Space and habitat use by elephants (*Loxodonta africana*) in the Maputo Elephant Reserve, Mozambique

C.P. NTUMI

Dedicated to my daughter Dinema and my son Kevin

Space and habitat use by elephants (*Loxodonta africana*) in the Maputo Elephant Reserve, Mozambique

By

Cornélio Pedro Ntumi

Submitted in partial fulfillment of the requirements for the degree of

MSc (Zoology)

In the

Faculty of Natural & Agricultural Sciences
University of Pretoria

October 2002

Space and habitat use by elephants (*Loxodonta africana*) in the Maputo Elephant Reserve, Mozambique

by

Cornelio Pedro Ntumi

Supervisors: Professor R.J. van Aarde
Conservation Ecology Research Unit
Department of Zoology and Entomology
University of Pretoria, Pretoria 0002
South Africa

Dr. Neil Fairall
Conservation Ecology Research Unit
Department of Zoology and Entomology
University of Pretoria, Pretoria 0002
South Africa

Abstract

Information collected during a helicopter survey (non-overlapping transects) and the satellite tracking of five elephants (VHF radio's and UHF satellite PTT's) have been used to access space and vegetation use in the Maputo Elephant Reserve. The CALHOME program with *Adaptive Kernel and MCP (Minimum Convex Polygon)* techniques was used to determine home ranges. An Arcview vegetation map of the Maputo Elephant Reserve was used to interpret vegetation use by elephants.

The home range areas of radio-collared cows ranged from 169 to 267 km^2, whilst that of the bull was 453 km^2. The core areas cover less than 6 % of the area of the Reserve. Season did not influence home range sizes.

Elephants did not use the available vegetation types at random and the forest and Futi floodplain vegetation types were selected, whilst grasslands and woodlands were avoided. Preference for a vegetation type was not a function of the time of day. The sex of individuals also did not affect preferences though the male did make use of woodlands outside the Reserve that the females did not use. The mean distance between successive locations was negatively correlated with biomass and plant cover of the vegetation type.

Various explanations for home range size differences and vegetation preference were considered. These results have general implications for the development of the Futi Corridor as a conservation area for elephants.

ACKNOWLEDGEMENTS

The study was supported through grants from the Dutch Embassy in Maputo and Peace Parks Foundation. My sincere thanks are extended to Tudor Conservation Company, the Parsons Aviation, the USA Wildlife Services and the Germany Grant (Europaische Reiseversicherung Grant) for their financial support. Other institutions that have contributed to this research include BP, INCM and the DEIBI-Project.

I remain deeply grateful to Prof. Rudi van Aarde and Dr. Neil Fairall, my supervisors, who supported and guided my studies. The present study would not have been possible without the permission of DNFFB.

The rangers of the Reserve provided assistance and companionship during the many short and long drives in search of elephants. A special word of thanks to the Principal Wardens for their commitments and interest in the project.

Dr. Fred de Boer shared with me the birth of this project and provided me with continuous support in all stages thereof. As a student and colleague we shared unforgettable moments and had fruitful discussions, even after his return to Holland.

Dr. Ian Whyte contributed in this study by darting tracked elephants and during the helicopter survey. His contributions that made this study possible are thanked.

My colleagues of the Department of Biological Sciences of the Eduardo Mondlane University are here deeply acknowledged for their comments and the good spirit. Special thanks are directed to Ana Massinga of the Ministry of Environmental Coordination for her help. I would also like to thank Manuela Muianga, Domingos Manguengue and Jotamo Mazive for all the support, both during bad and good times. Finally, the part of my family, who did not have chance to deny my absence, but accepted it with love, I thank you. Thanks to my wife Josefina Daniel and our Dinema and Kevin. You were always the source of inspiration.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

GENERAL INTRODUCTION

The establishment of the Maputo Elephant Reserve (MER) in southern Mozambique in 1932 stemmed from the need to protect the local African elephant (*Loxodonta africana* (Blumenbach, 1797)) population from destruction by man. However, the introduction of species such as the white rhino (*Diceros bicornis bicornis* (Linnaeus, 1758) during the early 1970's marked a change in attitude of protecting elephants, to one of conserving biota typical of the region.

At present the department of conservation, Direcção Nacional de Áreas de Conservação (DINAC) still considers the protection of elephants a conservation priority. As a consequence, the Department of Biological Sciences (DCB) of the University of Eduardo Mondlane established an ecological research program in cooperation with the department of forestry and wildlife, Direcção Nacional de Florestas e Fauna Bravia (DNFFB) some four years ago. Though this program contributed greatly to our knowledge on the biota of the MER, we still have very little information on the interactions between plants and animals occurring in the MER.

As part of the post-war development of southern Mozambique the local government authorized the Blanchard Project as a venture into developing a profitable ecotourism industry. In 2000, the government also sanctioned investigations into the inclusion of the Maputo Elephant Reserve in the Lubombo Transfrontier Conservation Area. The development of both these programs requires information about the consequences such developments will have for the biota of the region, and more specifically for the African elephant, which in this region is considered a flagship species for conservation.

The Blanchard Project started with the introduction of waterbuck (*Kobus ellipsiprimnus* Ogilby, 1833) and kudu (*Tragelaphus strepsiceros* Pallas, 1766) into the MER and with the construction of an electric fence all along the 26 km western border of the Reserve. This project came to an end in 1998 and further developments are in the hands of those negotiating the renewal of the concession.

The development of a Transfrontier Conservation Area (TFCA) in the region aims at restoring the Maputo plains elephant population by reuniting the elephants of MER and Tembe Elephant Park through the so-called Futi Corridor into a single population. The simulation of the consequences of the establishment of such a TFCA for both the region and for the elephant populations depend on fundamental information on the following:

1) the population ecology of the fragments of elephant populations of the region,
2) the interaction between elephants and their habitats, and
3) the socio-economic status of local people and their interaction with elephants.

The present study is directed at the elephant population of the MER and where possible the Futi Corridor. It focuses on the interactions between elephants and their habitats.

Earlier studies on the elephants of the Maputo Elephant Reserve focused on their diet through fecal analysis (Correia 1995, Mafuca 1996), distribution and habitat choice using fecal counts (Ntumi 1997), and crop damage and movement patterns through satellite tracking (Ntumi 1997). This population comprises only some 200 individuals over an area of 800km^2, an estimate that may negatively impact on the viability of the population (Frankel & Soulé 1981). The negative attitude of the local communities towards elephants as a consequence of crop damage (see de Boer & Baquete 1998, de Boer & Ntumi 2001, Soto *et al*. 2001) also may influence the elephant population. However, the protection of these elephants and the associated increase in their numbers without factors limiting their numbers within the confinement of the MER may have negative implications for the sand forests unique to this part of the world.

One of the ways of seasonally reducing local pressure on the vegetation would be to re-establish traditional movement patterns between the MER and the Tembe Elephant Park through the Futi Corridor. Such a periodic release of disruption may provide opportunity for the development of a dynamic and sustained interaction between elephants and their food plants.

The study centers on the use of space, habitat and vegetation by elephants in southern Mozambique and provides some of the information that will be required to simulate the consequences of the establishment of a TFCA in the region.

Habitat preference by elephant depends on vegetation type, quality and the vegetation type coverage (Laws 1970a; 1970b, Laws *et al*. 1975, Leuthold & Sale 1973, Sukumar 1990, van Wijngaarden 1985). It also is affected by water quality, availability and distribution (Weir 1972, Williamson 1975) and by human activities such as agricultural development and poaching (Sukumar 1989, Barnes *et al.* 1997, Deodatus & Lipiya 1991, Deodatus & Sefu 1992, Tchamba 1996).

The factors influencing elephant distribution in the MER have been speculated to include vegetation quality and biomass (Tello 1973, Correia 1995, Mafuca 1996, Osborn 1996, Ntumi 1997), water availability and salinity (Ntumi 1997), vegetation cover (Tello 1973, Ntumi 1997), and the avoidance of poachers (Ntumi 1997, de Boer *et al.* 2000).

Ntumi (1997) discussed the consequences of high densities of elephants for the sand forests of MER. Correia (1995) and Mafuca (1996) showed that plants of these sand forests are important sources of food for the elephant. However, Tello (1973), suggested that elephants here focused their year round activities on the floodplain of the MER, only seeking refuge in the sand forests when disturbed by poachers while moving between the Maputo River and the South African border. However, habitat preferences apparently have changed and elephants now spend most of their time in the sand forests (Mafuca 1996, Ntumi 1997).

Habitat fragmentation is one of the most important factors affecting wildlife in the southern parts of Mozambique (Pardal 1996). The agricultural settlements along the Futi River may lead to an increase in man-elephant conflict. This development started 10 to 15 years ago and Ostrosky & Matthews (1995) noted large-scale development schemes near Manhoca, some 6km north of the international boundary. Here some 16 000 hectares were cleared for agriculture purposes and large areas were subdivided and fenced for cattle ranching (Hatton *et al.* 1995, Ostrosky & Matthews 1995).

The Maputo Elephant Reserve[1]

The study was conducted in the Maputo Elephant Reserve (MER) and in the adjoining Futi Corridor. The 800km^2 MER is situated in southern Mozambique (26°25'S, 32°45'E, Fig. 1). Hot, rainy summers (October-March) and colder, drier winters (April-September) characterize the climate. Annual rainfall varies from 690 to 1000mm (Grossman & Loforte 1994). The soils are mainly sandy with some more

[1] The proper name is Reserva Especial de Maputo. It was created in 1932 specially to protect elephants. Further, the conservation objectives have been improved, using the elephants as a flagship to conserve

fertile, alluvial soils around the Futi and Maputo Rivers. Several, sometimes saline lakes can be found in the area. Geomorphologicaly, the area comprises unconsolidated quaternary to recent sediments, mostly sands (dunes, sandy plains with heavier textured soils), and *mananga* and alluvial soils (Massinga & Hatton 1996). White (1983), cited by Massinga & Hatton (1996) considered this area part of the Tongoland-Pondoland regional mosaic (TPRM). The high and unique biodiversity of the area is increasingly considered as of special scientific conservation and economic value. Van Wyk (1994) described this area as the Maputaland Center for Plant Endemism. Based on a modification of the descriptions of Tello (1973), Haandrikman (1998) and Vriesendorp (1998), de Boer *et al.* (2000) distinguished the following six plant communities (see also Fig. 2):

Mangroves, which border the Maputo bay and surround the deltas of the Maputo River and Bembe canal, mainly comprise *Avicennia marina* and *Rhizophora mucronata* trees.

Dune vegetation which mainly consists of pioneer plants (e.g. *Scaevola plumieri, Ipomoea pes-caprae, Canavalia rosea* with dune thicket and coastal dune forest (*Diospyros rotundifolia*, *Mimusops caffra* and *Sideroxylon inerme*, *Cyperus compactus*, *Monanthotaxis caffra*.

Grass plains are dominated by *Themeda triandra*, *Vernonia glabra*, *Cynodon dactylon*, *Sporobolus virginicus*, *Salacia kraussii and Dactylotenium aegyptium*. Parts of the grasslands are inundated during the rainy season.

Forests dominated *by Ochna natalitia, Mimusops caffra, Euclea natalensis, Psydrax locuples*, *Afzelia quanzensis*, *Dialium schlecterii*.

Woodlands are relatively open areas dominated by species such as *Strychnos madagascariensis*, *Strychnos spinosa*, *Dichrostachys cinerea*, *Garcinia livingstonei*, *Vangueria infausta*, *Syzigium cordatum*, *Sclerocarya birrea*, *Afzelia quanzensis*, *Terminalia sericea* (Massinga & Hatton 1996, Vriesendorp 1998).

[1] The proper name is Reserva Especial de Maputo. It was created in 1932 specially to protect elephants. Further, the conservation objectives have been improved, using the elephants as a flagship to conserve

Riverine vegetation along the seasonal Futi River comprises reed-beds dominated by *Phragmites australis, Juncus kraussii* and *Cyperus compactus*, sometimes fringed by patches of riverine forest of *Ficus sycomorus*, *Syzygium cordatum* and *Kigelia africana, Helichrysum kraussii, Panicum maximum.*

Different herbivore species have been recorded in the past (Tello 1973). However, during the civil war, most of them were decimated through poaching. Reedbuck (*Redunca arundinum*), red duiker (*Cephalophus natalensis*), suni (*Neotragus moschatus*), common duiker (*Sylvicapra grimmia*), hippopotamus (*Hippopotamus amphibius*), bushpig (*Potamochoerus porcus*) and crocodile (*Crocodilus niloticus*) can still be found in the MER and the Futi Corridor.

Little information exists on the ecology of elephants of the MER. Population estimates for the past 30 years ranged from 80 to 350 individuals (see Table 1). Most of these seem to be educated guestimates rather than estimates with known levels of precision and accuracy .

Elephants use to move between the MER and the Tembe Elephant Park (Tello 1973, Hall-Martin 1988, Ostrosky & Matthews 1995). According to Hall-Martin (1988), the Tembe Elephant Park consists predominantly of leached sands of low fertility and the quality of the forage for elephants is generally poor. During their south-north-south movements elephants preferred the flood plain grassland and marsh habitat between the lower reaches of the Muzi River (called the Futi River in Mozambique) and the flood plain of the Maputo River. This area has relatively fertile alluvial soils, which provide better quality food (Gouveia & Azevedo (1955) cited by Hall-Martin 1988). Thus, the elephants may have been crossing the northern border of the Tembe Elephant Park into southern Mozambique to obtain higher quality food sources on the alluvial soils of the flood plains (Gouveia & Azevedo 1955, cited by Hall-Martin 1988).

The range of the elephant groups living in the MER (see Ntumi 1997) apparently have not changed much since Tello (1973) when they used the area from Futi River to the so-called "elephant plains" (now called Chango's plains) (DNFFB 1997). The elephant population of the MER appears to be on the increase (van Aarde

---

the biological diversity.

& Fairall 2001), probably in response to the efficient protection they are receiving within the limits of the MER.

Most of the people of the southern Mozambique region live along the western side of the MER between the towns of Bela Vista and Salamanga and in the vicinity of Zitundo to the south (see Fig. 1). Some people (around 500 individuals) live in a few settlements around the main lakes within the MER and apparently depend on resources collected within the MER.

The 26km of electric fence erected as part of the Blanchard Project along the western boundary of the MER gave rise to a lot of conflict with people living close to the MER, thereby increasing the negative perception that the local population already had of conservation (de Boer & Ntumi 2001).

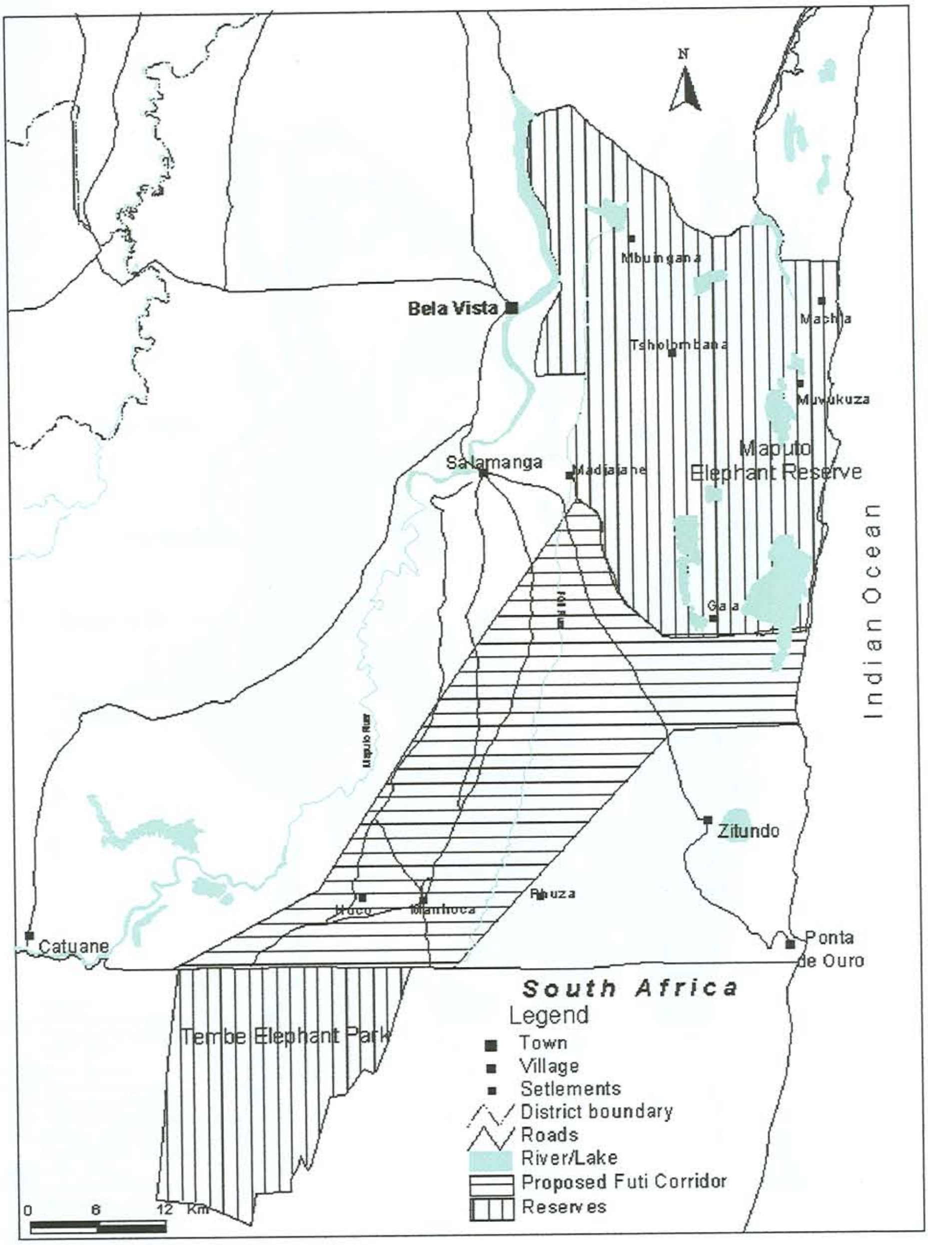


Figure 1: The location of boundaries of the Maputo Elephant Reserve in southern Mozambique. See details of the map in Figure 2.

