Use of space and habitat by elephants (*Loxodonta africana*) in the Maputo Elephant Reserve, Mozambique

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Satellite tracking units fitted to five elephants in the Maputo Elephant Reserve provided information on habitat use. We used the CALHOME program with Adaptive Kernel and MCP (minimum convex polygon) techniques to calculate home range sizes. We interpreted vegetation use by elephants using a vegetation map in conjunction with ArcView GIS. The home range areas (90% adaptive kernel) of cows ranged from 169–267 km^2, while that of a bull measured 453 km^2. The core areas (50% adaptive kernel) covered less than 6% of the reserve's area. Season did not influence home range size. Elephants did not use the available habitats randomly – the forest and Futi floodplain were preferred, while mangroves, tidal wetlands and the Maputo floodplain were seldom, if ever, used. Habitat preference was not a function of time of day.

Key words: conservation, elephant, habitat, Maputo Elephant Reserve, Mozambique, satellite tracking.

INTRODUCTION

The Maputo Elephant Reserve (MER) was established in 1932 to protect savanna elephants (*Loxodonta africana*) living in southern Mozambique. The reserve is part of the Maputaland regional centre of plant endemism (van Wyk 1994) and a biodiversity hotspot (Cowling & Hilton-Taylor 1994). Sand forests are typical of the region, supporting a range of endemic species (Matthews *et al.* 2001) that may be sensitive to elephant damage. Tello (1973) suggested that elephants in the MER focus their year round activities on the floodplains, only seeking refuge in the sand forests when disturbed by poachers. De Boer *et al.* (2000) and Mafuca (2000), however, claim these elephants spend most of their time in sand forests. Elephants may therefore damage endemic tree and shrub species unique to these sand forests.

A fence was erected during 1989 along the northern border of Tembe Elephant Park (South Africa). This fence segregates the elephant population of MER and Tembe Elephant Park. The development of a Transfrontier Conservation Area in the region will reunite the elephants of MER and the Tembe Elephant Park through the Futi Corridor, that runs several kilometres either side of the Futi River (Fig. 1).

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Elephant population estimates in the MER over the past 30 years range from 80–350 individuals (Tello 1973; Klingelhoeffer 1987; Ostrosky & Matthews 1995). A recent helicopter census indicated a population of 200 elephants, spread over an area of 800 km^2 (Ntumi 2002). Factors that influence the distribution and habitat use of these elephants across southern Mozambique may include vegetation quality and biomass (Tello 1973), vegetation cover, water availability and salinity (Ntumi 1997), and human disturbances in response to crop damage (see De Boer & Baquete 1998; De Boer *et al.* 2000; De Boer & Ntumi 2001; Soto *et al.* 2001). Our study aims to quantify habitat use by elephants in the MER. This should allow us to evaluate the influence elephants may have on sensitive local ecotypes such as sand forests.

Elephants in the MER prefer grass plain plant species to forest plant species (De Boer *et al.* 2000). They also feed on more plant species during the wet season than the dry season. Since habitat preference may reflect diet choice, we hypothesized that habitat preference would be broader and less specialized, during the wet season than the dry season.

STUDY AREA

The MER (800 km^2) in southern Mozambique (26°25′S, 32°45′E; Fig. 1) experiences hot, rainy

