPENDIX 9

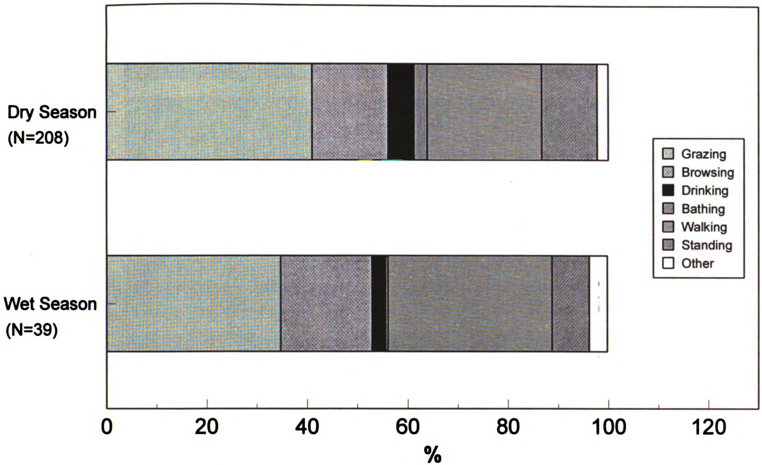


Figure 38. Percentage of time elephants spent feeding and other activities from September 1990 to October 1994 in the southern part of Tsavo East National Park: differences for two seasons (247 observation periods) for Table 8.

APPENDIX 10

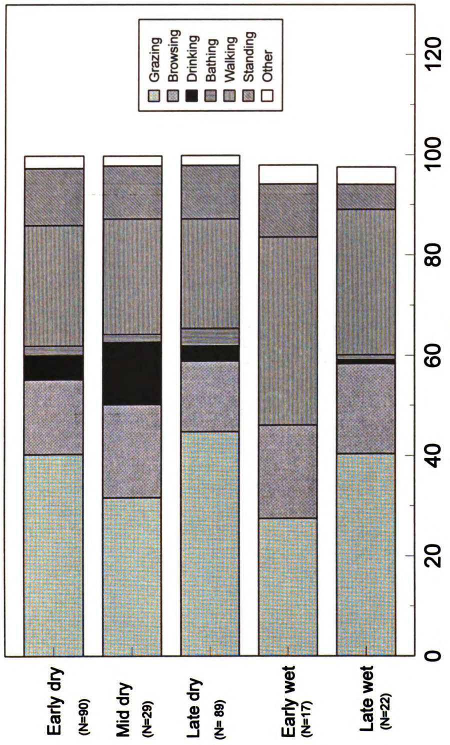


Figure 39. Percentage of time elephants spent feeding and other activities from September 1990 to October 1994 in the southern part of Tsavo East National Park: differences for five seasonal categories (247 observation periods) for Table 9.

APPENDIX 11

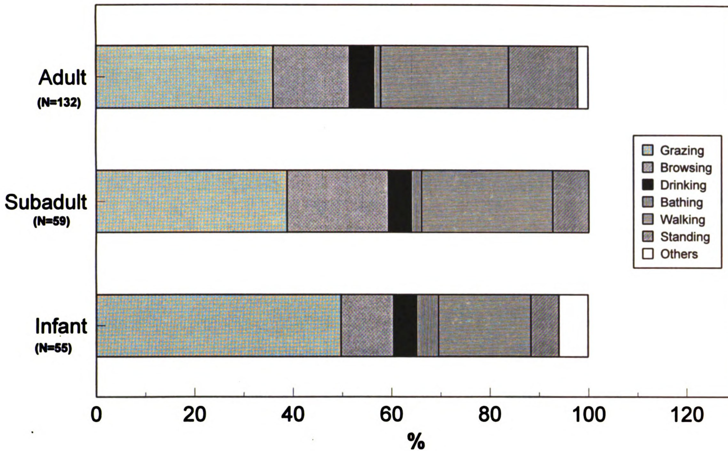


Figure 40. Percentage of time elephants of different age classes spent feeding and other activities from September 1990 to October 1994 in the southern part of Tsavo East National Park (246 observation periods) for Table 10.