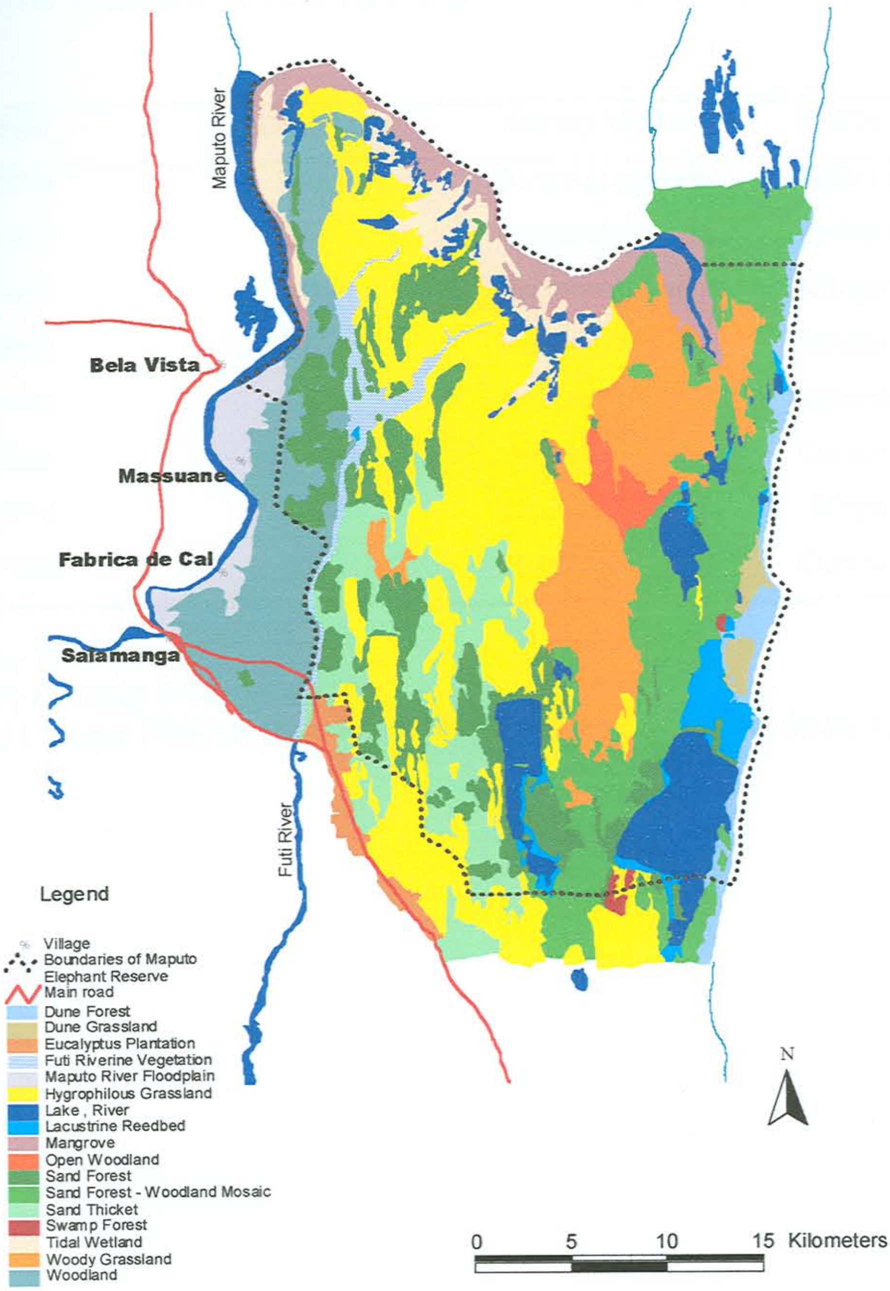


Figure 2: A vegetation map of Maputo Elephant Reserve based on a modification of a map produced by the Departamento de Ciências Biológicas (DCB 2000).

Table 1: The population estimates for elephants in the Maputo Elephant Reserve.

Year	Population size	Survey Method	Source
1970	350	Personal opinion	Tello (1973)
1972	269	Personal opinion	Tinley & Dutton (1972)[a]
1979	80	Personal opinion	Klingerhoefer (1987)
1995	137	Personal opinion	Davies (1995)[b]
1995	150	Personal opinion	Ostrosky & Matthews (199
1996	100-300	Personal opinion	Correia *et al*. (1996)
1998	180	Helicopter count	Whyte (pers. comm.)[1]
1999	205	Helicopter count	Current study

[a] Cited by Tello (1973)
[b] Cited by Ostrosky & Mathews (1995)
[1] I. Whyte, Kruger National Park, Private Bag X402, Skukuza 1350, South Africa.

The Futi Corridor

The Futi Corridor is part of the proposed Maputo TFCA (Transfrontier Conservation Area), situated in the southern-eastern part of the Maputo province (GEF 1996). It includes 2km on either side of the Futi River from Marco Viana (North of MER) up to the international border with South Africa (Oglethorpe 1997). Based on Landsat TM 1990-1991 imagery, field surveys and the interpretation of aerial photographs (Grossman & Loforte 1994; DINAGECA 1994; Hatton *et al.* 1995; Ostrosky & Matthews 1995; Haandrikman 1998) the following plant communities can be distinguished here:

Forests dominated by *Afzelia quanzensis, Mimusops caffra, Dialium schlechterii, Pteleopsis myrtifolia, Ptaeroxylon obliquum and Ochna barbosa.*

Grass plains are dominated by *Cymbopogon excavatus, Themeda triandra, Cynodon dactylon, Sporobolos virginicus* and *Phragmites australis, Dichrostachys cinerea, Strychnos madagascariensis, Strychnos spinosa (*Grossman & Loforte 1994, Hatton *et al*. 1995) and *Hyphaene coriacea* forms the woody component.

Woodlands dominated by *Afzelia quanzensis*, *Albizia adianthifolia* and *Sclerocarya birrea*, *Garcinia livingstonei*, *Terminalia sericea* and *Syzygium cordatum*.

Riverine vegetation comprises reedbeds dominated by *Phragmites ausatralis*, *Juncus kraussii* and *Cyperus compactus*, fringed by riverine forest of *Ficus sycomorus*, *Syzygium cordatum* and *Kigelia africana*.

People within the Corridor make a subsistence living through small-scale agriculture, hunting, and collection of fruit and roots for eating (Felgate 1986, GEF 1996). The main threat to indigenous biological resources in the areas is the uncontrolled poaching of wildlife and loss of habitat due to encroachment and conversion (GEF 1996). Ilala palm (*Hyphaene coriacea*) wine production is one means of earning cash income, particularly for the Ndlovo and Puza comunities. According to GEF (1996), poverty, and the lack of alternative sources of income is a significant factor in the area's natural resources use.

Agricultural production is estimated at US$200 per family per year, while forest products used annually were valued at US$118 (GEF 1996, Negrão (1996) cited by Massinga & Hatton 1996). The yearly consumption of medicinal plants totaled US$59 per family, while the consumption of animal protein amounted to US$118. The value of construction materials totaled US$50 (Negrão (1996) cited by Massinga & Hatton 1996).

AIMS

The present study is directed at determining if the type and/or state of vegetation and human activities are factors influencing the distribution, range use, habitat use and movement of elephants of the MER. The following objectives were formulated:

- To determine the range and habitat use of elephants of the MER and Futi Corridor.
- To relate range and habitat use to management implications for the MER and Futi Corridor elephant population.

CHAPTER 2

SPACE USE

Methods

Aerial survey

The distribution and population size of elephants in the MER and the Futi Corridor were assessed by a helicopter survey carried out over a five–day period from 13-18 October 1999. During the helicopter survey, we conducted a total count along non-overlapping transects as described by Norton-Griffiths (1975) and Douglas-Hamilton (1996). Thirty hours of flying was enough to cover the entire surveying area (800 km^2 of the MER and the Futi Corridor (470 km^2). The area was divided into six counting sections, delineated by features such as roads, cut-lines, protected area boundaries or rivers. The crew consisted of a pilot, a Front Seat Observer (FSO) and two Rear Seat Observers (RSO) (see Douglas-Hamilton 1996 for more details).

The survey was planned as a total count, covering 100% of the area (instead of random transects and data extrapolation techniques). Total counting has been adopted as the best alternative as elephants are large animals and relatively easy to spot and count (Douglas-Hamilton 1996). The survey comprised east-west orientated strip-transects. The road between Salamanga and Ponta de Ouro and the Futi River were used to cut the transects in shorter parts, which enhanced observer concentration. We initially planned that the strip transects would be measured during the survey and fixed. During this survey no elephants were noted within the strip transects but several elephants were noted beyond these strips. As a result we counted these elephants by changing the flight plan to enable closer scrutiny, thereafter returning and continuing the survey along to the original transects. The population size could only be estimated by summing the observations of elephants recorded outside the strip transects and correcting these for resightings. All observations were recorded and mapped on a detailed 1:50.000 vegetation map of the study area. As elephants are difficult to detect in the forests (personal observations during previous surveys) we decided to reduce flying height over these forests so as to enhance the likelihood of spotting elephants by flushing them from their hide outs. The flying height over forests was 60m and

92m while surveying woodlands and grasslands. The flight speed was 100km/h with 200m strip width.

The GPS (Geographical Positioning System) in the helicopter was used to assist in navigation and for recording waypoints (observation points) as recommended by Douglas-Hamilton (1996). For each group or individual elephant sighted we recorded the location as waypoints with GPS co-ordinates, the group size, the number of individuals is each age classes (adult or calves), the number of individuals of each sex (for adults only) and the vegetation type where the individual or the group was located. In some cases, photographs were taken to enable a more detailed count and check at a later stage.

Satellite tracking

Satellite tracking data denoting the locations of four young elephant cows and a bull between February 1998 and August 1999, were obtained using the techniques described by Lindeque & Lindeque (1991), Thouless (1996), Tchamba (1996) and Ntumi (1997). Five collars were used in this study, both fitted with a ST-14 Platform Transmitter Terminal (PTT) for satellite transmission and a MOD-600 VHF beacon transmitter (Telonics Inc. 932 Impala Ave, Mesa, Arizona 85204-6699, USA). All PTT's had different identification numbers and identifier signals and the VHF transmitters were transmitting on different frequencies. The PTT's used a frequency of 401.650 MHz with a 24/48 hour on/off duty schedule to extend battery life to about 2 years. The VHF transmitters were continually transmitting a 60 ms pulse per minute on the 177.200 MHz; 177.300 MHz; 177.400 MHz; 177.500 MHz and 177.600 MHz frequencies, respectively. For ground reception and location we used a a Telonics TR-2 receiver and a three element Yagi RA-14K hand-held antenna

The five collars were placed onto elephants during February 1998. We selected four young elephant cows from different groups for collaring, as they are known to rarely leave their natal herds (Moss 1996). The young bull that we selected for collaring was known to be a member of a separate group than the four cows. The selected elephants were immobilized with the anaesthetic M99 (Etorphine hydrochloride) delivered through a dart following the procedures as described by Kruger-Med Pharmaceuticals (Pty.) Ltd.(Whyte 2001). Various body measurements (see Appendix 2) were taken during about 10 minutes while the collars were attached.

Due to the difficulty of receiving a signal and the decrease in accessibility of the MER, VHF-radio telemetry was not used to obtain the data on elephant locations during this study. VHF telemetry was used only to locate the PTTs for retrieval.

Service Argos, in Toulouse, France calculated the locations of the PTT's, when receiving identifier signals. A successfully received identifier signal is called an uplink and information from several uplinks are combined to calculate a location based on the angle of reception. From Toulouse, France the data were sent to Maputo, Mozambique by e-mail at three-day intervals.

Data Analysis

Due to the resources shortages, no beacons (PTT's placed at known locations in the study area for future corrections on acquired elephant satellite locations) were used in the study. To avoid the inaccuracy of the locations, those with a quality of class 1 and class 0 (where accuracy was ≤ 1000 m and > 1000 m, respectly) were excluded from calculations on home ranges. Only class 2 and 3 data were analyzed (for more details see ARGOS 2000; Tchamba 1996). Class 3 data comprise locations in which accuracy was ≤ 150 m. Class 2 data have an accuracy of ≤ 350 m.

The local time in Mozambique was calculated by adding two hours to the GMT location hour. The UTM distances between successive locations (x_i,y_i) and x_{i+1}, y_{i+1}) was determined from the equation given by White & Garrot (1990):

$$\text{Distance} = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

where, x is the latitude and y is the longitude.

The minimum speed an elephant moved was calculated by taking the straight line distances between two subsequent locations per time that have elapsed between locations using the equation *speed* = *distance*/$t_{i+1} - t_i$, where, t is the time and **i** is the location (White & Garrot 1990).

Locations obtained between 06:00 am and 18:00 pm. were categorized as daytime observations and those from 18:01 pm. to 05:59 am as nighttime observations.

The time spent by the elephant in a particular habitat was assessed calculating the time that elapsed between locations within a given habitat. The assessment of the influence of season on movement and habitat use was based on distinguishing the wet season data (those collected from November to April) from the dry season data (those collected from May to October). Due to individual differences in the period of data collection only data collected over the first six months of the study were used to assess the individual identity on movement patterns. The Adaptive Kernel (AK) and the Minimum Convex Polygon (MCP) routines of the Calhome program (Kie *et al.* 1996) were used to calculate home range variables such as the core areas. Geographic coordinate data were converted to UTM using the MADTRAN program, also part of Calhome. Comparisons with other studies (Leuthold 1977a; Lindeque & Lindeque 1991; Tchamba 1996) are based on the Minimum Convex Polygon areas as described by White & Garrot (1990), Harris *et al.* (1990). However, due to the disadvantages of the Minimum Convex Polygon method (White & Garrot 1990 and Harris *et al.* 1990), the Adaptive Kernel method was used in this study to quantify home ranges and for comparisons between animals. It produces an area with very little bias and gives surface estimates with the lowest error (Seaman & Powell 1996).

The ARCVIEW GIS query package (ESRI 2000) was used to determine and illustrate the locations and the extent of home ranges of individual elephants during the seasons and the time of day. The Calhome program also calculated distances between successive locations. The proportional overlap of the home ranges of individual elephants was calculated by dividing the home range size of each elephant by that of the others with which it overlapped.

Mean monthly rainfall and climate records for the periods 1970 to 1974 and 1995 to 1999 for Bela Vista Meteorological station (4km from MER) were obtained from the National Meteorological Institute of Mozambique[2].

Seasonal differences in home range areas were tested using the paired T-test (Conover 1980, Zar 1984). The daytime/night distances between successive locations were tested using the Wilcoxon Matched Pairs Test (Motulsky 1995). A Mann-Whitney U-Test (Motulsky 1995) was used to test the distance between successive locations when the male was in or outside the MER.

---

[2] Instituto Nacional de Meteorologia. Caixa Postal, 256 - Maputo. MOÇAMBIQUE

RESULTS

Helicopter Survey

Most (97%) of the 311 elephants sighted during the October 1999 aerial survey occurred within the MER. A few (2%) were noted outside the MER (western boundary) and only 2 bulls were recorded along the Futi Corridor. During the survey 36.7% of elephants were noted in woodlands, 34.7% in forests and 28.6% in grasslands. By excluding resightings the minimum size of the population has been estimated at 205 individuals.

Satellite tracking

Five elephants (four females and a male) were fitted with satellite tracking collars. Two of them, a female and a male were tracked for less than a year, as their collars were broken at the end of the 1998. The other three cows were followed for periods ranging from sixteen months to twenty-three months (Table 2). In total, 3997 locations were successfully obtained from the satellites (see Table 2).

Most (83.5%) of the locations fell within classes 2 and 3 (≤ 350 m). Excluding these locations and repetitive locations, the locations available for analyses for the first six months of tracking were dramatically less than that reflected in Table 2 (see Table 3).

Since the number of locations may affect calculated estimates of home range size, the minimum number of the locations considered as the optimum for the analysis in this study was 20 locations (Adaptive Kernel method) (Harris *et al.* 1990, Powell 2000) (see Fig. 3). However, estimates for individual home ranges reached asymptotes at different values and followed different trends (Fig. 3).

Seasonal Movements

The patterns of movement were uniform during the study considering the seasonality of use of space available for elephants in the MER. Both rainy and dry seasons elephant movements were restricted to the vicinity of the Futi River (Figs 4 & 5). The male, moved into the Massuane, Salamanga and Maputo floodplain areas outside the MER (see Fig. 6).

During this study the elephants did not move more than 5km to the south of the MER along the Futi River (Fig. 7).

Space use

Home range polygon sizes calculated with the Adaptive Kernel (95%) are shown in Table 4 and Figs 4 & 5. The Minimum Convex Polygon (MCP)(90%) and 50 and 70 % core areas determined by the Kernel method for all elephants are also presented in Table 4.

The information in Table 4 and in Figs 4, 5 & 7 and Appendix 1 reveal that although the MER extends over an area of 800 km^2 the range of the elephants tracked during this study covered only 33.0% of the total surface area. The core area for all elephants collectively calculated as 50% Adaptive Kernel extend over less than 6% of total surface area of the MER. The differences between the areas of elephant home ranges during the dry and rainy seasons were not statistically significant (Paired T=-1.33, df=4, p>0.05). However, values for the females for the rainy season were greater than those for the dry season (Table 4). The dry season range covered 22% of the total surface area of the Reserve whilst the wet season range covered 26% thereof.

The male had a larger home range than the females (Table 4 and Figs 4 & 5). The home ranges of individual elephants in the MER overlapped considerably (see Table 5). The area of these ranges was at the lower end of those recorded for other areas (Table 6).