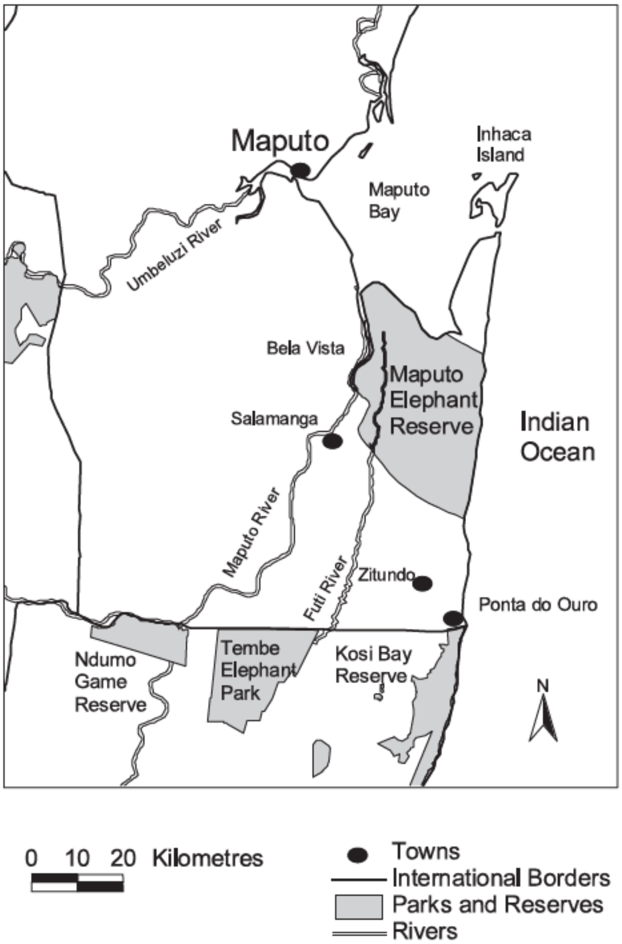

Fig. 1. The location of Maputo Elephant Reserve in relation to nearby conservation areas and river systems.

summers (October–March) and colder, drier winters (April–September). Some rain does, however, fall throughout the year. Annual rainfall varies from 690–1000 mm (De Boer *et al.* 2000). The soils are mainly sandy with more fertile, alluvial soils occurring around the Futi and Maputo Rivers. Several freshwater and saline lakes are located through the reserve. Forming part of the Tongoland-Pondoland regional mosaic (White 1983), the reserve's high and unique plant biodiversity is increasingly considered of special scientific, conservation and economic value (van Wyk 1994).

De Boer *et al.* (2000) recognized six plant communities within the reserve. Mangroves border Maputo Bay and surround the deltas of the Maputo River and Bembe Canal. This community is predominantly comprised of *Avicennia marina* and *Rhizophora mucronata* trees. The dune vegetation consists of pioneers (*e.g. Scaevola plumieri, Ipomoea pes-caprae,* and *Canavalia rosea)* along the beaches. Dune thickets and coastal dune forest support species such as *Diospyros rotundifolia, Mimusops caffra* and *Sideroxylon inerme,* with *Cyperus compactus,* and *Monanthotaxis caffra* in the ground layer. Grasslands are mainly made up of *Themeda triandra, Cynodon dactylon, Sporobolus virginicus* and *Dactyloctenium aegyptium.* Some grasslands are inundated during the rainy season. Forests are dominated by *Ochna natalitia, Mimusops caffra, Euclea natalensis, Psydrax locuples, Afzelia quanzensis,* and *Dialium schlecterii.* Woodlands are relatively open areas dominated by species such as *Strychnos madagascariensis, Strychnos spinosa, Dichrostachys cinerea, Garcinia livingstonei, Vangueria infausta, Syzygium cordatum, Sclerocarya birrea, Afzelia quanzensis,* and *Terminalia*

Table 1. Home range areas (km^2) of five elephants in the Maputo Elephant Reserve. Locations were obtained through satellite tracking from February 1998 to August 1999. Areas were calculated using the adaptive kernel and minimum convex polygon (MCP) techniques (see Kie *et al.* 1996). The 90% home range areas presented for the dry (May to October) and rainy (November to April) seasons are based on the adaptive kernel technique.

