ASSESSMENT OF SEASONAL HOME-RANGE USE BY ELEPHANTS ACROSS SOUTHERN AFRICA'S SEVEN ELEPHANT CLUSTERS

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Report Summary

This report represents the preliminary synthesis of CERU's research into home-range use by elephants. CERU's next step is to move from a descriptive appraisal of home-range use, to applying this data within an ecological framework. Eventually it should allow us to predict elephant landscape use in relation to such key environmental variables as water availability, habitat preferences and human disturbance.

The report contains information from all seven of the recognised elephant conservation clusters. The aim of this report is to synthesise the current information we have for every satellite-collared elephant CERU has monitored. These include units that have only just been fitted, as well as those that have expired. We present our most important findings on range use to date. The report also provides an opportunity to reflect on ways in which our operations can be improved. It also provides a platform to identify critical gaps within our collaring network.

Introduction

The Peace Parks Foundation aims at bolstering conservation through the establishment of transfrontier conservation areas (TFCA's) across southern Africa. With the involvement of the Southern Africa Development Corporation's (SADC) Secretariat and Member States, as well as the Status Report on existing and potential transfrontier conservation areas in the SADC region, the Foundation developed a more holistic approach to the development of such areas. A recent TFCA feasibility study identified at least 20 TFCAs that can form the basis for a regional approach to conservation as a form of land-use (see www.peaceparks.org).

By providing an ecological framework for the delineation of TFCAs, the Megapark Research Programme of the Conservation Ecology Research Unit (CERU) contributes to the objectives of the Peace Parks Foundation. CERU's studies focus on elephants as a flagship of conservation. The distribution of elephants across southern Africa indicates that most elephants occur in seven clusters of conservation areas across the sub-continent (Fig. 1). These clusters are of key importance to the objectives of both the Peace Parks Foundation and CERU. Not only do they represent the cornerstones of elephant conservation through southern Africa, they also represent the cores of several potential TFCA's. CERU's research programme aims at defining the population, spatial and conflict dynamics of elephants living in these clusters. Conservation plans that accommodate spatial and temporal requirements and that reduce conflict between people and elephants should meet the conservation requirements for most other common co-occurring species. Our research, therefore, focuses on variables that could assist in the design of mega-parks based on meta-population theory as an alternative conservation approach.

The research activities we report on here form part of a project aimed at defining elephant home-range use and resource selection. Ultimately we aim to model space use by elephants against landscape suitability. This will help to design suitable landscape linkages between conservation areas and may allow for the formation of functional elephant metapopulations. In this report, we detail the initial stage of this operation and provide a preliminary description of home-range use by elephants.

The report focuses on almost all elephants that have been satellite collared from the inception of CERU's Megapark Research Programme. These include collaring operations that have been funded by the Peace Parks Foundation, as well as a number of other major collaborators including, amongst others, the International Fund for Animal Welfare, Conservation Foundation Zambia, Conservation

International and the US Fisheries and Wildlife Service. CERU initially deployed nine collars on elephants within the Maputaland cluster in September 2000. Most recently, we deployed collars on six cows in Namibia's Kaudom Game Reserve, during late October 2004. In total CERU has deployed collars on 70 individuals across all southern Africa's elephant clusters. The only site we do not include in this report is Kaudom, due to the limited data so far available for these animals. In addition, Dr Keith Leggett has kindly provided us with access to data for nine elephants from the Namibian Desert Elephant and Rhino Foundation.

Objectives

1. To describe home-range use by 73 satellite-collared elephants in southern Africa's seven and around the seven principle conservation clusters.
2. To identify any shortcomings of the present initiative in order to optimise on future operations.
3. To identify serious gaps within the present network of collared elephants that need to be addressed in order to better understand home-range use within the context of defining a network of TFCAs.