The distances between successive locations moved by these elephants during the night (mean = 2.91 km, S.E. = 0.12; N = 786) and during the day (mean =3.78 km, S.E. = 0.14; N=727) were not similar (Wilcoxon Matched Pairs Test, T =1; N=10; p < 0.05) (Fig. 8). Distances between successive locations for the dry season (mean = 2.92 km, S.E. = 0.12; N = 737) differed significantly (Wilcoxon Matched Pairs Test, T =2; N=10; p < 0.05) from those for the rainy season (mean = 3.73 km, S.E. = 0.13; df = 776) (Fig. 9).

In areas outside the MER where humans have settled (Salamanga and Massuane) the mean distance between successive locations for the bull (mean = 3.33, S.E. = 0.45 and N = 97) was greater but not significantly (Mann-Whitney U-Test, $U_{36/97}$ = 1562; p > 0.05) than those within the MER (mean = 3.16, S.E. = 0. 31 and N = 36).

Table 2: The number of successful locations for the different elephants as a function of accuracy class and the period over which the movements of each individual was tracked.

Elephant	ID - Code	Accuracy Class 1[a]	2[b]	3[c]	Total (1+2+3)	Period in months
Female 1	6454	211	396	553	1160	23
Female 2	6455	223	224	517	964	20
Female 3	6456	118	214	268	600	11
Female 4	6457	24	176	758	958	16
Male 1	6458	84	125	106	315	11
Total		660	1135	2202	3997	

[a] locations where Argos estimates $\sigma \leq 1000$ m

[b] locations where Argos estimates $\sigma \leq 350$ m

[c] locations where Argos estimates $\sigma \leq 150$ m

Table 3: The number of class 3 locations for each of the five elephants collected over a six-month period of satellite tracking as a function of season. Here the dry season includes locations collected between May and October, while the rainy season include those collected between November and April.

Elephant	ID – Code	Dry season	Wet season	Total
Female 1	6454	79	63	142
Female 2	6455	43	24	67
Female 3	6456	64	38	102
Female 4	6457	88	36	124
Male 1	6458	60	55	115

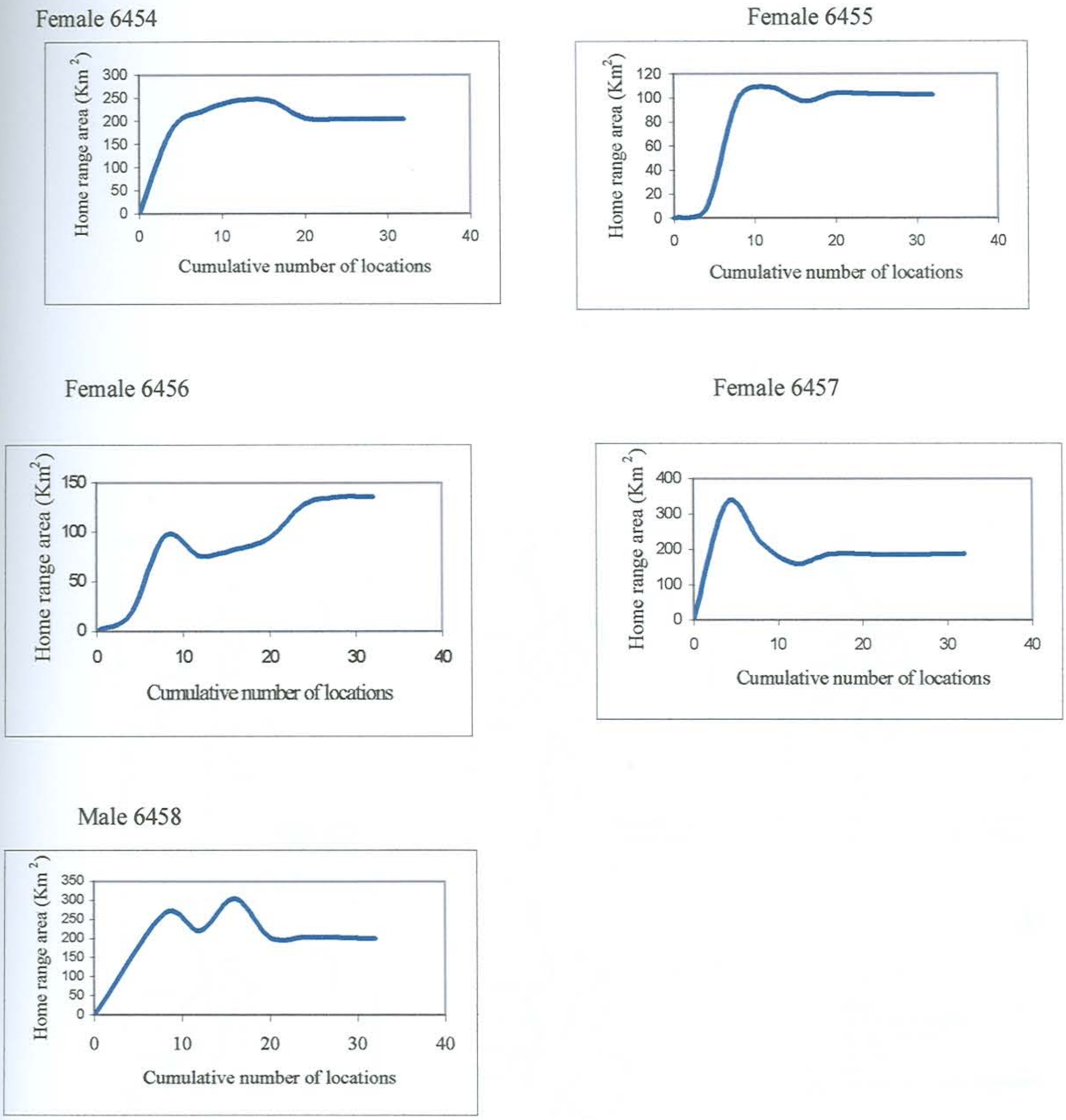


Figure 3: Home range area as a function of the cumulative number of locations included in the estimate using the Adaptive Kernel method for five individual elephants.

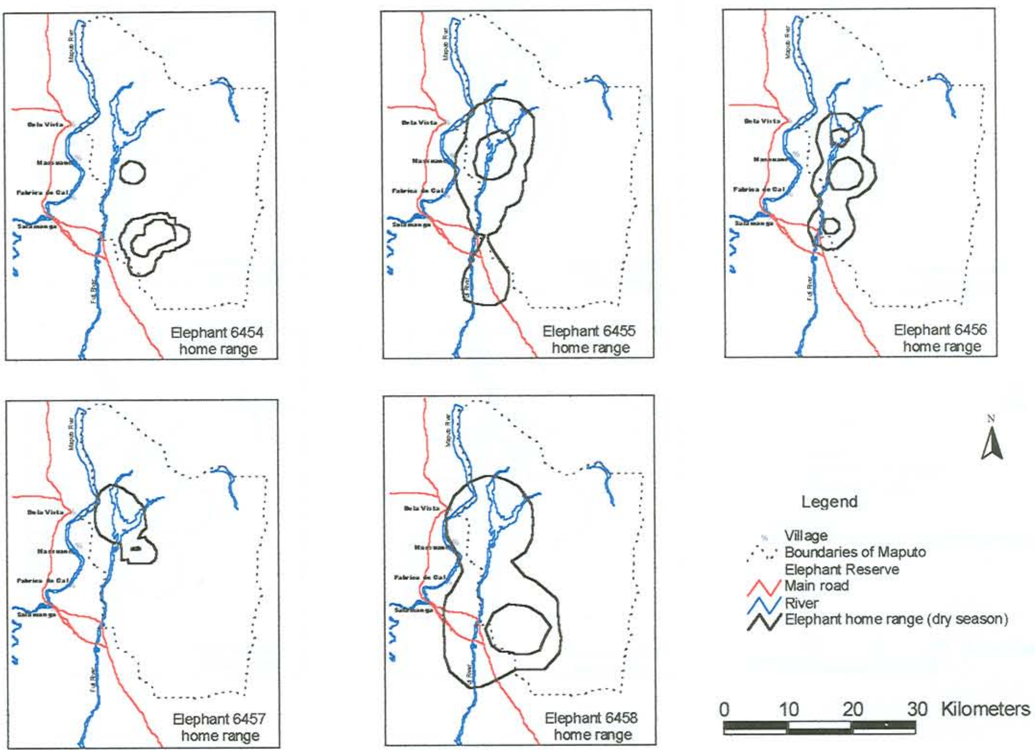


Figure 4: Home range locations and shapes of the tracked elephants during the dry season from February 1998 to August 1999. Here the dry season includes locations collected between May and October of each year.

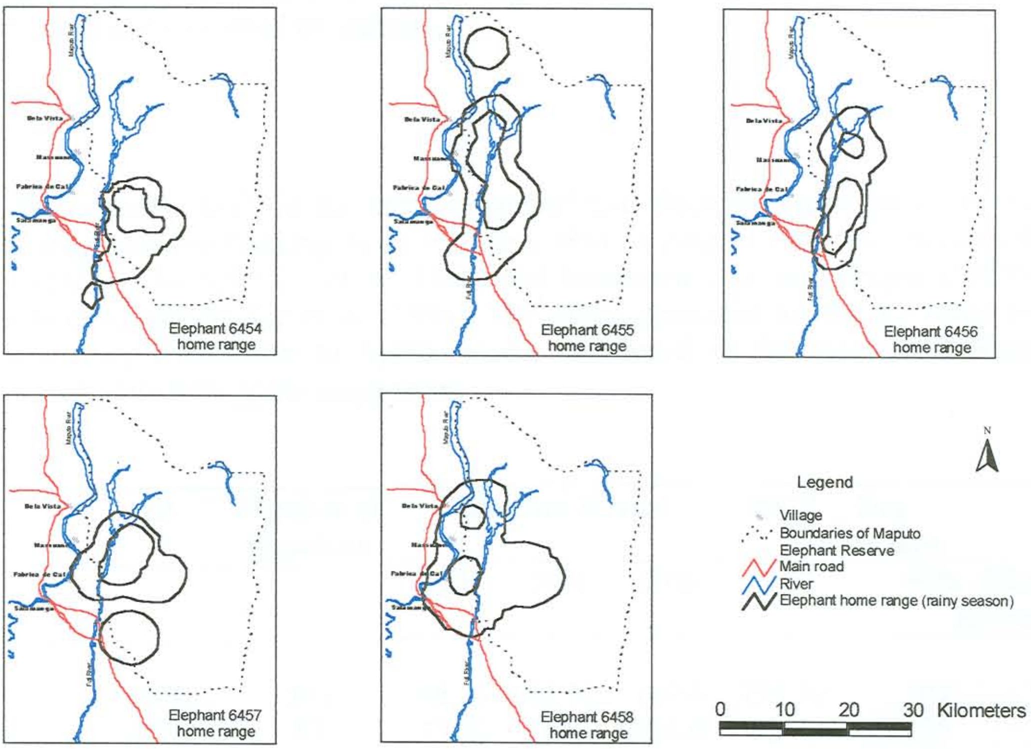


Figure 5: Home range locations and shapes of the tracked elephants during the rainy season from February 1998 to August 1999. Here the rainy season includes locations collected between November and April of each year.

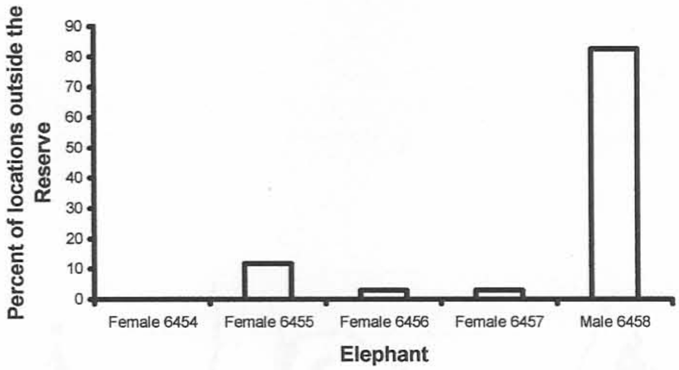


Figure 6: The frequency of locations for individual elephants beyond the boundaries of the Maputo Elephant Reserve during the study period (February 1998 to August 1999). The male spent most of his time on the Salamanga, Massoane and Madjajane floodplains that are inhabited and cultivated by humans.

Table 4: The areas (in km^2) of the home ranges of five elephants based on locations obtained through satellite tracking from February 1998 to August 1999 and calculated using the Adaptive Kernel (Kie *et al.* 1996) and Minimum Convex Polygon (MCP) techniques as described by Kie *et al.* (1996). The values presented for the dry (May to October) and rainy (November to April) seasons are based on the Adaptive Kernel technique to calculate 90% home range areas.

Elephant	**ID**	**Number of locations**	**Adaptive Kernel**			**MCP**	**Dry season**	**Rainy season**
			50%	70%	90%		90% Adaptive Kernel	
Female 1	6454	142	46.56	81.11	169.4	156.30	105	130.4
Female 2	6455	67	73.82	103.3	266.6	121.6	195	208.6
Female 3	6456	102	42.36	73.66	218.8	102.6	125	196.7
Female 4	6457	124	0.52	28.26	218.1	95.37	64.43	206.2
Male 1	6458	115	66.06	140.7	452.9	206.8	381.2	286.8
Mean for females			40.81	71.58	218.23	118.97	122.36	185.48
S.E for females			30.27	31.51	39.68	27.24	54.59	37.07

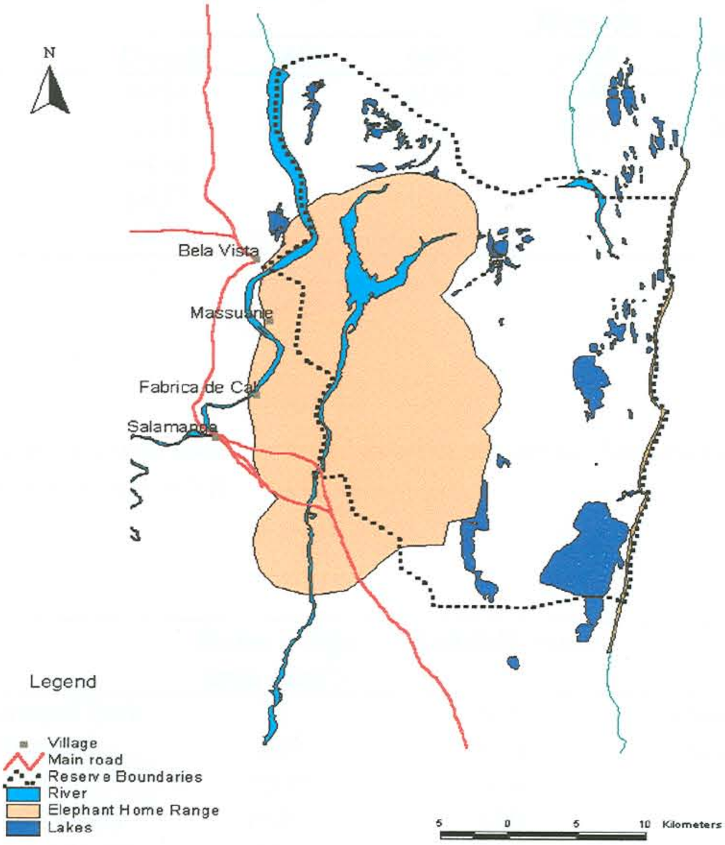


Figure 7: The collective home range (90% Adaptive Kernel) of five elephants based on satellite locations collected from February 1998 to August 1999.

Table 5: The proportional overlap of the home ranges of individual elephants based on data obtained through satellite tracking from February 1998 to August 1999.

		ID-code				
Elephant	**ID-code**	**6454**	**6455**	**6456**	**6457**	**6458**
Female 1	6454	1	0.64	0.46	0.77	0.39
Female 2	6455		1	0.72	0.84	0.6
Female 3	6456			1	0.6	0.84
Female 4	6457				1	0.51
Male 1	6458					1

Table 6: Elephant home range areas recorded in other studies on African elephants. All these estimates are based on the MCP method.

Area	**Home range area (km^2)**	**Rainfall (mm)**	**Reference**
Lake Manyara National Park	33	825	Douglas-Hamilton (1972)
Tarangire Game Reserve	330	650	Douglas-Hamilton (1972)
Sabi Sand Reserve	<200	619	Fairall (1979)
Tsavo National Park (East)	1620	550	Leuthold & Sale (1973)
Tsavo National Park (West)	746	260	Leuthold & Sale (1973)
Kruger National Park	436	590	Hall-Martin (1984)
Kruger National Park	523	590	Whyte (2001)
Northern Namib Desert	2172	64	Viljoen (1988)
Etosha National Park	7250	171	Lindeque & Lindeque (1991)
Waza National Park	1660	700	Tchamba (1996)
Gola Forest Reserve	250	3000	Meiz (1986)
Middle Zambezi Valley	179 (cows)	793	Dunham (1986)
MaputoElephant Reserve	129	845	Ntumi (1997)
Maputo Elephant Reserve	311	845	This study

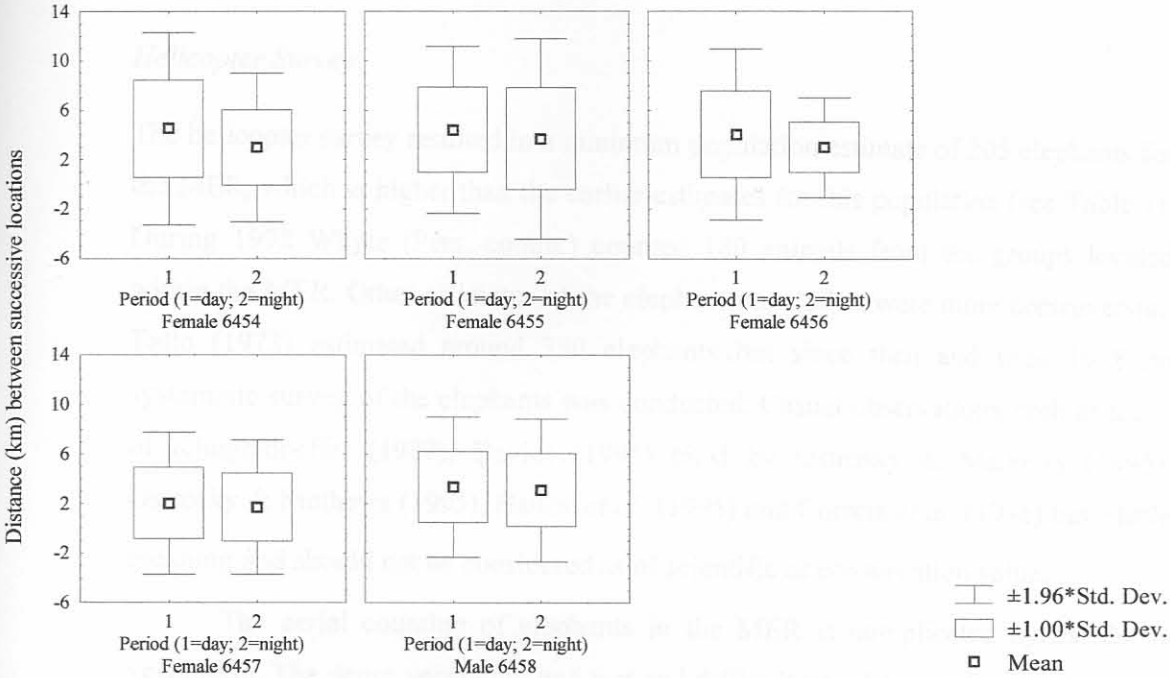


Figure 8: Mean distance (km) between successive locations as a function of the period of time that elephants have been tracked in the Maputo Elephant Reserve.