Elephant ID	Fixes (*n*)	Home range (km^2)					
		Adaptive kernel			MCP	Dry season	Rainy season
		50%	70%	90%			90% adaptive kernel
Female 6454	142	46.6	81.1	169.4	156.3	105.0	130.4
Female 6455	67	73.8	103.3	266.6	121.6	195.0	208.6
Female 6456	102	42.4	73.7	218.8	102.6	125.0	196.7
Female 6457	124	25.1	28.3	218.1	95.37	64.4	206.2
Male 6458	115	66.1	140.7	452.9	206.8	381.2	286.8
Females' mean home range area		47.0	71.6	218.2	118.9	122.4	185.5
S.E. of mean for females		20.2	31.51	39.68	27.24	54.59	37.07

sericea (Massinga & Hatton 1996; Vriesendorp 1998). The riverine vegetation along the Futi River comprises reed-beds dominated by *Phragmites australis, Juncus kraussii* and *Cyperus compactus.* These reed-beds may be fringed by patches of riverine forest dominated by *Ficus sycomorus, Syzygium cordatum* and *Kigelia africana. Helichrysum kraussii, and Panicum maximum* occur in the ground layer.

MATERIALS AND METHODS

Space use

Space and habitat use by elephants in the MER were inferred from locations obtained by satellite tracking from February 1998 to August 1999. Our research methods were similar to those of Lindeque & Lindeque (1991) and Thouless (1996a). We used collars fitted with ST-14 Platform Transmitter Terminals (PTT; Telonics, Arizona, U.S.A.) for the satellite transmission of geographic locations. Each PTT had a unique frequency. To extend battery life to ~2 years the identifier signals had a duty schedule of 24 hours of transmission out of every 72 hours (24 hours on, 48 hours off). We selected four young elephant cows and a young bull from different groups for collaring. To facilitate collaring a veterinarian anaesthetised the elephants with M99 (etorphine hydrochloride) as prescribed by Kruger-Med Pharmaceuticals (Whyte 2001).

Service Argos uses several identifier signals to calculate the locations of the PTT's based on the angle of reception. The service provider recognized three accuracy classes for the data (see ARGOS 2000). Class 3 data consist of locations with an accuracy ≤150 m and class 2 data have an accuracy of 150–350 m. We only analysed class 2 and 3 data. Most (83.5%) of the 3997 logged satellite locations fell within classes 2 or 3, but many of these were daily duplicates. To reduce autocorrelations we limited our analyses to one location per elephant at three-day intervals. The number of locations per animal varied (Table 1) depending on the signals received and the functional life of the collar. We distinguished between wet (November to April) and dry season (May to October) data.

We used the Adaptive Kernel (AK) method and the Minimum Convex Polygon (MCP) routine of the CALHOME software (Kie *et al.* 1996) to calculate home range areas. To do this, geographic coordinate data were converted to UTM coordinates using the MADTRAN routine of CALHOME. The MCP routine provided values that we could compare with those of other studies (*e.g.* Leuthold 1977; Lindeque & Lindeque 1991). However, due to the disadvantages of the MCP method (White & Garrot 1990; Harris *et al.* 1990; Kenward *et al.* 2001) we preferred the adaptive kernel method (Worton 1989) to express home range sizes. It produces an area with very little bias, gives surface estimates with low errors (Seaman & Powell 1996) and can identify multiple core areas.

We used the ArcView GIS query package (ESRI 2000) to portray the locations and the extent of the home ranges during the different seasons and different times of day. Seasonal differences in the areas of home range were tested using the paired *t*-test (Zar 1984).

Table 2. Elephant home range areas recorded in a selected number of studies on savanna elephants across Africa. 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	550	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
Laikipia-Samburu	5144	400	Thouless 1996b
Middle Zambezi Valley	179 (cows)	793	Dunham 1986
Maputo Elephant Reserve	129	845	Ntumi 1997
Maputo Elephant Reserve	311	845	This study

Habitat use

The areas of habitats were calculated from digitized polygons in ArcView (available from DCB 2000). We limited the assessment of habitat availability (see Johnson 1980 and Aebischer *et al.* 1993) to the 528 km² area on the western side of the reserve used by elephants during the study. We based preference indices (PI) on the method of White & Garrott (1990). For this exercise, we defined nine habitat types (hygrophilous grassland, forest, woody grassland, woodland, Futi vegetation, tidal wetland, mangrove, Maputo flood plain and others (including sand forest mosaic, eucalyptus plantations and lacustrine reedbed). We used GIS to determine the area of each of these and the proportion of each habitat available (πo). The number of locations in each habitat type for each elephant was used to calculate the proportion of locations in each habitat type (p). Ranked PI values (p/πo) indicated habitat preference. We used a Wilcoxon matched pairs test (Zar 1984) to investigate differences between day and night, and dry and rainy season use of habitats.