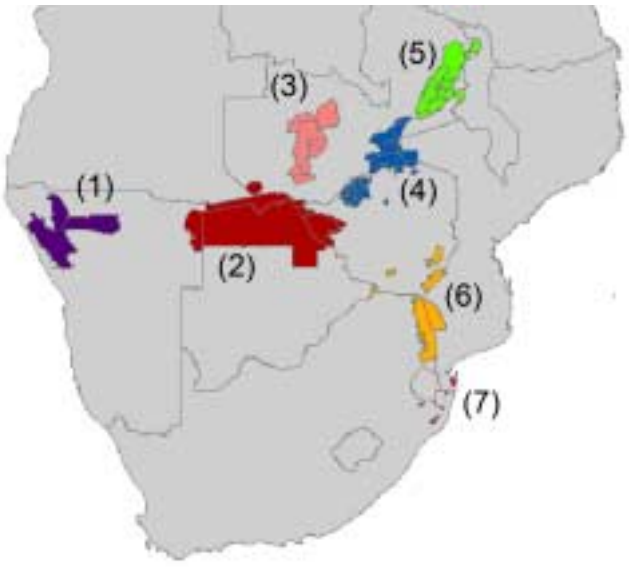


Figure 1. The location of the seven clusters of conservation areas within southern Africa that forms the platform for the present research initiative. 1. Etosha/Kunene, 2. Chobe, 3. Kafue, 4. Zambezi, 5. Luangwa, 6. Limpopo, 7. Maputaland.

Methods

Elephant collaring

We chose adult male and female elephants for collaring. Individuals were immobilised by darting from a helicopter. A ground crew that moved in to attend to the sedated animal typically supported this operation. We cooled animals with water while they were restrained. We did not collar animals during the heat of the day, when the chance of overheating was exacerbated. A qualified veterinarian was present to supervise all collaring and sedation procedures. All elephant handling operations were conducted under permit from the relevant conservation organisation and the animal ethics committee of the University of Pretoria (permit number AUCC-040611-013).

The original collars we used were designed and built by Telonics (Mesa, Arizona, USA). These units worked on the Argos Satellite System and were employed on elephants in Maputaland. Fixes were uploaded to an ImmarSat low orbiting satellite. With a maximum stated resolution of <150m, their accuracy was relatively low, and they could only be programmed to download fixes once every three days. The real position of ten locations obtained from five transmitters prior to deployment ranged from 60 m to 180 m (mean 117 ± (SD) 45 m). We had to filter the available data, as many of the fixes are only guaranteed to a lower resolution (see ARGOS 2000 and Hays *et al.* 2001).

Africa Wildlife Tracking (Pretoria, South Africa) designed and produced all subsequent units that we used. These were fitted to all the remaining elephants within the scope of this report. These units employ a Garmin GPS receiver and Vistar satellite unit. As they communicate with a geostationary satellite (ImmarSat), their accuracy is substantially improved compared to the Telonics units, to a resolution of 10-15m (*pers. comm.* M.A. Haupt, African Wildlife Tracking). Our own trials on six collars in the Etosha National Park yielded values <5m. Fixes were downloaded via satellite through StarTrack (Australia), who transmit this data on to Skygistics (South Africa).

For the present report we reduced all data to daily fixes to allow a valid comparison to be made between different data sets. These collars are built to transmit location data over a two-year period. We advanced the time at which daily location fixes were obtained by two hours every week. This prevented data collection being biased towards a particular time of the day – for instance early afternoon, when animals may be more likely to drink or to be close to water.

Rainfall

Our definition of wet and dry seasons is based on the rainfall patterns we collated for the various study sites. Where possible we obtained rainfall data for the last 25 years. Preference was given to weather stations close to the centre of collaring activity within a particular conservation area. If these data were not available, rainfall information was acquired from the nearest weather station. For many of the conservation areas rainfall data are erratic, or non-existent. This problem should be addressed with the relevant conservation authorities. In fact, in some areas where satellites collars are presently employed, authorities are collecting no rainfall data.

Based on the rainfall patterns we observed, we standardised the wet and dry season periods for all study sites. Thus, for the consistency of this report, we consider the wet season to run from December–April and the dry season from May–November (see page 12: Regional rainfall patterns).