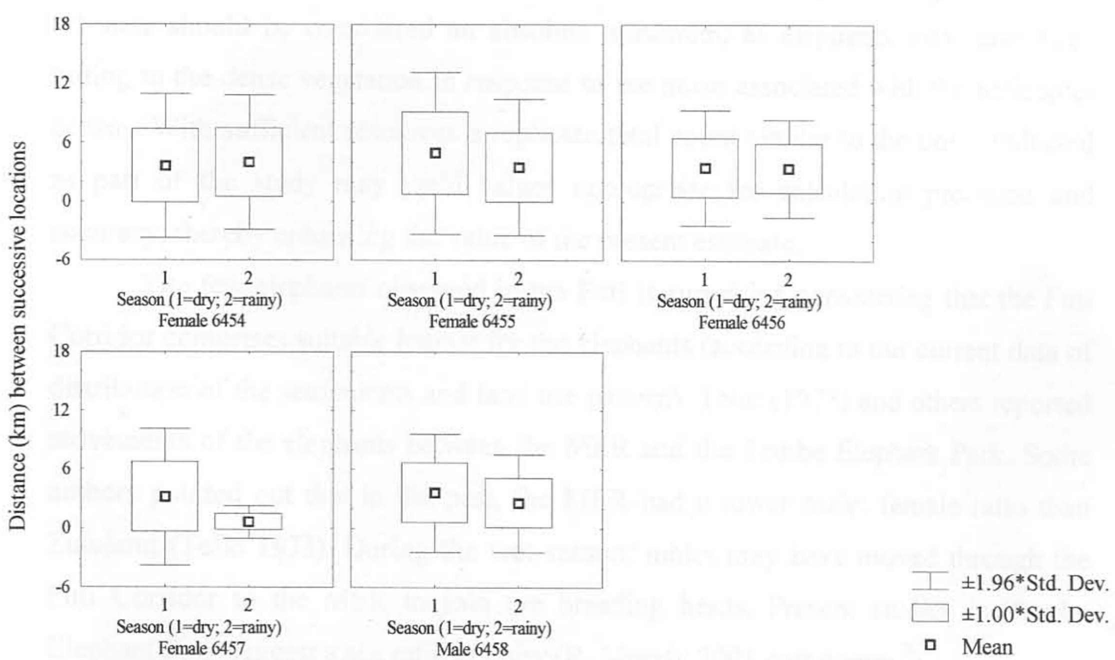


Figure 9: Mean distance (km) between successive locations as a function of the season that elephants have been tracked in the Maputo Elephant Reserve.

Discussion

Helicopter Survey

The helicopter survey resulted in a minimum population estimate of 205 elephants for the MER, which is higher than the earlier estimates for this population (see Table 1). During 1998 Whyte (Pers. comm.) counted 180 animals from the groups located within the MER. Other estimates of the elephant population were more controversial. Tello (1973) estimated around 350 elephants but since then and until 1998 no systematic survey of the elephants was conducted. Casual observations such as those of Klingelhoeffer (1987), Davies (1995) cited by Ostrosky & Mathews (1995), Ostrosky & Mathews (1995), Hatton *et al.* (1995) and Correia *et al.* (1996) have little meaning and should not be considered as of scientific or conservation value.

The aerial counting of elephants in the MER is complicated by the dense vegetation. The dense vegetation and wet and difficult traveling conditions prevailing in the MER also rendered ground counts nearly impossible with the limited logistical support that was available during the present study. Elephants living here are also rarely seen from the ground, except when they are out on the grasslands. Due to the conditions within the MER and the nature of the present helicopter survey, the present estimate should be considered an absolute minimum, as elephants may have been hiding in the dense vegetation in response to the noise associated with the helicopter census. With sufficient resources a replicate total count similar to the one conducted as part of the study may yield values appropriate for calculating precision and accuracy, thereby enhancing the value of the present estimate.

The few elephants observed in the Futi is surprising considering that the Futi Corridor comprises suitable habitat for the elephants (according to our current data of distribution of the settlements and land use pattern). Tello (1973) and others reported movements of the elephants between the MER and the Tembe Elephant Park. Some authors pointed out that in the past, the MER had a lower male: female ratio than Zululand (Tello 1973). During the wet season, males may have moved through the Futi Corridor to the MER to join the breeding herds. Present studies in Tembe Elephant Park suggest a sex ratio at unity (R. Morely 2001 pers.comm.[3]).

3 Conservation Ecology Research Unit (CERU), University of Pretoria, Pretoria 0002, South Africa

At the mid dry season in Mozambique (October), the temperatures rise (see Appendix 3) and herbaceous biomass becomes less available (personal observation). In the Ruaha National Park, Tanzania, rising temperatures during the mid-dry season (September-October) were associated with low food availability (Barnes 1983). Under these circumstances elephants experienced a much greater heat load and as a consequence spend more time resting. As they may be resting in the shade provided by the dense forests they may not have been noted during the helicopter survey.

The few elephants noted during the survey of the present study also contrasts with more recent observations based on satellite tracking. A study from September 2000 to December 2001 showed that elephants do move all along the Corridor and those individuals can be encountered throughout the Futi Corridor (van Aarde & Fairall 2001). The few elephants noted in the Futi Corridor during both the October 1999 (present study) and April 2001 (van Aarde & Fairall 2001) helicopter surveys may be the result of poor visibility in the dense vegetattion or elephants being seasonally elsewhere.

Satellite tracking

Conventional radio tracking locations are only estimates and not exact locations (Harris *et al.* 1990, Garrot & White 1990). Factors that increase the size of the error include the distance away from the animal, the nature of the terrain and the atmospheric conditions. Satellite tracking locations are also estimates (ARGOS 2000). Tchamba (1996) placed beacons in various habitats in Cameroon. He used information from them to correct satellite locations. No beacon was used in the present study and it was not possible to correct for the inaccuracy of the satellite locations through a similar method. However, System Argos does give figures which allow an estimate of the accuracy of the locations given by the platform transmitters (ARGOS 2000). According to this all locations used in the present study should be within 350 m of the actual position, with most being within 150 m. Given the elephants movement capabilities a 350 m radius can be considered very accurate and only locations on the edges of habitat units could present measurement difficulty. This distance is also likely to be within the accuracy of measurement of the vegetation map used to interpret habitat use (see Chapter 3).

Estimates for individual home ranges reach asymptotes at different values (Figure 3). Previous studies on elephants argued that a hundred locations are sufficient for home range analysis using the Minimum Convex Polygon (MCP) (Leuthold 1977a) and 20 locations for kernel analysis methods (Powell2000). For the current study 20 locations may thus be considered the minimum number of fixes needed. The irregular distribution of preferred vegetation types and water might influence the number of fixes required (White & Garrot 1990), while the period over which the study was done (only one annual cycle in this case) and the accuracy of locations would also affect the number of fixes required (N. Fairall 2001 pers comm.[4]).

The actual number of locations in the present study are constrained by the time that the various collars were functional. In most cases this was in any event more than 100 with 67 being the lowest number, this conforms with the minimum requirements as stated in the literature and as can be seen in Figure 3 provides an asymptotic value.

Movements pattern

Very few mammal species use the space within their home ranges randomly (Harris *et al.* 1990) and elephants are no exception. Elephants select certain preferred areas, considered *core* areas (see Appendix 1) and, although home ranges of all collared elephants during the study have shown some overlap (Table 5) they showed mutually exclusive *core areas*. This means that these individuals probably belong to different elephant groups (Leuthold 1977a, Moss 1988).

Whyte (1996) correlated elephant movement in the Kruger National Park with rainfall. He observed increased distances between successive locations during the rainy season just after heavy rains. It is not clear what governs elephant movement in the MER. The north-south and east-west movements observed during the dry and rainy seasons, were also observed by Ostrosky (1987) in the Tembe Elephant Park. A monitoring program of elephant movements across the international border between South Africa and Mozambique in the Tembe Elephant Park before the electric fence was erected (Ostrosky 1987, 1988 and 1989) revealed peaks of elephant movements from Tembe to Mozambique during the wet season. These groups comprised breeding herds, lone bulls and bachelor groups. During the dry season, a reduction of movements was observed and were limited to bulls. Game scouts of the Tembe

Elephant Park (mentioned by Ostrosky 1987) recorded that elephants crossing into Mozambique returned to the Tembe Park in the same night or after a few days.

Scientific data regarding the Maputaland (Tongaland)[4] elephant ecology are scarce. Thomson (1974) cited by Klingelhoeffer (1987) mentioned that the elephant population at Muzi-Sihangwana area (Zululand) was in excess of 20 with a possible maximum of 50. He suggested that there were three to four small mixed groups (i. e. with cows and calves) permanently resident in the thickly wooded areas around Muzi-Sihangwana northern KwaZulu-Natal, whilst the remaining herds comprised only bulls (Klingelhoeffer 1987). According to the Red Data Book on large mammals of South Africa (Skinner, Fairall and Bothma 1977 cited by Klingelhoeffer 1987), the number of elephants estimated for northern Tongaland was not more than 30, where no confirmed sightings of breeding herds were reported since 1946.

The elephant populations of the Tembe Elephant Park and the MER use to be a single entity connected through the Futi Corridor (van Aarde & Fairall 2001). The separate sub-populations are seen as being maintained through an artificial barrier in the form of an electrified fence erected during 1989. The ecological consequences resulting from this fence have not been studied.

Space Use

Size and shape of individual home ranges

Differences in the size of the home ranges of elephants have been noted in other studies (Harris *et al.* 1990, Tchamba 1996 and references therein). Those differences are mainly due to the pattern of resource distribution (Douglas-Hamilton 1972, Hanks 1979, Dunham 1986, Laws *et al.* 1975, Whyte 2001), sex of the elephant (Owen-Smith 1988), environmental factors (Laws *et al.* 1975, Hanks 1979, Owen-Smith 1988, Whyte 2001) and to the method used to study the movements of the animals (as elephants are not the exception) (Kenward 1987, Garrot & White 1996, Harris *et al.*

[4] Maputaland is a recognised center of plant endemism (van Wyk 1994) and stretches across the international boundary between Mozambique and South Africa. It encompasses the area from Indian Ocean to Pongola River northern KwaZulu Natal and to the Lebombo mountains across Maputo River flood plains, southern Mozambique. This area has a high biodiversity, distributed over the Tembe – Ndumo area, Futi River floodplains and the Maputo Elephant Reserve. The sand forest and woody grassland are endemic to Maputaland (van Wyk & Smith 2000, cited by van Aarde & Fairall 2001). Floristically, the sand forest is unique and supports a large number of neo-endemics, suggesting recent and ongoing evolutionary processes (van Aarde & Fairall 2001).

1990, Seaman & Powell 1996, Powell 2000). Food quantity and quality, and the availability of water are the most important factors determining how far elephants move (Hanks 1979).

The results of the MCP, has highest variances (Garrot & White 1996, Harris *et al.* 1990, Seaman & Powell 1996, Powell 2000). The adaptive Kernel method of describing home ranges shows accurate estimates of home range areas and had the smallest variance (Powell 2000; Seaman & Powell 1996). According to Powell (2000) and Seaman & Powell (1996), the adaptive Kernel estimator overestimates true home range area by about 25 percent. Kernel estimators share three shortcomings with most other home range estimators. First, they ignore time sequence information available with most data on animal locations. Second, sometimes the method produces 95 percent home range outlines that have convoluted shapes or disjunctive islands of use. Third, the method does not estimate how important these disjointed islands of the home range are to the animal (Garrot & White 1990, Powell 2000).

The home range size of the tracked elephants in this study measured as MCP, is within the range of values recorded by Douglas-Hamilton (1972) for the Tarangire Game Reserve, Douglas-Hamilton (1972) for Lake Manyara Park, Tanzania, Fairall (1979) for Sabi Sand Reserve, Leuthold & Sale (1973) for Tsavo National Park, Hall-Martin (1984) for Kruger National Park, Whyte (2001) for Kruger National Park and Ntumi (1997) for MER (see Table 6). However, these values were well below those recorded elsewhere. For instance in the savanna of Tsavo East National Park, Kenya, female elephants were radio-tracked over areas of up to 1800 km^2 (Leuthold 1977a, Owen-Smith 1988). More recently, Lindeque & Lindeque (1991) recorded home ranges over 8700 km^2 in northwestern Namibia. The Etosha National Park, northwestern Namibia, is an arid environment with limited food and water, suggesting that elephants cope by being highly mobile and opportunistic (Lindeque & Lindeque 1991). The observed small and stable elephant home ranges in Kruger National Park by Whyte (2001) are seen as related to the existing artificial waterholes network throughout the Park and to the well distributed system of permanent and semi-permanent rivers. Thus, most of the tracked elephants by Whyte (2001) had direct access to the permanent rivers within their home range.

During the present study home range (position or area) was probably related to the distribution of water (Figs 4 and 5) and vegetation types in the MER (Fig. 10). Small home range sizes of family units in the Lake Manyara Park were observed in forest habitat with abundant ground water (Douglas-Hamilton 1972). Grasslands and sand forest mosaics dominates the eastern areas of the MER. The western side comprises of sand forest patches and green riverine vegetation along the Futi River (DCB 2000). Ntumi (1997) reported that water distribution did not limit elephant distribution in the MER. Many water sources are found throughout the MER such as the Lakes Chingute, Piti, Munde, Nele and Nhame, with low salinity for Lakes Piti, Munde and Nhame.During the present study elephants did not occur in the eastern areas of the MER. Aerial photographs taken during 1958 and comments by local people revealed that in the past, people occupied the eastern part of the MER and there were and intensely cultivated large portions thereof. This probably gave rise to the development of the grasslands and sand forests mosaics pattern, which is now common in the eastern part of the MER.

Fire decreases biomass in the short term (Mentis & Tainton 1984, Trollope 1984) and Bhima (1998) observed a small increase in height and crown volume of trees in burned plots in Liwonde National Park, Malawi. Nowadays, burning has been seen as playing a role in manipulating the distribution of elephants and their impact on vegetation in most African Parks (McShane 1987). Jachmann (1984) reported a negative relationship between elephant distribution and burnt areas in Kasungu National Park, Malawi. The reason that elephant tend to avoid burnt areas in Kasungu National Park is that burning scorches the leaves and thin twigs that make up an important component of their diet (Jachmann 1984). Plant productivity in tropical forest ecosystems is explained by a tight nutrient cycling, determined by the integration between the release of nutrients by decomposition and their uptake by the vegetation (Anderson & Swift 1983). In fact, tree ecosystems depend completely on input of natural N and leguminous trees and shrubs contribute to the nitrogen economy of tropical regions (Ishizuka 1992). The grasslands and woodlands in the eastern parts of the MER regularly burns. Through this both N and C are often volatized and removed from the system without replenishment. Fire may in this way reduce the fertility and productivity of the poor sandy soils of this part of the MER (Menaut *et al*. 1991, Holt & Coventry 1991, Scholes 1991).

Veld fires are common in the MER, especially in the open eastern areas. Few people are living here and human induced disturbances can thus not explain why elephants are not using this part of the MER. It is possible that the fire-induced reduction in vegetation cover as well as the low fertility of soils render this part less suitable for elephants than the other parts of the MER. However, range use may be affected by other factors and further increases in the elephant population may give raise these apparently marginal ranges also being used by elephants.

The distribution and supply of water affect home range size of elephants in most African Parks (Leuthold 1977b, Owen-Smith 1988, Viljoen 1988, Lindeque & Lindeque 1991, Tchamba 1996). According to Leuthold (1977b), the lack of open water in large parts of the Tsavo National Park limits their use by elephants during the dry seasons, as the elephants concentrated within reach of permanent water supplies. Water is widely distributed throughout the MER and is not a limiting factor (see Ntumi 1997) in both seasons. Owen-Smith (1988) pointed out that dry season range only covers 10% of the area of wet season range in different conservation areas as the elephants limit their movements to areas close to permanent water sources in the dry season. This was not the case in the present study, probably as a consequence of high plant productivity and food availability.

Home range size represents a compromise between individual metabolic requirements and social factors (Damuth 1981a cited by Owen-Smith 1988). Thus, for most African ungulates only female home ranges can be related directly to nutritional requirements, because male home range are more influenced by the fission-fusion patterns with breeding herds (Owen-Smith 1988). Different foraging strategies of females and males could explain the large home range of the male. Since the females are more selective than males (Owen-Smith 1988), they probably feed on more nutritious plants than the males, who need a larger amount of food, leading to the large home range recorded for the male during the present study.