RESULTS

Space use

The four female elephants in this study spent both the rainy and dry seasons near the Futi River in the MER. Only the male moved beyond the reserve and into the Massoane and Salamanga areas on the Maputo River floodplains. Jointly, the five home ranges covered about 33% of the total area of the MER. The dry and wet season ranges covered 22% and 26% of the total area of the reserve, respectively. The core area, for all elephants collectively, calculated as the 50% adaptive kernel, covered <6% of the reserve area. Season had no effect on range size (Wilcoxon matched pairs test: $t = -1.33$, d.f. = 4, $P > 0.05$), though female home ranges did appear to be larger during the rainy than the dry season (Table 1). The home ranges overlapped and their areas were amongst the smallest recorded for elephants elsewhere in Africa (Table 2).

Habitat use

The preference indices (PI) for individual elephants differed significantly (Table 3). For instance, Female 1 never used the riverine vegetation, while all other elephants showed high PI-values for this habitat. Habitat preference was affected by season (Table 4), and elephants used more habitats during the rainy season than the dry season. Time of day did not influence habitat use (Wilcoxon matched pairs test: $t = 15$, $n = 14$, $P > 0.05$).

DISCUSSION

Space use

Very few mammals use the space within their home ranges randomly (Harris *et al.* 1990). This probably results from the non-random distribution of resources. The factors responsible for the apparent preferences in space we recorded are not known. As elsewhere, elephants in the MER

Table 3. Individual elephant habitat preference indices and chi-square test results calculated following White & Garrot (1990).

Habitat type	Preference indices				
	Female 6454	Female 6455	Female 6456	Female 6457	Male 6458
Hygrophilous grassland	0.876	0.410	1.116	1.810	0.566
Forest	1.788	0.993	1.765	0.958	1.315
Woody grassland	0.452	0.355	0.312	0.771	0.554
Mangrove	0.000	0.000	0.000	0.000	0.000
Woodland	0.674	1.931	0.127	0.244	1.577
Futi vegetation	0.000	3.366	1.924	2.176	1.280
Tidal wetland	0.000	0.000	0.000	0.000	0.000
Maputo flood plain	0.000	0.000	0.000	0.000	0.538
Others	2.981	0.000	2.290	0.377	0.406
χ^2 (d.f. = 8)	60	57.83	52.85	60.82	28.20

Table 4. Habitat preference indices and chi-square values for the dry and rainy seasons calculated following White & Garrot (1990). Both season and elephant identity influenced preference indices.

Habitat	Preference indices for each elephant									
	Female 6454		Female 6455		Female 6456		Female 6457		Male 6458	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Hygrophilous grassland	1.251	0.876	0.516	0.411	1.016	1.116	1.996	1.810	0.867	0.566
Forest	1.939	1.788	0.915	0.930	1.857	1.765	0.941	0.958	1.921	1.315
Woody grassland	0.408	0.452	0.000	0.366	0.498	0.312	0.000	0.771	0.000	0.554
Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Woodland	0.000	0.674	1.919	1.936	0.067	0.127	0.098	0.244	0.648	1.577
Futi vegetation	0.000	0.000	3.504	3.383	2.299	1.924	2.508	2.176	1.226	1.28
Tidal wetland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maputo flood plain	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.538
Others	2.994	2.981	0.000	0.000	2.189	0.377	0.000	0.377	0.000	0.406
χ^2 (d.f. = 8)	56.3	60	42.10	57.83	38.50	52.85	64.20	60.82	25.60	28.20

may opt for landscapes that optimize energy needs and expenditures associated with their day-to-day activities, or that minimize conflict with people (*e.g.* Verlinden & Gavor 1998; Stokke 1999; De Boer *et al.* 2000; Stokke & du Toit 2002). The elephants of the MER confined their home ranges to the northwestern part of the reserve, where water is available throughout the year and where people did not live at the time of the study.