Home-range estimation

Home-range sizes were calculated using two widely used methods – minimum convex polygons (MCP) and fixed kernels. Both have been used commonly in reporting elephant home-range data (reviewed by Osborn, 2004). The MCP is the most widely used method. 100% MCPs determine the smallest polygon encompassing all external locations of a data set (Kenward, 2001). Animal movements within the home-range or the statistical distribution of the data set do not, therefore, affect MCP estimates. Due to outliers, however, MCP estimates can include large unused areas. 100% MCPs are, therefore, very sensitive to sample size (Kenward, 2001). As part of this report, we examine the minimum number of data points necessary to generate meaningful estimates of home-range size. Harris *et al.* (1990) suggest that 100-300 locations are necessary to reach asymptotic levels for the MCP. We compare this information in relation to (1) elephants from different clusters, (2) differences between seasons and (3) differences between sexes. Without this information, it would be impossible to make meaningful statements regarding the home-ranges of elephants from the seven regional clusters we report on. Using these results, only home-ranges for which enough fixes were available to provide asymptotic values for home-range size are used in our report. Using fewer fixes will provide an underestimate of home-range size and can lead to considerable bias to any results or conclusions.

Fixed-kernel (KER) estimators use a distribution function used to calculate the density of space use. Home-range boundaries are built up by joining sites of equal density. It is, arguably, the method providing the closest correspondence between

home-range shape and locations (Worton, 1995). Fewer fixes are needed to provide an accurate estimate of home-range size than using the MCP method. Seaman *et al.* (1999) suggest at least 50 fixes be used when reporting home-range based on KER estimates. We calculated home-ranges using 95% and 50% of fixes. The 95% value is commonly used to eliminate the most distant locations, which greatly increase the estimated area. The 50% home-range estimate we used reflects on core areas of intensive activity (Girard *et al*., 2002). By definition, these are the most heavily used areas. To obtain these values the harmonic mean of all locations were determined, and fixes farthest from the centre of the home-range were gradually excluded.

Home-range sizes were calculated using the Animal Movement Extension (Hooge & Eichenlaub, 1997) for ArcView GIS 3.3 (Environmental Systems Research Insitute, Inc., Redlands, CA).

Calculating home-range

In order to make effective comparisons in home-range activity, we first had to asses the effect of various parameters on home-range estimates. For instance, males reportedly have larger home-ranges than females (e.g Hall-Martin, 1987). In addition, home-range reportedly varies on a seasonal basis (Leuthold, 1977), as well as with rainfall (Osborn, 2004). The estimated home-range for an individual is also dependent on the method used to calculate home-range and the number of locations used in this estimation (Girard *et al*., 2002). High biases in home-range estimate occur when too few locations are used in home-range calculation. It is not clear, however, how many elephant fixes are needed to accurately calculated home-range during the different seasons. In addition, differences may occur between conservation areas in the number of fixes needed to accurately record home-range. We therefore analysed data that considered the effect of season, gender and locality on home-range. Analyses were conducted using a bootstrap design, in which home-ranges were repeatedly calculated (50 repeats) using an interval of 10 fixes between repeats, for each individual under consideration. Calculations were carried out using the MCP Sample Size Bootstrap function within ArcView's Animal Movement Extension.

Season and home-range

In order to compare home-range data between seasons, we used fixes collected from elephants in the Ngoma area of southern Kafue. This site was chosen for the analysis as it contained the greatest number of individuals. Our results are presented

in Fig. 2 and clearly demonstrate the effect of the number of fixes within a season on an elephant's calculated home-range size. It is clear that as the number of fixes increases (1) home-range size increases towards an asymptote and (2) the standard error of these home-ranges decreases towards an asymptote.