Without a regular registration of the rainfall in the MER, travelled distance between successive locations cannot be discussed in relation to the local rainfall.

The larger distance between successive locations observed outside the MER suggests that elephants were more mobile, maybe because of conflicts with humans in Madjajane, Massuane and Salamanga as was observed in Cameroon by Tchamba (1996). Most of the excursions out of the MER were made during rainy season and the night by the male. This suggests that the roaming out of the MER is associated with feeding on agricultural crops and supports the Sukumar's (1989) observation that crop damage is caused mainly by male elephants rather than females, and normally takes place at night during the rainy season..

Another factor promoting increased nocturnal activity by megaherbivores is the maintenance of a thermal equilibrium. Metabolic rates are related to the proportion of surface area available for dissipating body heat (Owen-Smith 1988). It is advantageous for megaherbivores to be more active at night, when there is a reduced environmental heat load. But the small travelled distance between successive locations at night observed during this study, contradicts those explained above. It may due to the other external factors influencing elephant behaviour at the MER (see Chapter 3). Without a systematic ambient temperature record during this study it was not possible to correlate this factor to the calculated home range sizes.

Conclusions

The elephants of the MER confined their home range to the North West boundary of the MER. With absence of regular movements synchronised by season, I can conclude that there are no elephant migrations in the MER.

Small home range sizes of elephants were observed in this study and no significant differences were found between seasonal home ranges sizes. Short daily distance in the dry season was found. This result is consistent with expected dependence between elephants and surface water distribution and food as the MER receives from 690 to 1000 mm (see Appendix 4) of rain per year considerable more than of any of the mentioned areas in table 6. Therefore, I can conclude that, water and food distribution, determine the elephant space use in the MER.

CHAPTER 3

HABITAT USE

Methods

Elephant distribution is affected by ecological and population variables. Habitat analysis includes the determination of the availability, the degree of utilization and the preference for each habitat type by the elephants (White & Garrott 1990).

As the concept of habitat is so controversial (Garshelis 2000; Klingelhoeffer 1987), only the vegetation types will be considered as habitat in this study. The measurement of the availability of each vegetation type in the MER was assessed from the digitised polygons of each vegetation type of the Arcview vegetation map of the MER. A section of 527.8 km^2 covering the western side of the MER that was intensely used by elephants, was selected to represent the availability of vegetation types. All polygons named in the MER vegetation map as Sand Forest (SF) and Sand Thicket (ST) were treated as forest.

The number of locations obtained in a particular vegetation type for each animal was assumed to correspond with the percentage of time spent in that vegetation type and as such could be used as a relative measurement of vegetation type use. All locations were displayed on the digitised map using Arcview GIS.

The number of locations in each vegetation type was counted and vegetation type preference was calculated by assuming that if one vegetation type was preferred, more locations in that specific vegetation type were recorded than could be expected on the basis of the area occupied by this vegetation type within the home range of a given animal. If a vegetation type is preferred, one or more of the remaining vegetation types would have been avoided because of the time constraints (White & Garrott 1990). Thus, the Chi-squared test proposed by White & Garrott (1990) and Wonnacott & Wonnacott (1990) was used to test for the goodness of fit of utilized vegetation type to available vegetation types as well as if the elephant vegetation types utilisation was affected by seasons. Preference Indices (PI) have been determined for all five elephants as described below (White & Garrott 1990, Wonnacott & Wonnacott 1990) (see Table 7).

A preference index (PI) >1 suggested that the vegetation type was preferred; if 1>PI>0.5, the preference for the vegetation type was neutral and PI<0.5, the vegetation type was considered to be avoided.

Plant biomass and vegetation cover was taken from DCB (2000), Haandrikman (1998) and Vriesendorp (1998) and included into the MER vegetation map. Excel spreadsheet computer calculations were used to calculate the local time in Mozambique from GMT elephant locations data. After this, the time spent in a particular habitat type was calculated. Distance and speed travelled were determined from successive locations, which formed part of one cycle of tracking[5].

A paired T-test (Zar 1984) was used to test for differences between daytime/night and dry/rainy vegetation preference. A Wilcoxon Matched Pairs Test (Motulsky 1995) was used to test if the roaming speeds through the vegetation types were influenced by the time of day. T-test was used to test for difference on habitat preference by sex of elephant.

Results

Vegetation type preference

The vegetation types were not randomly used by elephants as would be expected on the basis of area covered by each vegetation type (see Table 10B). Elephants preferred Forest and Futi riverine vegetation types, whilst the use of grasslands and woodland were relatively neutral or with a low preference (for more details see Tables 8 & 9 and Fig. 10).

The preference for vegetation types by the male was similar to that of the females (T-test, T=-0.26, df=16, p>0.05). However, the male did use woodlands outside the MER more frequently than the females, mainly during the rainy season (Tables 10, 11 & 12).

---

[5] The PTT's have a 24/48 hour on/off duty schedule. One cycle is a period of time that PTT's were continually transmitting the signal during the 24 hours.

Table 7: Preference Index calculation based on White & Garrott (1990) and Wonnacott & Wonnacott (1990) methodology. This example is related to the elephant Female 6455 tracked from February 1998 to August 1999.

Habitat type	Area (km^2)	πo	Observed frequency	Expected Frequency	χ^2	p	1,96√p(1-p)/n	π (95% CI)	PI = p / π o	SD
Forest	146.570	0 .278	24.000	24.186	0.001	0 .276	0 .094	0 .182-0.370	0 .993	0 .338
Woodland	122.210	0 .232	39.000	20.184	17.649	0 .448	0 .105	0 .344-0.553	1.931	0 .453
Hygrophilous grassland	162.290	0 .307	11.000	26.709	9.274	0 .126	0 .070	0. 057-0.196	0 .410	0 .228
Futi vegetation	21.520	0 .041	12.000	3.567	20.142	0 .138	0 .072	0. 065-0.210	3.366	1.756
Maputo flood plain	17.050	0 .032	0.000	2.784	2.810	0.000	0.000	0. 000-0.000	0.000	0.000
Woody grassland	16.570	0 .031	1.000	2.697	1.097	0 .011	0 .022	0. 011-0.034	0 .355	0 .710
Tidal wetland	17.250	0 .033	0.000	2.871	2.843	0.000	0.000	0 .000-0 .000	0.000	0.000
Mangroves	13.040	0 .025	0.000	2.175	2.149	0.000	0.000	0 .000-0 .000	0.000	0.000
Others	11.300	0 .021	0.000	1.827	1.863	0.000	0.000	0 .000-0 .000	0.000	0.000
Total	527.800	1.000	87.000	87.000						

Where:

πo is the probability if **Ho** is true (area of the habitat type/total area of all habitat types)
Expected frequency = **πo** in a specific habitat type **x** total observed frequency
p=Observed frequency/n
n=Total frequency
π=p±1.96√p(1-p)/n
PI = preference index
SD=1.96√p(1-p)/ πo

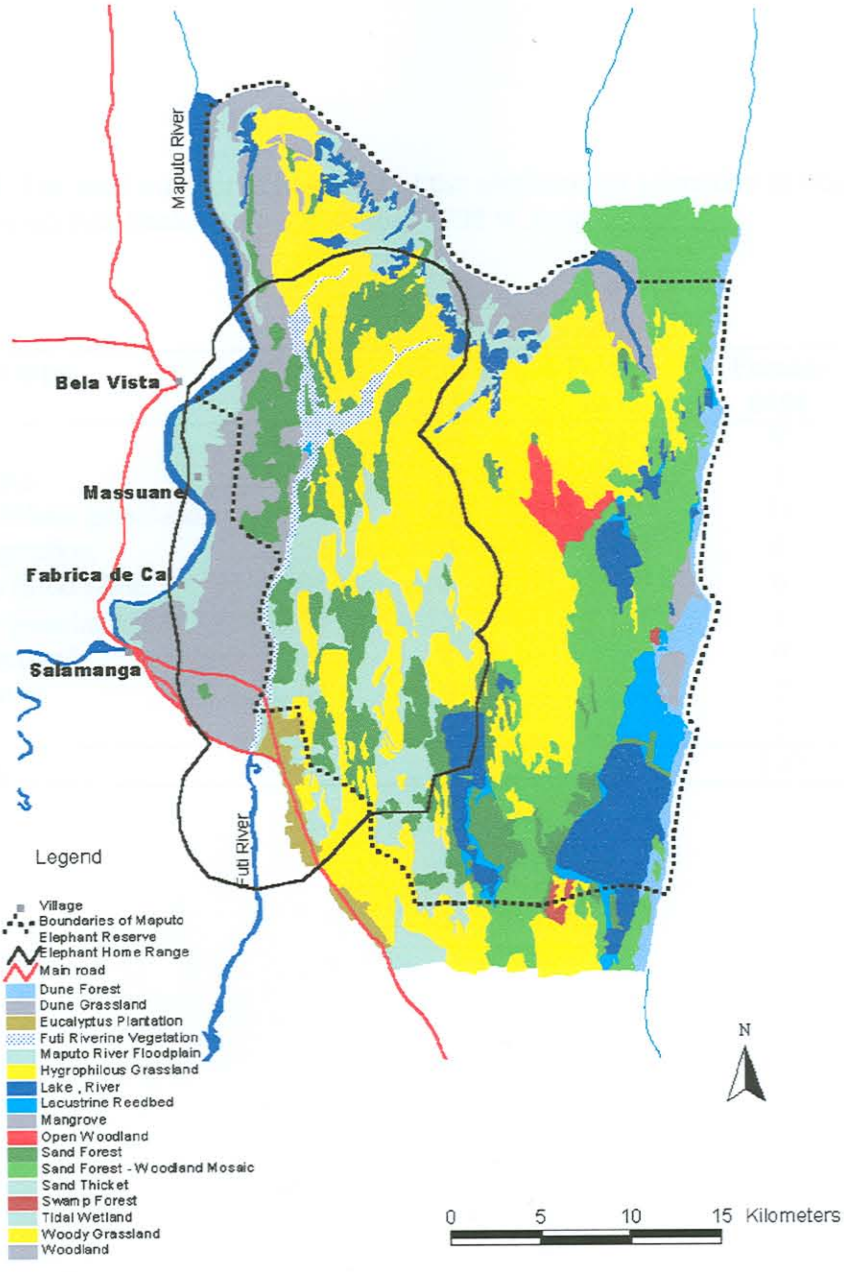


Figure 10: Vegetation types in the Maputo Elephant Reserve. The bold black line delineates the collective home range of the five elephants tracked from February 1998 to August 1999.

Table 8: The total number of locations of the elephants as a function of vegetation type based on satellite tracking from February 1998 to August 1999.

		Locations				
Habitat type	**Area (km^2)**	**Female 6454**	**Female 6455**	**Female 6456**	**Female 6457**	**Male 6458**
Forest	146.57	70	24	50	33	42
Woodland	122.21	22	39	3	7	42
Hygrophilous grassland	162.29	38	11	35	69	20
Futi vegetation	21.52	0	12	8	11	6
Maputo flood plain	17.05	0	0	0	0	2
Woody grassland	16.57	2	1	1	3	2
Tidal wetland	17.25	0	0	0	0	0
Mangroves	13.04	0	0	0	0	0
Others	11.30	9	0	5	1	1
TOTAL	527.80	141	87	102	124	115

Table 9: The number of locations of the elephants as a function of vegetation type based on satellite tracking from February 1998 to August 1999 during the dry season (May to October of each year) and rainy season (November to April of each year).

Habitat type	Area (km^2)	Locations									
		Female 6454		Female 6455		Female 6456		Female 6457		Male 6458	
		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Forest	146.57	42	28	16	8	33	17	23	10	32	10
Woodland	122.21	0	22	28	11	1	2	2	5	9	33
Hygrophilous grassland	162.29	30	8	10	1	20	15	54	15	16	4
Futi vegetation	21.52	0	0	9	3	6	2	9	2	3	3
Maputo flood plain	17.05	0	0	0	0	0	0	0	0	0	2
Woody grassland	16.57	1	1	0	1	1	1	3	3	2	2
Tidal wetland	17.25	0	0	0	0	0	0	0	0	0	0
Mangroves	13.04	0	0	0	0	0	0	0	0	0	0
Others	11.30	5	4	0	0	3	2	0	1	0	1
TOTAL	527.80	78	63	63	24	64	38	88	36	60	55

Table 10A: Preference indices and Chi-squared test results (A) calculated as methodology described in the methods section (see Table 7 and 8).

				Habitat type								
Elephant	**$\chi 2$**	**Df**	**P**	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female 6454	60	8	<0.001	0.876	1.788	0.452	0.000	0.674	0.000	0.000	0.000	2.981
Female 6455	57.83	8	<0.001	0.411	0.930	0.366	0.000	1.936	3.383	0.000	0.000	0.000
Female 6456	52.85	8	<0.001	1.116	1.765	0.312	0.000	0.127	1.924	0.000	0.000	2.290
Female 6457	60.82	8	<0.001	1.810	0.958	0.771	0.000	0.244	2.176	0.000	0.000	0.377
Male 6458	28.20	8	<0.001	0.566	1.315	0.554	0.000	1.577	1.280	0.000	0.538	0.406

Table 10B: The avoided, neutral or preferred vegetation types as a function of the identity of the five elephants. If in the table A, the preference index (PI) was more than 1, the respective vegetation type was considered as preferred in the table B; if 1>PI>0.5, preference for the vegetation type was considered neutral and PI<0.5, the vegetation type was considered avoided in the table B. Vegetation types are: Hygrophilous grassland(HG), Forest (FOR), woody grassland (WG), woodland (WOL), Futi vegetation (FV), Tidal wetland (TW), Mangrove (M), Maputo flood plain (FPL), OTHERS (including sand forest mosaic, eucalyptus plantation and lacustrine reedbed).

Elephant	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female 6454	Neutral	Prefer	Avoid	Avoid	Neutral	Avoid	Avoid	Avoid	Prefer
Female 6455	Avoid	Neutral	Avoid	Avoid	Prefer	Prefer	Avoid	Avoid	Avoid
Female 6456	Prefer	Prefer	Avoid	Avoid	Avoid	Prefer	Avoid	Avoid	Prefer
Female 6457	Prefer	Neutral	Neutral	Avoid	Avoid	Prefer	Avoid	Avoid	Avoid
Male 6458	Neutral	Prefer	Neutral	Avoid	Prefer	Prefer	Avoid	Neutral	Avoid

Table 11A: Preference Indices (PI) and Chi-squared test results for the dry season calculated as methodology described in the methods section (see Table 7 and 9).

				Habitat								
Elephant	**$\chi 2$**	**df**	**P**	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female 6454	56.3	8	<0.001	1.251	1.939	0.408	0.000	0.000	0.000	0.000	0.000	2.994
Female 6455	42.1	8	<0.001	0.516	0.915	0.000	0.000	1.919	3.504	0.000	0.000	0.000
Female 6456	38.5	8	<0.001	1.016	1.857	0.498	0.000	0.067	2.299	0.000	0.000	2.189
Female 6457	64.2	8	<0.001	1.996	0.941	0.000	0.000	0.098	2.508	0.000	0.000	0.000
Male 6458	25.6	8	<0.001	0.867	1.921	0.000	0.000	0.648	1.226	0.000	0.000	0.000

Table 11B: The avoided, neutral or preferred vegetation types by the five elephants. If in the table A, the preference index (PI) was more than 1, the respective vegetation type was assumed as preferred in the table B; if 1>PI>0.5, the vegetation type was neutral and PI<0.5, the vegetation type was considered avoided in the table B. Vegetation types are: Hygrophilous grassland(HG), Forest (FOR), woody grassland (WG), woodland (WOL), Futi vegetation (FV), Tidal wetland (TW), Mangrove (M), Maputo flood plain (FPL), OTHERS (including sand forest mosaic, eucalyptus plantation and lacustrine reedbed).

				Habitat					
Elephant	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female 6454	Prefer	Prefer	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Prefer
Female 6455	Neutral	Neutral	Avoid	Avoid	Prefer	Prefer	Avoid	Avoid	Avoid
Female 6456	Prefer	Prefer	Avoid	Avoid	Avoid	Prefer	Avoid	Avoid	Prefer
Female 6457	Prefer	Neutral	Avoid	Avoid	Avoid	Prefer	Avoid	Avoid	Avoid
Male 6458	Neutral	Prefer	Avoid	Avoid	Neutral	Prefer	Avoid	Avoid	Avoid

Table 12A: Preference Indices (PI) and Chi-squared test results for the rainy season calculated as methodology described in the methods section (see Table 7 and 9).

				Habitat								
Elephant	**$\chi2$**	**df**	**P**	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female1	30.700	8	<0.001	0.413	1.600	0.506	0.000	1.508	0.000	0.000	0.000	2.966
Female2	18.000	8	<0.001	0.136	1.200	1.327	0.000	1.979	3.066	0.000	0.000	0.000
Female3	16.600	8	<0.001	1.284	1.611	0.000	0.000	0.227	1.291	0.000	0.000	2.458
Female4	9.310	8	<0.001	1.355	1.000	2.654	0.000	0.600	1.361	0.000	0.000	1.297
Male1	47.400	8	<0.001	0.237	0.655	1.158	0.000	2.591	1.338	0.000	1.126	0.849

Table 12B: The avoided, neutral or preferred vegetation types by the five elephants. If in the table A, the preference index (PI) was more than 1, the respective vegetation type was assumed as preferred in the table B; if 1>PI>0.5, the vegetation type was neutral and PI<0.5, the vegetation type was considered avoided in the table B. Vegetation types are: Hygrophilous grassland(HG), Forest (FOR), woody grassland (WG), woodland (WOL), Futi vegetation (FV), Tidal wetland (TW), Mangrove (M), Maputo flood plain (FPL), OTHERS (including sand forest mosaic, eucalyptus plantation and lacustrine reedbed).