The MCP home range sizes of elephants in the MER are towards the lower end of the ranges recorded for elephants living elsewhere (Table 2). Elephants are highly mobile opportunistic animals. Those living in arid environments with limited food and water may move over vast areas (Lindeque & Lindeque 1991), while the artificial supply of water may give rise to relatively small and stable elephant home ranges, such as those in the Kruger National Park (Whyte 2001). Recorded differences in the size of the home ranges across the range of elephants may be due to patterns of resource distribution (Douglas-Hamilton 1972; Whyte 2001), gender (Owen-Smith 1988; Stokke 1999), and research methodologies (Garrot & White 1996; Harris *et al.* 1990; Seaman & Powell 1996).

Although the home ranges of our study animals overlapped, they had mutually exclusive core areas. This suggests these elephants were from different groups (Leuthold 1977; Moss 1996). These well-defined core areas also suggest that habitat use was not at random and that elephants may follow a central place foraging strategy (Lewison & Carter 2004). The larger home range of the male observed in our study, may be ascribed to their nutritional requirements (Owen-Smith 1988).

Habitat use

Like elsewhere (*e.g.* Douglas-Hamilton 1972; Leuthold 1977; Owen-Smith 1988; Western & Lindsay 1984), elephants do not use the habitats of the MER randomly (Table 3). Our results are consistent with an earlier study in southern Mozambique (De Boer *et al.* 2000). This may be due to differences in the physical variables (temperature, rainfall) of different habitats, differences in resources including food, water and shelter (*e.g.* Owen-Smith 1988) or simply by differences in habitat heterogeneity at different scales (Kie *et al.* 2002). We did not, however, find support for the findings of an earlier study in MER (see De Boer *et al.* 2000) that the landscapes used at night differs from those used during the day. In spite of individual differences, habitat types with a relative closed canopy (woodlands, forests, riverine thickets) featured prominently in the preferences of all our elephants, as did vegetation types associated with water (riverine thickets and hygrophilous grasslands). Our elephants did not use the eastern portion of the reserve, which is inhabited by subsistence farmers. Here people may have disturbed elephants in the past (De Boer *et al.* 2000), while frequent fires may keep them away today.

Sand forests and thickets contain ample material on which to browse. Relatively little of the biomass here is, however, available in leaf form. On the other hand, grasslands and floodplain vegetation contain little browse material – most of this vegetation is available to grazers at intermediate biomass values (Tello 1973; De Boer *et al.* 2000; DCB 2000). Elephants are mixed feeders and those living in the MER feed largely on monocotyledons (De Boer *et al.* 2000). This may account for the preference elephants showed in our study for the Futi Floodplain and hygrophilous grassland vegetation.

Elephants in the MER may prefer to use forested areas at certain times of the year for reasons other than foraging. Here elephants can also find shade while foraging on woody species. The related shift in their diet may also differ seasonally. In the reserve, the quality of forage in grasslands increases during the rainy season, enabling elephants to select between a broader range of habitats providing to their needs. As habitat choice increases during the rainy season, the number of plants in their diet also increases markedly (De Boer *et al.* 2000). Alternatively, elephants may simply spend more time in dense forests during the late dry season due to a reduction in food availability in grasslands, while forests can still provide green browse.

The sand forests of Maputaland are unique and support a large number of neo-endemics (van Wyk & Smith 2000). The continued rise in elephant numbers in the MER may increase pressure on these neo-endemics. Extending the MER towards the south and along the Futi River will help alleviate the impact of elephants on sensitive habitats. Such an extension could be mitigated by the development of a transfrontier conservation area that will restore some of the traditional land use patterns of elephants in Maputaland. This will decrease elephant densities locally and will re-instate some of their historical seasonal movements. Other mammals living in the region would also benefit from such developments.

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