APPENDIX 12

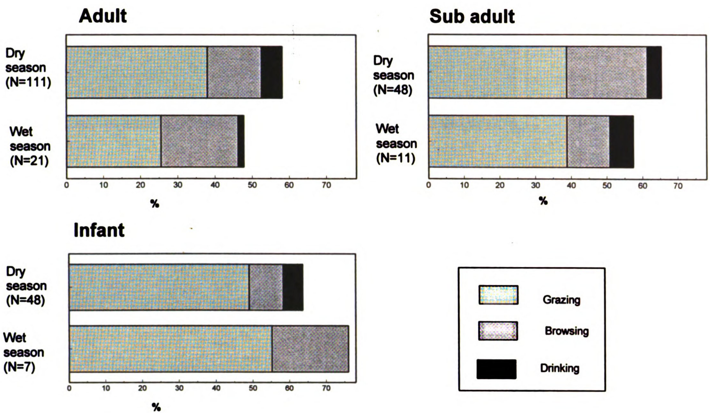


Figure 41. Percentage of time elephants of different age classes spent feeding activities for two seasons from September 1990 to October 1994 in the southern part of Tsavo East National Park (246 observation periods) for Table 11.

APPENDIX 13

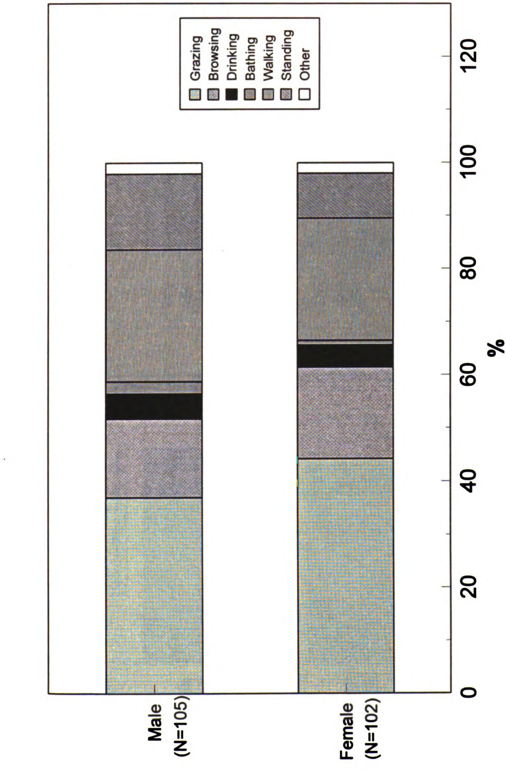


Figure 42. Percentage of time male and female elephants spent feeding and other activities from September 1990 to October 1994 in the southern part of Tsavo East National Park (207 observation periods) for Table 12.

APPENDIX 14

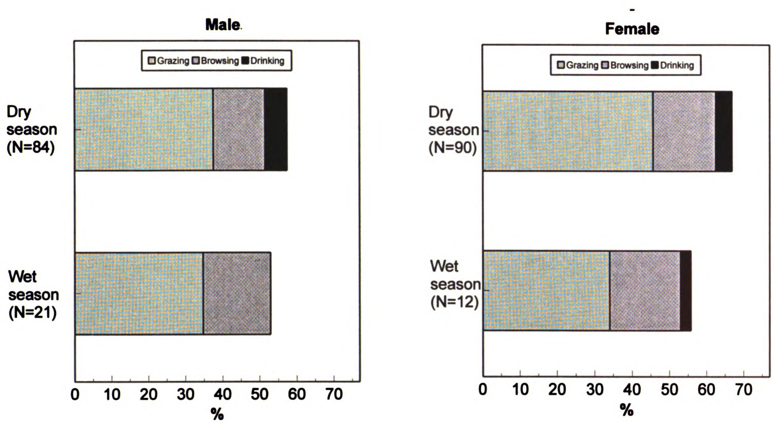


Figure 43. Percentage of time male and female elephants spent feeding activities for two seasons from September 1990 to October 1994 in the southern part of Tsavo East National Park(207 observation periods) for Table 13.

APPENDIX 15

Table 41. Manganese for plants eaten or uneaten by elephants that contain higher values.

Species	Season	Mn (ppm)
Commelina erecta	Wet season: Presence	206 ± 57
Cyperus articulatus	Late dry season	540 ± 133
Dobera glabra (stems)	Early dry season	678 ± 605
Premna hostii (leaves)	Early dry season	252 ± n.a.
(leaves)	Wet season: Absence	662 ± 56
Strychnos deccusata (leaves)	Wet season: Absence	1,947 ± 493
(stems)	"	253 ± 3

1. The details for each plant are described in Appendix 4.
2. The data for Premana hostii are cited from Table 20.
3. Strychnos deccusata was never observed as elephant food as described in Appendix 4.

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