	Habitat								
Elephant	**HG**	**FOR**	**WG**	**M**	**WOL**	**FV**	**TW**	**FPL**	**OTHERS**
Female1	Avoid	Prefer	Neutral	Avoid	Prefer	Avoid	Avoid	Avoid	Prefer
Female2	Avoid	Prefer	Prefer	Avoid	Prefer	Prefer	Avoid	Avoid	Avoid
Female3	Prefer	Prefer	Avoid	Avoid	Avoid	Prefer	Avoid	Avoid	Prefer
Female4	Prefer	Prefer	Prefer	Avoid	Neutral	Prefer	Avoid	Avoid	Prefer
Male1	Avoid	Neutral	Prefer	Avoid	Prefer	Prefer	Avoid	Prefer	Neutral

The preference for vegetation types was affected by season (see Tables 11B & 12B) .

Distances between successive locations were larger in areas with a low percent of cover (grassland and woodland) than in the forested areas (see Table 13). Elephants, moved relatively slowly through vegetation types with a high biomass and plant cover (see Fig. 11). The time of day did not influence habitat use (Table 14). Significant differences were found between day and night time roaming speeds (Wilcoxon Matched Pairs Test, T=15; N=14; $p< 0.05$) (see Fig. 12).

Discussion

The habitats of the MER are not used randomly by elephants (Ntumi 1997, de Boer *et al.* 2000) as was also pointed out by Douglas-Hamilton (1972), Leuthould (1977a, 1977b), Owen-Smith (1988), Western & Lindsay (1984), and Laws, Parker & Johnstone (1975) in other Parks of Africa. A possible explanation for this phenomenon is that animal behaviour changes according to changes in the physical environment (temperature, rainfall) (Leuthould 1977b), the presence of habitat resources (including food, water and refuge from weather extremes) (Owen-Smith 1988) and quantity and quality of food (Leuthould 1977b). On the other hand the pattern of habitat use noted in MER also may be ascribed to: i) unequal number of successful locations obtained during the study; ii) unequal tracking period per elephant iii) the short period of elephant tracking and iv) differences in the areas of each habitat.

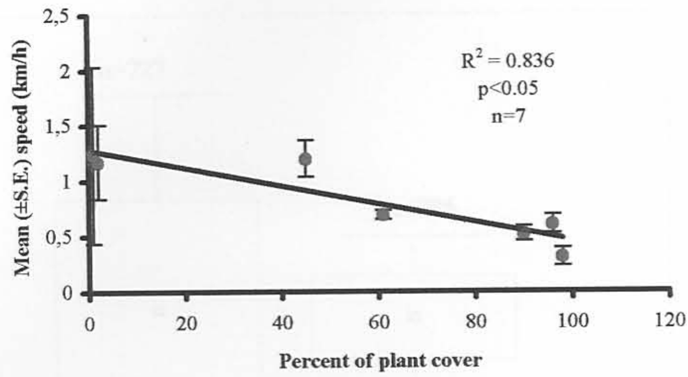
Small woody grassland (WG) patches adjacent to the more preferred habitats (forested areas) had significantly more elephant locations, which gave rise to high preference indices for woody grassland (WG) during the rainy season (see Table 12). Based on the characterisation of tropical forage quality described by Iason & Van-Wieren (1999) forested areas in the MER should offer a high food quantity (DCB 2000) but a lower food quality than the grasslands and woodlands. Thus elephants may accept the low food quality of forests in return for food quantity and an increased safety from disturbance (see Western & Lindsay 1984).

Although the preferences for vegetation types were not affected by sex of the tracked elephants in the present study the Futi riverine vegetation was more preferred by females, whilst the woodland was more preferred by the male. The Futi riverine vegetation comprises tall and green *Phragmites australis*, *Juncus kraussii* and green riverine forest composed by *Ficus sycomorus* (see details in Chapter 1). Has also high herbaceous biomass (Table 13). Probably, due to the high herbaceous biomass and high herbaceous percent of cover, the females may spend more time searching for food and seeking refuge. Some of the woodlands are close to the populated Salamanga and Massuane and to the agricultural fields in this area. The higher preference for the woodland close to agricultural fields by the male may be due to him raiding crops during the rainy season. It should be noted that this statement is based on observations on only one male and that his foraging behaviour may not be representative of that of all males in this population.

I could not discriminate between time devoted to feeding, foraging and resting by elephants in each habitat. A short distance between successive locations in the forest as well as the negative correlation observed between biomass, percentage cover and roaming distances may be the consequence of increased feeding, foraging or resting behaviour.

Elephants may select forest to balance the maximisation of forage intake with minimisation of risks, or to minimise exposure to intense sunlight and associated high ambient temperatures. The following explanations for this apparent behaviour may be formulated.

A



B

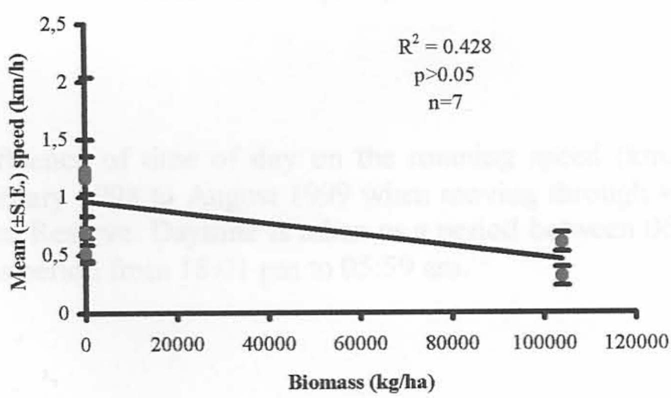


Figure 11: Mean roaming speed (Km/h) as a function of percent plant cover (A) and plant biomass (B). The analysis is based on the raw values estimated by DCB (2000) for Hygrophilous grassland, Sand forest, Sand thicket, Woody grassland, Woodland, Maputo River floodplain and Futi vegetation (see Table 13).

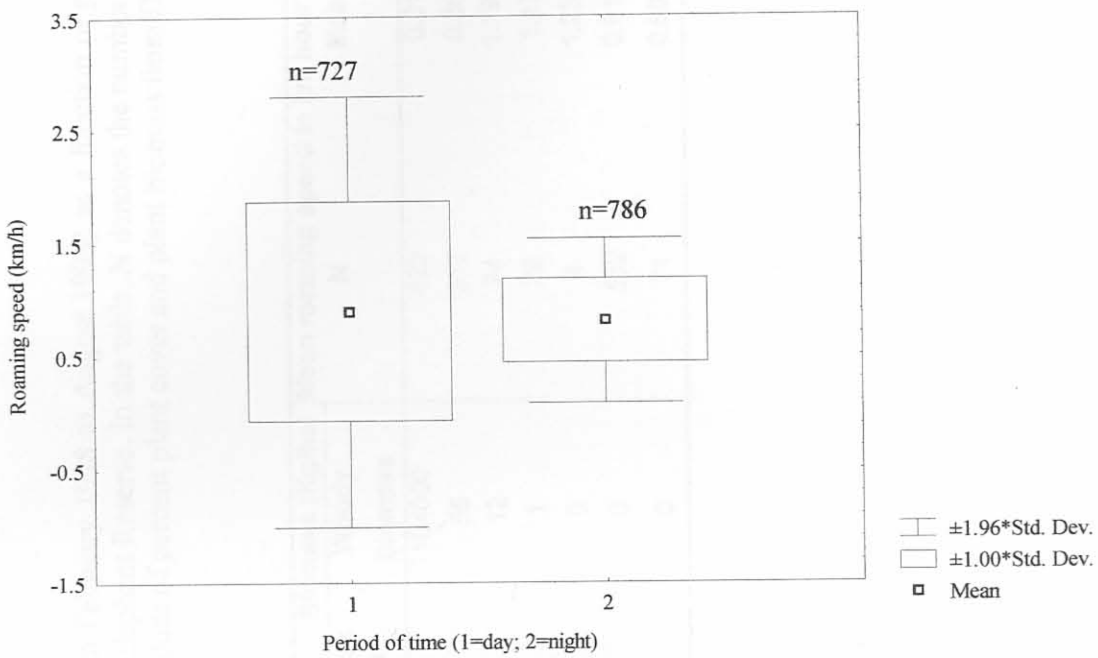


Figure 12: The influence of time of day on the roaming speed (km/h) of the tracked elephants from February 1998 to August 1999 when moving through vegetation types in the Maputo Elephant Reserve. Daytime is taken as a period between 06:00 am and 18:00 pm and nighttime as period from 18:01 pm to 05:59 am.

Table 13: Mean roaming speed (km/h) of the tracked elephants from February 1998 to August 1999) as a function of percent plant cover and plant biomass of the main vegetation types of the Maputo Elephant Reserve. In the table, N denotes the number of locations in the respective vegetation types. The analysis is based on the raw values of percent plant cover and plant biomass from DCB (2000).

	Percent of cover		Biomass (Kg/ha)		Mean roaming speed in km hour^{-1}		
Vegetation type	Herbaceous layer	Woody Layer	Herbaceous biomass	Woody biomass	N	Mean	S.E
Sand Forest	65	98	200	104000	422	0.31	0.011
Sand Thicket	80	61	800	55	317	0.69	0.041
Woodland	51	45	600	12	74	1.195	0.164
Woody Grassland	78	2	1100	1	26	1.17	0.334
Maputo River Floodplain	99	1	1500	0	4	1.234	1.407
Hygrophilous Grassland	90	0	1600	0	552	0.518	0.068
Futi Riverine Vegetation	96	0	3000	0	71	0.604	0.082

Table 14: The mean ± S.E. day and night time roaming speed in km hour^{-1} of the tracked elephants from February 1998 to August 1999 by the main vegetation types of the Maputo Elephant Reserve. In the table, **n** denotes the number of locations in the respective vegetation type.

Vegetation type	**Mean ± S.E. (n) roaming speed in km hour^{-1}**	
	Day time (06:00 – 18:00)	**Night time (18:01 – 17:59)**
Hygrophilous grassland	0.432±0.045 (282)	0.608±0.131 (270)
Forest	0.803±0.443 (343)	0.577±0.144 (396)
Woody grassland	2.985±2.744 (9)	0.600±0.329 (17)
Woodland	1.020±0.610 (24)	1.036±0.413 (50)
Futi vegetation	0.663±0.318 (29)	0.550±0.181 (42)
Tidal wetland	0.122±n/a (1)	0.659±0.654 (2)
Maputo flood plain	0.241±n/a (1)	1.565±1.207 (3)

Foraging reason

Elephants, like other animals, cannot obtain their essential nutrients without simultaneously exposing themselves to increased risks to their predators (Altman 1998). Thus, an adequate foraging strategy adopted by elephant would result not only in short-term effects but also in long-term consequences, such as the change of their foraging habits or their preferences.

The metabolic requirements of mammals increases with body mass to the power of 0.75 (Iason & van Wieren 1999). In contrast, the capacity of the gastrointestinal track increases linearly with body mass (Iason & van Wieren 1999). O'-Reagain & Goestsch (1996) have demonstrated that quantity of food ingested depends on the height of the herbage, the greenness and its digestibility. The more digestible a forage is, the higher quality is and the lower the percentage lignin it has (Iason & Van Wieren 1999).

Bell (1971) pointed out that larger animals could tolerate a lower forage quality. Mammals with a smaller body size are more selective, which increases diet digestibility but results in a negative relationship with intake rate because of the greater time required. Therefore, selectivity appears to be constrained by the costs of searching for and discriminating between forage resources (Wallis de Vries *et al.* 1994).

Chemical analysis revealed that generally, grasses have a high percentage NDF (Neutral Detergent Fibre), low percentage lignin, high percentage nitrogen and low percentage condensed tannin (Van Wieren 1996). Vegetation studies conducted in the MER by Tello (1973), Hatton (1995), Maria (1998), Vriesendorp (1998), Haandrikman (1998), Chuma (1999) and DCB (2000) revealed that the sand forest and sand thicket (composed mainly of dicotyledons) have a high percentage of browse and biomass while grasslands (mainly monocotyledons) have a high percentage of grasses and low total biomass. Elephant diet studies (Correia 1995, Mafuca 1996 and Banze 2000) in the MER noted that a large part of the diet consisted of dicotyledons. To be able to take in sufficient volumes of browse, high volumes of woody material with high lignin values and of low digestibility have to be ingested.

Apparently, a lower food quality was taken by elephants in the forest in an effort to increase total intake. The quantity-quality balance of the diet of elephants influences their food choice differently in each season. With a reduced availability of forage in the open areas and the forest providing green browse during the late dry season, elephants spend more time in the dense forests. Here they are able to find shade and also to forage on woody species under the canopy (Dublin 1996). But in the early wet season, inundated grasslands in the MER become green, increasing forage biomass and quality. According to Dublin (1996), elephants select primarily on the basis of forage quality but may be limited in their choice by the amount of food available within their range. The reported preference for forests during the dry season could be aimed at increasing forage biomass while the open areas (hygrophilous grasslands) with high forage quality were preferred during the wet season.

Refuge seeking

The foraging reason does not explain why elephants avoid forests close to Lake Piti and in the south of the MER along the Futi River. It also does not explain why elephants forage in the reedbeds of the MER. Probably, the home range of the elephant may not be limited only by food resources but by social, behavioural, physiological and/or other factors as Stern (1998) pointed out for elephants elsewhere.

Since elephants return to preferred habitats, resources within the revisited habitats should be reduced, eventually showing signs of vegetation damage (Stern 1998). However, there are no significant signs of elephant damage in the forests in the MER (Haandrikman 1998, Vriesendorp 1998). Because of the high biomass, the forest has a high percentage cover (DCB 2000) and thus, habitat selection may be dependent on cover. Large groups of elephants in open areas may be associated with a more defensive elephant behaviour (Western & Lindsay 1984). Breaking into small groups when they enter the forest could therefore be an immediate response to the artificial disturbance. In fact, during the elephant capture operations (1996, 1998) and the aerial survey (1999), we observed that the helicopter forced large groups of elephants feeding on the grasslands to break into small herds that fled into the forest.

Based on the elephant defensive behaviour and immediate response to the disturbance, I suspect that the grasslands and sand forest mosaics of eastern MER are probably less preferred by elephants in the MER for three main reasons: i) most of these areas are open, ii) are more accessible by roads, and iii) have fewer control posts, which could induce a higher poaching pressure.

Low cover in these habitats reduces refuge potential and poachers prefer open areas where antelopes can be caught more easily (personal observation).

Poaching in the MER by people from Maputo has been reported mainly from open areas and occurs during the night (Chambal 1996) and it is not directed at elephants. Only five small elephants have been poached during the last five years (personal observation).

During the last ten years poaching for antelopes has become more severe in the MER and has probably stressed the elephants which may have changed their preference from open areas (Tello 1973) to the sand forests (de Boer *et al.* 2000). Those observations could support the refuge seeking, which influence elephants' behaviour observed during this study and the differences on habitat use on day/night times (see Chapter 3, result section).

Physiological reasons

Leuthold (1977b) pointed out that climatic factors affect thermoregulatory behaviour, activity patterns and movements. Sunshine and temperature, wind and rain may act simultaneously and produce a variety of effects. As a general response to high temperatures, many ungulates seek shade and remain inactive during much of the day (Sikes 1971; Leuthould 1977b). According to Brooks (1961) cited by Leuthold (1977b), in cases where no shade is available wind can be used for cooling.

The enormous ear pinnae of African elephants facilitate cooling. Ear fanning rates are correlated with ambient temperature, and the temperature of the blood leaving the ear is cooler than that of the blood entering it (Buss & Estes 1971 cited by Owen-Smith 1988). Randall *et al.* (1997) refers to use of behavioural mechanisms for thermoregulation when the elephants move to a part of the environment where heat exchange with the environment favours attaining optimal body temperature. Regular daily temperature records from the MER do not exist. Mean monthly temperature recorded at Changalane post (Matutuine District) does not show significant changes from 1970 to 1999 (see Appendix 3) that can explain changes in elephant preference, from open areas (Tello 1973) to sand forest (Ntumi 1997, de Boer *et al.* 2000). The relatively high roaming speed during a day (Fig.12) may not be supported by those changes in mean temperature.

With the limited information available we may speculate that space and habitat use by elephants of the MER is affected by human disturbances (de Boer *et al.* 2000) induced by burning and poaching. Regular fires may reduce plant cover and biomass and convert forested areas into open grasslands. These open areas are prone to fire and poaching which force elephants to move to the forested areas (west of MER), where fires are at low intensity and there is high biomass, water and better game scout control.

Conclusion

The preferred habitat of the elephants of the MER has high biomass and high percentage of cover. The avoided ones are open and situated at east part of the MER where human disturbances are common. But, forested areas that are preferred by elephants have low biomass quality than avoided grasslands by elephants. However, the observed negative influence of plant biomass and the percent of cover on the elephant roaming speed appears that elephants may select forests by balancing the maximisation of intake and minimisation risks.

I can conclude then, that with the limited information available, habitat use by elephants in the MER is affected by human disturbances such as that induced by burning and poaching at east of the MER.

CHAPTER 4

IMPLICATIONS FOR MANAGEMENT

The MER and adjacent areas may have supported high densities of elephants in the past (Pardal 1996). Habitat changes and an increase in human densities may have resulted in the dispersion of elephants (Pardal 1996), compressing them into small areas, which have been declared Reserves (Cox 1997). Tello (1973) reported a large elephant home range in the MER but the pattern of elephant movements and their habitat use have changed (see Tello 1973, de Boer *et al.* 2000). We initiated this study to evaluate current home range size and habitat use by elephants in the MER and to discuss possible factors influencing home range size and habitat use. Some of these may be important for the management of the MER.

During my study the five elephants with satellite collars ranged over about one third of the area of the MER. They concentrated their activities in a core area which comprises about 6% of the MER and which was situated between the Futi and Maputo Rivers (see Fig. 7). The studied elephants may represent four to five of the breeding herds within the population and other herds may thus be using other parts of the MER. Counts during the helicopter survey conducted in October 1999 suggest that there may be as many as eight breeding herds in the population. Elephants thus in reality may be using a much larger proportion of the MER as is also supported by a more recent (September 2000 to September 2001) satellite tracking study of five elephants in southern Mozambique (N. Fairall pers. comm.).

Based on reports from the local people of the region the area between the MER and the Maputo River was used freely by elephants in the recent past. At that time, this area was covered by suitable habitats, including forests and thickets. Subsequently local communities settled and cleared the area for agricultural fields, thereby decreasing the availability of suitable elephant habitat. This may have given rise to increased conflict between the local human population and elephants.

Elephants still raid this area during the night and during the wet season (de Boer & Ntumi 2001). This could indicate that new ranges are required to allow to the elephant population to expand. Ecological management, including the possibility of enlarging the MER to include the area between the Reserve and the Maputo River will provide extra range and recover the traditional area for elephants. However, it will not reduce elephant-human conflict into the region. For this reason, the long-term viability for the elephant conservation with low human-elephant conflict and an extra elephant range may be achieved through the establishment of the Futi Corridor which could be electrically fenced on both sides of the Corridor.

Osborn (1996) and H. H. T. Prins (pers. comm[6].) suggested that the vegetation of the MER maybe have a poor quality and can not support high animal densities. It is not possible in this discussion to argue the Orborn and Prins's perceptions about the Maputo Elephant vegetation quality. However, the MER belongs to the sour veld type (van Rooyen *et al.* 1996) where, most important types of grazing plants lose their palatability and nutritional value at maturity. As a consequence nutritional deficiencies can occur for at least three months of the year (van Rooyen *et al.* 1996). The sour veld vegetation type is found in the other Southern African conservation areas which supports too many elephants (see van Rooyen *et al.* 1996). The area in MER preferred by elephants (Fig. 10) is relatively more suitable (in terms of plant biomass and percent of cover) than the avoided one, east of the MER. The forested patches more common in this area (see Fig. 10) have a higher plant biomass and high percentage of plant cover (see DCB 2000) than the grasslands dominating the east of the MER.

During the present study habitat use by elephants was not random and they preferred forest and Futi floodplain vegetation. Many explanations have been considered as influencing habitat selection by elephants. Biomass and plant cover seem to offer the best answers to the elephant habitat use. Elephants require a large amount of food and a high percentage of cover for refuge seeking from human disturbance but, although the forest has a high biomass and a high percentage of cover, they are patchily distributed in the MER (see DCB 2000). Within the elephant's home range (see Fig. 10), 57 small forest patches were recorded. Elephants are area-sensitive and it is likely that large patches are preferable for them to smaller ones with the same total area (Cox 1997).

The impact of elephants on the MER may result in high pressure in certain localised parts of the MER with high conservation value. In fact the home range

6 Tropical Nature Conservation and Vertebrate Ecology Group, Wageningen University, The Netherlands

polygon measured covers the sand forest, sand thicket and woodland (Fig. 8). The sand forest and woody grassland are endemic to Maputaland (van Wyk & Smith 2000 cited by van Aarde & Fairall 2001). Floristically, the sand forest is unique and supports a large number of neo-endemics, indicating recent and ongoing evolutionary processes (van Aarde & Fairall 2001).

The protection of endangered species includes the designation of critical habitat, consisting of areas either within or outside the range of the species that are essential to its conservation (Cox 1997). Although the elephants of the MER mainly feed of trees and shrubs (de Boer *et al*. 2000) available in sand forests, sand thickets and woodlands, few signs of damage of the vegetation in these habitats by elephants were reported by Haandrikman (1998), Vriesendrop (1998).

The confinement of elephants within the MER could eventually increase their impact on the vegetation. To avoid an increased elephant pressure, the proposed extended Trans-frontier Conservation Area (TFCA) in which elephants can move freely will reduce the potential impact on the vegetation even further.

As has been recorded during this study the elephants occur mostly near the Futi River and in the sand forest. These areas have low human density and very little human conflict is experienced, making the use of the Futi as a Corridor between the MER and Tembe Elephant Park possible. People live along the Maputo River and on the Palm veld to the east of the lower Futi River, where they brew a palm wine. In the MER, the number of houses in the eastern area between Lake Munde and the sea is increasing (van Aarde & Fairall 2001). From a management point of view, it is recommended that the influx of people to the MER and to the Futi Corridor be controlled.

CHAPTER 5

SYNTHESIS

The conservation of the African elephant, *Loxodonta africana*, presents a challenge, not only due to the ethical issues that are involved, but also because of the dearth of information on which management decisions could be based.

Elephants have few natural predators (Laws *et al.* 1975, Hanks 1979), a long life expectance (Hanks 1979) and destructive feeding behaviour (Laws *et al.* 1975, Malan 1992 and references therein). Because of that, at high population densities modify the diversity of a conservation area by turning areas of high diversity into wastelands with little or no conservation value (Bhima 1998).

This implies that well-defined elephant management practices might be also useful to conserve the biodiversity of the ecosystem, using elephants as a flagship species (van Aarde & Fairall 2001). Elephant management practices involve studies on elephant space and habitat relationship as have been done during the current study in one of the recognized centre of endemism, the Maputaland Centre of Endemism (van Wyk 1994).

This study has been based on the recognized dependence of elephant distribution and movement to the resources (Douglas-Hamilton 1972, Hanks 1979); human disturbance (Barnes *et al.* 1991, Hoare & du Toit 1999, de Boer *et al.* 2000) and environmental factors (Laws *et al.* 1975, Hanks 1979, Whyte 2001).

The distribution of the elephants, current elephant population size and the respective space and habitat use study was carried out following public perceptions that the high incidence elephant-human conflict, as reported by de Boer & Ntumi (2001), may be due to increased number of elephants in the MER. There have been many speculations about the movements and supposed existing migrations of elephants in the MER. The wildlife authorities in Mozambique, are interested on establishing the Futi Corridor, linking the MER and Tembe Elephant Park as a Conservation area.

205 elephants were counted during the survey, most of them (98%) in the MER and the remaining 2% in the Futi Corridor. Because of the very dense vegetation in the MER and in the Futi Corridor, counting elephants from the air was

found difficult and, for that, this estimate should be considered as the minimum. The elephants did not randomly use the total area of the MER and concentrated their activities to the north western parts of the MER. I did not find evidence supporting an increased incidence of raiding of agricultural crops in areas adjacent to the MER. Elephant movements are normally local and generally confined to home ranges within the MER. This study also does not support evidence of reported elephant migrations. However, elephants do move along the Futi Corridor, which may be part of a traditional route used by them in earlier days.

My analyses showed that the elephants did not use the available vegetation types at random and the forest and Futi floodplain vegetation types were selected, whilst grasslands and woodlands were avoided. Preference for a vegetation type was function of the time of day. The mean distance between successive locations was negatively correlated with biomass and plant cover of the vegetation type. With the limited information available I may deduce that space and habitat use by elephants of the MER as being affected by human disturbances (de Boer *et al.* 2000) induced by burning and poaching. Regular fires reduce plant cover and biomass and converts forested areas into open grasslands. These open areas are prone to fire and poaching which force elephants to move to the forested areas (west of MER) where fires are at low intensity and there is high biomass, water and better game scout control.

I found evidence that explain the lack of habitat quality in the east of MER, mainly due to the human disturbance. The confinement of elephants within the MER could eventually increase their impact on the vegetation (Laws *et al.* 1975, Hanks 1979 and references therein).

Since I recorded that the male comes regularly into conflict with humans during the rainy season, maintaining elephants and human together will raise the conflict between these two populations. I can state that because of human disturbance in the east of the MER and the consequence of that in the elephant population behaviour, elephants need more space and more resources south west of the MER. A long-term management measure, which minimizes conflicts between elephants and humans and maximizes elephant conservation in this area through the establishment of the Futi Corridor as a conservation area would provide for the foraging needs of an increasing elephant population. Therefore, this study supports the Trans-Frontier Conservation initiative aimed to link the MER (Mozambique) and Tembe Elephant Park (South Africa) through the Futi Corridor.

Summary

This study on elephant space and habitat use was carried out in the MER, southern Mozambique. Created in 1932, with an area of 800 km^2, the MER is a very important wildlife conservation area in southern Mozambique, both for elephants and other animals.

Increased human density in southern Mozambique during the last century has reduced the available habitat for wildlife, especially elephants, which have been compressed in the MER. Elephants occasionally do come into conflict with human populations outside the MER. This may explain the negative attitude of some humans on elephant conservation (de Boer & Baquete 1998).

A minimum of 205 elephants lived in the MER during October 1999.

The range preferred by elephants has not changed since Tello (1973) reported on elephant movements in the MER. However, inside this range, elephants now prefer closed areas to the open areas. 30% of the total available area of the MER and an additional area outside are utilised by elephants. On average, the 70% Adaptive kernel contour included about 10.7% of the annual home range, suggesting a high concentration of activity in a relatively small portion of the home range along the Futi River. This result is consistent with the expected dependence of the elephants on the water and their high plant biomass requirement.

The analyses of vegetation types selected inside each home range showed that forested areas with high biomass and a high plant cover as well as the Futi riverine vegetation were preferred. This suggests that the use of vegetation types can be allocated in proportion to food, water or both and the elephants may adjust the size of home range in response to decreasing habitat resources. Thus, I argue that the food availability was not a single factor determining the use of space and habitat.

The frequency of occurrence of elephants outside the MER (Tello 1973, Osborn 1996, de Boer *et al.* 2000 and de Boer & Ntumi 2001) is likely to be due to insufficient resources. This result is consistent since the forested areas are preferred by elephants and van Aarde & Fairall (2001) pointed out that 12% (97km^2) of the total area of the MER is covered by sand forest while the Futi Corridor comprises some 25% (168km^2) of the area.

Game numbers are presently low due to hunting and poaching in the past. These practises will have to be controlled before restocking is considered. Correia (1995) and Mafuca (1996), showed diet overlap between elephant and other big mammals, but no cases of stress due to competition have been reported yet. Past studies reported a high human density in the MER until the 1980's, which has resulted in vegetation changes. Now, the human population settlements around the MER and in the eastern areas (between Lake Munde and the sea) are increasing and new initiatives for the establishment of the Dobela project are also developing. Since elephants and people do not mix well (Leuthold 1977a) the potential for conflict is considerable. I attributed the change of elephants preference in the MER, from open areas (Tello 1973) to forested ones (de Boer *et al*. 2000) to the effect of the human disturbance.

From this and preceding sections, important conclusions for MER management can be formulated:

- The minimum and maximum home range areas required by females were estimated at 169 and 267 km^2, respectively whilst the male home range was 453 km^2, but these can overlap.
- Space *per se* is not a constraint on elephant movement in MER and because the home ranges can overlap, there is considerable space for increase of the elephant population size.
- Because of high variability of data, no significant differences between elephant home range sizes were observed during the dry and rainy seasons.
- Forest, Futi riverine vegetation and the hygrophilous grassland are the most preferred elephant vegetation types at the MER.
- Foraging efficiency may play a major role in the distribution of elephant.
- The establishment of the Futi Corridor will increase the area available to elephant, reduce potential conflicts with humans and decrease potential pressure on the most preferred habitats.

REFERENCES

ALTMAN, S. A. 1998. *Foraging for Survival: Yearling Baboons in Africa.* The University of Chicago Press, USA.

ANDERSON, J. M. & M. J. SWIFT. 1983. Decomposition in Tropical Forests. In S. L. Sutton; T. C. Whiltmore and A. C. Chadwick (Eds.) *Tropical Rain Forest: Ecology and Management,* pp. 287–309. Blackwell Scientific Publications, Oxford.

ARGOS. 2000. *User's Guide: satellite data Collection and Location System.* Argos, Toulouse.

BANZE, C.F.O. 2000 . *Avaliação dos Danos Causados Pelos Elefantes na Reserva Especial do Maputo.* Unpublished Report. Universidade Eduardo Mondlane, Moçambique.

BARNES, R. F. W. 1983. Elephant behaviour in a semi-arid environmental. *Afican Jounal of Ecology* **21**: 185 -196.

BARNES, R. F. W., BARNES K. L., ALERS M. P. T. & BLOM, A. 1991. Man Determines the Distribution of Elephants in the Rain Forests of North-eastern Gabon. *Afican Jounal of Ecology* **29**: 54-63.

BARNES, R. F. W., BEARDSLEY K., MICHELMORE F., BARNES K. L., ALERS M. P. T. & BLOM, A. 1997. Estimating Forest Elephant Numbers with Dung Counts and a Geographic Information System. *Journal of Wildlife* **61**(4): 1384-1393.

BELL, R. H. V. 1971. A grazing ecosystem in the Serengeti. *Scientific American Journal* **225**: 86-93.

BHIMA, R. 1998. *Habitat Utilization and Population Dynamics of the African Elephant Loxodonta africana in the Liwonde National Park, Malawi.* PhD thesis University of Pretoria, South Africa.

CHAMBAL, M. 1996. *Reserva Especial de Maputo. Relatório do Progresso Setembro 1995-Maio 1997.* Interin report. DNFFB, Maputo.

CHUMA, M. 1999. *Estudo da Vegetação e da Herbivoria através da Instalação de Quadrículas Definitivas na Reserva Especial de Maputo.* Unpublished Report. Universidade Eduardo Mondlane, Maputo.

CONOVER, W. J. 1980. *Practical Nonparametric Statistics*. Second Edition. John Wiley & Sons, New York.

CORREIA, A. U., de BOER F., NTUMI C. P. 1996. Trabalho de Investigação junto `a Reserva Especial de Maputo. In D. Dias, P. Scarlet, J. Hatton and A. Macia (Eds.) *O Papel da Investigação na Zona Costeira,* pp. 45-49, Universidade Eduardo Mondlane, Maputo.

CORREIA, A.U. 1995. *Determinação da Dieta de Cinco Espécies de Herbívoros Grandes da Reserva de Maputo pelo Método das Análises Fecais.* Unpublished Report. Universidade Eduardo Mondlane, Maputo.

COX, G. W. 1997. *Conservation Biology. Concepts and applications.* Second Edition. Wim. C. Brown Publishers, USA.

DCB-Department of Biological Sciences 2000. *Vegetation Map of Maputo Elephant Reserve.* Eduardo Mondlane University, Maputo.

DE BOER, F. W. & NTUMI, C. P. 2001. Elephant crop damage and electric fence construction in the Maputo Elephant Reserve, Mozambique. *Pachyderm* 30:57-64.

DE BOER, F. W., NTUMI C. P., CORREIA A. U. & J. M. MAFUCA . 2000. Diet and distribution of elephant in danger: The Maputo Elephant Reserve, Mozambique. *African Journal of Ecology* **38**: 188-201.

DE BOER, F. W. & D.S. BAQUETE. 1998. Natural resource use, crop damage and attitudes of rural people in the vicinity of the Maputo Elephant Reserve, Mozambique. *Environmental Conservation* **25**(3): 208-218.

DEODATOS, F. D. & A. K. LIPIYA. 1991. *Public Relations & Crop Protection Electric Fencing, Kasungu National Park.* FO: MLW/87/010, Field Document 0019. FAO, Malawi.

DEODATOS, F. D. & L. SEFU. 1992. *Wildlife Management and Crop Protection, National Survey of Wildlife Pests.* FO:MLW/87010. Field document 0024. FAO, Malawi.

DINAGECA. 1994. *Mapa Florestal.* Projectos FAO/PNUD MOZ/86/003CMOZ/92/013. Mozambique.

DNFFB. 1997. *Plano de Maneio da Reserva Especial de Maputo:* 1997-2001. DNFFB, Maputo.

DOUGLAS-HALMILTON, I. 1972. *On the Ecology and Behaviour of the African Elephant.* PhD thesis. Oxford University, England.

DOUGLAS-HAMILTON, I. 1996. Counting Elephants from the air – Total Counts. In K. Kangwana (Ed.) *Studying Elephant*, pp. 28-37. African Wildlife Foundation, Nairobi.

DUBLIN, H. T. 1996. Elephants of the Masai Mara, Kenya: seasonal habitat selection and group size patterns. *Pachyderm 22:25-35.*

DUNHAM, K. M. 1986. Movements of elephant cows in the unflooded Middle Zambezi Valley, Zimbabwe. *Afican Jounal of Ecology* 29: 287-291.

ESRI-Environmental Systems Research Institute 2000. *Arcview GIS ESRI.* California.USA.

FAIRALL, N. 1979. A radio tracking study of young translocated elephants. In Amlaner, C. J. & Macdonald, D. W. (Eds.) *A Handbook on Biotelemetry and Radio Tracking*. Pergamon Press, Oxford.

FELGATE, W. S. 1986. *The Tembe Thonga of Natal and Mozambique: An Ecologial Approach. Occasional Publications no 1.* Department of African Studies. University of Natal, Durban.

FRANKEL, O. H. & M. E. SOULÉ 1981. *Conservation and Evolution.* Third edition. Cambridge University Press. Cambridge, UK.

GARSHELIS, D. L. 2000. Delusions in Habitat Evaluation: Measuring Use, Selection, and Importance. In Boitani, L. & T. Fuller, K. (Eds.) *Research Techniques in Animal Ecology. Controversies and Consequences. Methods and Cases in Conservation Science,* pp. 65-110. Columbia University Press, New York.

GEF (Global Environment Facility) 1996. *MOZAMBIQUE Transfrontier Conservation Areas Pilot and Institutional Strengthening Project. Report number 15534-MOZ.* The World Bank.

GROSSMAN, R. & LOFORTE, A. 1994. The Feasibility of TFCA Development in Southern Maputo Province. In: *GEF Transfrontier Conservation Area and Institution Strengthening Project, pp.* 99-145. Oxford Environmental Development Group, Oxford.

HAANDRIKMAN, V. H. 1998. *Vegetation and Elephants in Reserva Especial de Maputo*. Mozambique. MSc thesis. Agricultural University of Wageningen, Wageningen.

HANKS, J. 1979. *A struggle for survival. The Elephant Problem.* C. Struik Publications. Cape Town.

HALL-MARTIN, A. J. 1984. Conservation and management of elephants in the Kruger National Park, South Africa. In Cumming, D. H. M. & Jackson, P. (Eds.) *The Status and Conservation of Africa's Elephants*. IUCN, Gland.

HALL-MARTIN, A. 1988. *Comments on The Proposed Fencing of The Northern Boundary of The Tembe Elephant Park*. National Parks Board, Pretoria.

HARRIS, S., CRESSWELL, W., FORDE, P. G., TREWHELLA, W., J., WOOLLARD, T. & WRAY, S. (1990). Home-range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* **20**: 97-123.

HATTON, J. C. 1995. *A Status Quo Assessment of the coastal zone, Mozambique phase 1: Ponta do Ouro-Xai-Xai*. UICN, Maputo.

HATTON, J. C.; CHANDE, B.; SERÓDIO, K. & JUJUMEN, A. 1995. *A Status quo Assessment of the Maputo Transfrontier Conservation Area*. Unpublished Report. Universidade Eduardo Mondlane, Maputo.

HOARE, R. E. & du TOIT, J. 1999. Coexistence between people and elephants in African Savannas. *Conservation Biology* **13** (3): 633-639.

HOLT, J. A. & COVENTRY, R. J. (1991). Nutrient cycling in Australian savannas. In: Werner, P. A. (Ed.) *Savanna Ecology and Management. Australian Perspectives and Intercontinental Comparisons*, pp. 83-88. Blackwell Scientific Publications, Oxford.

IASON, G. R. & VAN WIEREN, S. E. 1999. Digestive and ingestive adaptations of mammalian herbivores to low-quality forage. In Off, H., Brown, V.K. & Drent, R. H. (Eds.) *Herbivores: Between Plants and Predators.* Groningen, pp: 337-369. Groningen.

ISHIZUKA, J. 1992. Trends in biological nitrogen fixation research and application. In: *Development in* Ladha, J. K., George, T. & Bohlool, B. B. (Eds.) *Plant and Soil Sciences: Biological Nitrogen Fixation for Sustainable Agriculture*, pp: 197-209. Blackwell Scientific Publications, Oxford.

JACHMAN, H. 1984. *The Ecology of the Elephants in the Kasungu National Park, Malawi; with Specific Reference to Management of Elephant Populations in the Brachystegia Biome of Southern Central Africa*. PhD thesis. University of Groningen, The Netherlands.

KENWARD, R. 1987. *Radio-Tracking: Equipment Field Techniques and Data Analysis. Biological Techniques Series*. Third edition. Academic Press, London.

KIE, J. G., BALDWIN, A. & EVANS, C. J. 1996. CALHOME: a program for estimating animal home ranges. *Wildlife Society Bulletin* **24**(2): 342-344.

KLINGELHOEFFER, E. W. 1987. *Aspects of the ecology of the elephant Loxodonta africana (*Blumenbach, *1797), and a management plan for the Tembe Elephant Reserve in Tongoland, Kwazulu*. MSc thesis. University of Pretoria, Pretoria.

LAWS, R. M. 1970a. Elephants and Habitats in North Bunyoro, Uganda. *East African Wildlife Journal* **8**: 163-180.

LAWS, R. M. 1970b. Elephants as Agents of Habitats and Landscape Change in East Africa. *Oikos*. **21**:1-15.

LAWS, R.M., PARKER, I.S.C. & JOHNSTONE, R.C.B. 1975. *The ecology of elephants in North Bunyoro, Uganda*. Clarendon Press, Oxford.

LEUTHOLD, W. & SALE, J. B. 1973. Movements and Patterns of Habitat Utilization of Elephants in Tsavo National Park, Kenya. *East African Wildlife Journal* **11**: 369-384.

LEUTHOLD, W. 1977a. Spatial organization and strategy of habitat utilization of elephants in Tsavo National Park, Kenya. *Zeitschrift fur Saugetierkunde* **42**: 358-379.

LEUTHOLD, W. 1977b. African Ungulates. A Comparison Review of Their Ethology and Behavioral Ecology. *Zoophysiology and Ecology* **8**.

LINDEQUE, M. & LINDEQUE, P. M. 1991. Satellite Tracking of Elephants in Northwestern Namíbia. *African Journal of Ecology* **29**(3): 196-206.

MAFUCA, J. M. 1996. *Estudo da Dieta de Cinco Espécies de Herbívoros da Reserva Especial de Maputo pelo Método de Análise Fecal*. Unpublished Report. Universidade Eduardo Mondlane, Maputo.

MALAN, J. W. (1992). *The relationship between elephants and the riverine tree communities of the Northern Tuli Game Reserve, Botswana*. MSc thesis. University of Pretoria, Pretoria.

MARIA, F. 1999. *Estudo da Composição Específica e Biomassa das Comunidades Vegetais na Reserva do Maputo*. Unpublished Report. Universidade Eduardo Mondlane, Maputo.

MASSINGA, A. & J. HATTON 1996. Status of the Coastal Zone of Mozambique. In Lundin, C. G. & Lundin, O. (Eds.) *Integrated Coastal Zone Management in Mozambique,* pp. 7-68. Jessica Lindstrom Battle, Upsala.

MCSHANE, T. O. 1987. Elephant-fire relationships in *Combretum* and *Terminalia* woodland in south-west Niger. *African Journal of Ecology* **25**: 79-94.

MENAUT, J. C., GIGNOUX, J., PRADO, C., CLOBERT, J. 1991. Tree community dynamics in a humid savanna of the Côte-d'Ivoire: modelling the effects of fire and competition with grass and neighbours. In: Werner, P. A. (Ed.) *Savanna Ecology and Management. Australian Perspectives and Intercontinental Comparisons,* pp. 127-137. Blackwell Scientific Publications, Oxford.

MENTIS, M. T. & TAINTON, N. M. 1984. The effect of fire on forage production and quality. In: Booysen, P. de V. & Tainton, N. M. (Eds.) *Ecological effects of fire in South African ecosystems*, pp. 245-254. Springer, Berlin.

MOTULSKY, H. 1995. *Intuitive Biostatistics*. Oxford University Press. USA.

MOSS, C. J. 1988. *Elephant memories. Thirteen years in the life of an elephant family*. Elm Tree Books, London.

MOSS, C. J. 1996. Getting to know a population. In Kangwana, K. (Ed.) *Studying Elephants,* pp. 58-74. African Wildlife Foundation, Nairobi.

NORTON-GRIFFITHS, M. 1975. The numbers and distribution of large mammals in Ruaha National, Tanzania. *East African Wildlife Journal* **13**: 121-140.

NTUMI, C.P. 1997. *Estudo de Distribuição e do Movimento dos elefantes e o seu impacto nas machambas adjacentes à Reserva de Maputo*. Unpublished Report. Universidade Eduardo Mondlane, Maputo.

O'-REAGAIN, P. J. & GOESTSCH, B. C. 1996. Investigation of the potential ingestion rates of different souveld grasses by cattle and sheep. *African Journal of Range and Forage Sciences* **13**(2): 49-53.

OGLETHORPE, J. 1997. *Plano de Maneio da Reserva Especial de Maputo, 1997-2001* **2**(9). DNFFB. Maputo.

OSBORN, L. 1996. *Elephant/Human Conflict Around the Maputo Elephant Reserve, Mozambique*. A report to IUCN and DNFFB, Maputo.

OSTROSKY, E. W. 1987. *Monitoring of elephant movements across the international border between South Africa and Moçambique in the Tembe Elephant Park.*

Second Annual Report, 1987. Typescript, Kwazulu Bureau of Natural Resources, Ulundi.

OSTROSKY, E. W. 1988. *The elephant population of the Tembe Elephant Park. Kwazulu: Management recommendations*. Typescript, Kwazulo Bureau of Natural Resources, Ulundi.

OSTROSKY, E. W. 1989. *Monitoring of Elephant Movements Across the international Border between South Africa and Moçambique in Tembe Elephant Park*. Third Annual Report, 1988. Typescript, Kwazulu Bureau of Natural Resources, Ulundi.

OSTROSKY, E. W. & MATHEWS, W. S. 1995. *The Transfrontier Conservation Initiatives in Southern Maputo Province, Mozambique: Comments on Feasibility of the Futi Corridor*. Prepared for DNFFB. Maputo.

OWEN-SMITH, R.N. 1988. *Megaherbivores–The Influence of Very Large Body Size on Ecology*. Cambridge University Press, Great Britain.

PARDAL, J. C. 1996. *Cambaco I – Caça Grossa em Moçambique*. 2ª edição. Editora Meribérica – Liber Editores Ltda, Lisboa.

POWELL, R. 2000. Animal Home Ranges and Territories and Home Range Estimators. In Boitani, L. & T. Fuller, K. (Eds.) *Research Techniques in Animal Ecology. Controversies and Consequences*. Methods and Cases in Conservation Science, pp. 65-110. Columbia University Press, New York.

RANDALL, D., BURGGREN, W. & FRENCH, K. 1997. *Eckert Animal Physiology - Mechanisms and Adaptations*. Fourth Edition. W. H. Freeman and Company, USA.

SCHOLES, R. J. 1991. The influence of soil fertility on the ecology of southern African dry savannas. In: Werner, P. A. (Ed.) *Savanna Ecology and Management. Australian Perspectives and Intercontinental Comparisons*, pp. 71-75. Blackwell Scientific Publications, Oxford.

SEAMAN, D. E. & POWELL, R. A. 1996. An evaluation of the accuracy of the Kernell density estimators for home range analysis. *Ecology* 77(7): 2075-2085.

SOTO, B., MUNTHALI, S. M. & BREEN, C. 2001. Perceptions of the Forestry and Wildlife Policy by the local communities living in the Maputo Elephant Reserve, Mozambique. *Biodiversity Conservation* **10**: 1723-1738.

STERN, S. J. 1998. Field Studies of Large Mobile Organisms: Scale, Movement and Habitat utilization. In Peterson, D. L. & Parker, V. T. (Eds.) *Ecological Scale: Theory and Applications*, pp. 290-307. Columbia University Press, New York.

SUKUMAR, R. 1989. Ecology of the Asian Elephant in Southern India. I. Movement and Habitat Utilization Patterns. *Journal of Tropical Ecology* **5**(1): 1-18.

SUKUMAR, R. 1990. Ecology of the Asian Elephant in Southern India. II. Feeding Habitats and Crop Raiding Patterns. *Journal of Tropical Ecology* 6(1): 33-53.

TCHAMBA, M. N. 1996. *Elephants and their Interactions with People and Vegetation in the Waza-Logone Region, Cameroon*. PhD thesis. University of Ultrecht, Ultrecht.

TELLO, J. L. P. L. 1973. Reconhecimento Ecológico da Reserva dos Elefantes do Maputo. *Veterinária de Moçambique* 6(2): 133-186.

THOULESS, C. R. 1996. Satellite Tracking of elephants. In: Kangwana, K. (Ed.) *Studying Elephants*, pp. 120-125. African Wildlife Foundation, Nairobi.

TROLLOPE, W. S. W. 1984. Fire in savanna. In: Booysen, P. de V. & Tainton, N. M. (Eds.) *Ecological effects of fire in South African ecosystems*, pp. 149-176. Springer, Berlin.

TROLLOPE, W. S. W. 1999. Veld Burning. In: Tainton, N. (Ed.) *Veld Management in South Africa*, pp. 217-245. University of Natal Press, Pietermaritzburg.

VAN AARDE, R. J. & FAIRALL, N. 2001. *Extending Conservation Initiatives in southern Mozambique. A proposal for the Development of the Futi Corridor as a Conservation Area*. CERU Technical Report 007. University of Pretoria, Pretoria. South Africa.

VAN ROOYEN, N., BREDENKAMP G. J. and THERON G. K. 1996. Veld Management. In: Bothma, J. (Ed.) *Game Ranch Management*, pp: 539-572. van Schaik, Pretoria.

VAN WIEREN, S. 1996. *Digestive strategies in ruminants and nonruminants*. PhD thesis. Wageningen Agricultural University, Wageningen.

VAN WIJNGAARDEN, W. 1985. *Elephants-Trees-Grass-Grazers: Relationships between Climate, Soil, Vegetation and Large Herbivores in a Semi-Arid Savanna Ecosystem (Tsavo, Kenya)*. PhD thesis. Agricultural University of Wageningen, Wageningen.

VAN WYK, A. E. 1994. Maputaland-Pondoland Region. South Africa, Swaziland and Mozambique. In (Eds.) *Centres of Plant Diversity. A guide and strategy for their conservation.* Vol 1. WWF & IUCN 227-235.

VILJOEN, P. F. 1988. *The ecology of the desert-dwelling elephants Loxodonta africana (Blumenbach, 1797) of western Damaraland and Kaokoland.* PhD thesis. University of Pretoria, Pretoria.

VRIESENDORP, B. 1998. *Vegetation mapping and elephant damage in the Maputo Elephant Reserve in Mozambique.* MSc thesis. Agricultural University of Wageningen, Wageningen.

WALLIS DE VRIES, M. F., DALEBOUDT, C. & DE VRIES, M. F. W. 1994. Foraging Strategy of catle patchy grassland. *Oecologia* 100: 98-106.

WEIR, J. S. 1972. Spatial Distribution of Elephants in an African National Park in Relation to Environmental Sodium. *Oikos* **23** (1): 1-13.

WESTERN, D. & LINDSAY, K. 1984. Seasonal herd dynamics of a savanna elephant population. *African Journal of Ecology* **22**: 229-244.

WHITE, G. C. & GARROT R. A. 1990. *Analysis of Wildlife Radio-Tracking Data.* Academic Press, London.

WHYTE, I. 1996. Studying elephant movements. In Kangwana, K. (Ed.) *Studying Elephants,* pp. 75-89. African Wildlife Foundation, Nairobi.

WHYTE, I. 2001. *Conservation management of the Kruger National Park elephant population.* PhD thesis. University of Pretoria, Pretoria.

WILLIAMSON, B. R. 1975. Seasonal Distribution of Elephant in Wankie National Park. *Arnoldia* 7(11): 1-16.

WONNACOTT, T. H. & WONNACOTT R. J. 1969. *Introductory Statistics.* Fifth edition. John Wiley & Sons, Toronto

ZAR, J. H. 1984. *Biostatistical Analysis.* Prentice Hall, London.

Appendix 1: Summary of data on core areas (km^2) within home ranges of the elephants of the Maputo Elephant Reserve, during the study.

Elephant	ID	Dry Season			Rainy Season		
		Core area	Percentage of Home range	Percentage of Observations	Core area	Percentage of Home range	Percentage of Observations
Female 1	6454	17.40	10.59	55.6	24.73	15.1	44.4
Female 2	6455	31.94	12.29	64.2	114.7	44.1	35.8
Female 3	6456	27.45	14.95	62.8	33.52	18.3	37.3
Female 4	6457	0.37	0.22	71.0	49.5	29.0	29.0
Male 1	6458	52.01	11.48	52.2	29.89	6.6	47.8
Mean females		19.29	9.91		55.61	28.6	
Mean all		25.83	10.49		50.47	20.5	

Appendix 2: Elephants measurements taken during the collaring operation on February 1998.

Elephant	Shoulder height (cm)	Front foot circumference (cm)	Tusk length (cm)	Tusk lip circumference (cm)
Female 6454	229	112	69	22
Female 6455	230	127	60	23
Female 6456	227	115	41	16
Female 6457	230	108	50	16
Male 6458	295	139	101	32

Appendix 3: Maximum mean temperatures (in degree Celsius) recorded at Belavista station for some years between 1970 and 1999. There are no data for years between 1974 and 1995 at the Mozambican National Meteorological Institute.

Month	Year						
	1970	1971	1972	1973	1996	1997	1999
January	31.9	30.8	32.1	31.5	30.8	32	31.5
February	31.3	29.4	28.4	31.7	31.1	31.3	32.2
March	30	31.3	29.5	33.5	29.8	30.7	32.5
April	29	29	29.2	30.1	28	29.8	31.5
May	27.2	26.5	25.7	27.3	27.2	27	30.1
June	25.5	24.1	23.7	25.8	26.5	27.2	28.4
July	25.7	25.2	20.3	24.6	24.8	25.5	26.9
August	27.1	27.1	23.9	25.7	25.9	27.8	28.3
September	28.9	27.4	27.5	26.2	31.2	27.8	29.8
October	27.1	27.1	28.2	27.4	31.1	27.6	27.6
November	30.5	28.7	28.5	27.5	31.4	29.7	30.4
December	32.5	30.2	31.1	24.7	32.7	30.4	30.6
Mean	28.9	28.1	27.3	28.0	29.2	28.9	30.0
S.E.	2.4	2.2	3.5	3.0	2.6	2.0	1.8

Appendix 4: Mean rainfall (in mm) recorded at Belavista station for some years between 1970 and 1999. There are no data for years between 1974 and 1995 at the Mozambican National Meteorological Institute.

Month	Year						
	1970	1971	1972	1973	1996	1997	1999
January	60.3	64.9	152.7	35.9	162.3	89.5	137.1
February	59.2	41.9	353.8	61.2	111.5	159.1	89.7
March	30.1	22.3	126.6	20	32.1	111.4	74.1
April	16.5	77.1	58.2	32.4	55.5	8	38
May	4	15.6	155.9	4.5	80.5	73.8	2.6
June	2.3	18.7	0	4.6	0	46.8	0
July	9.4	4.2	40.5	9.2	9	10.9	4.9
August	0	0	2.5	23.2	10.7	69.5	0
September	19	12.7	0	313.7	0	80	25.9
October	85	63.6	34	36.2	99.8	89.3	94
November	34.1	36.8	53.9	126.1	55	114.9	75.4
December	40.5	75.9	46.4	237.2	80.5	81.8	193.8
Total annual	360.4	433.7	1024.5	904.2	696.9	935	735.5