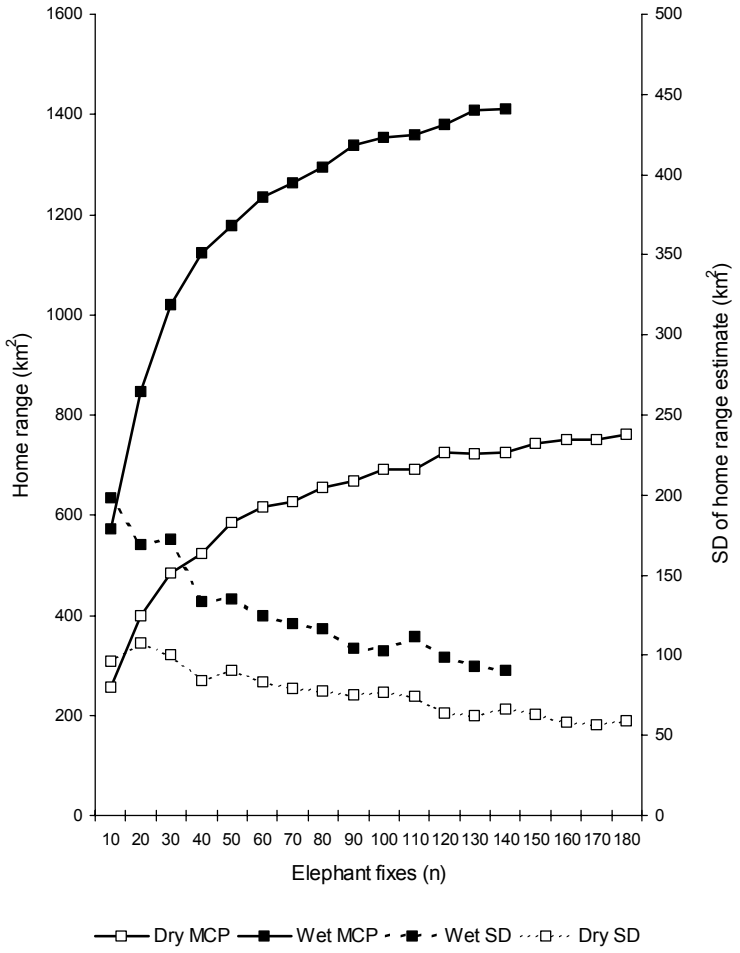


Figure 2. Calculated 100% minimum convex polygon home-ranges (and their standard deviation) of elephants from the southern Kafue population. The analysis is the result of a bootstrap approach that uses different sub-sets of the data and clearly shows the effect of both the number of fixes and season on the calculated home-range areas.

Table 1. The effect of the number of elephant fixes on the home-range size of elephants in southern Kafue National Park, in relation to their asymptotic home-range size.

	Dry season		Wet season	
Number of fixes (n)	100% MCP (km^2)	% maximum calculated MCP	100% MCP (km^2)	% maximum calculated MCP
10	256	34	572	41
20	398	52	846	60
30	485	64	1020	72
40	524	69	1124	80
50	584	77	1179	84
60	616	81	1234	88
70	627	82	1263	90
80	654	86	1294	92
90	667	88	1338	95
100	691	91	1354	96
110	691	91	1360	96
120	725	95	1380	98
130	722	95	1409	100
140	724	95	1410	100
150	743	98		
160	752	99		
170	752	99		
180	762	100		

Table 1 demonstrates that more fixes are required during the dry than the wet season to calculate home-range size. Thus with, for instance 40 fixes, the calculated dry season home-range reflects only 69% of the actual home-range, while the same number of fixes would reflect 80% of the wet season home-range. Table 1 also suggests, that for the Kafue population at least, a sample of 120 fixes would be sufficient to reflect at least 95% of the home-range are of individuals during both seasons. We therefore used a cut off of 120 fixes when analysing our data. We still include home-ranges consisting of less than 120 fixes in our home-range tables, but estimates are bracketed to highlight the unreliability of these data.

Gender and home-range

We examined differences in the gender of individuals on home-range size. While bull elephants generally may have larger home-ranges than cows, it is not clear to what extent the number of fixes we obtained effects these home-range estimates. The only elephant data set containing sufficient data from one area was gathered in Kafue National Park. Using dry season data (May–Nov 2003), we examined the effect of the number of fixes on the calculated home-range sizes for five male and five female elephants, for whom we had a minimum of 160 daily fixes.

Our results (Fig. 3) clearly demonstrate that bulls, at least within the southern Kafue population, had larger home-ranges than cows during the 2003 dry season. More importantly, we examined the number of fixes needed to reach 95% of the asymptotic (maximum predicted) home-ranges. These data are presented in Table 2.

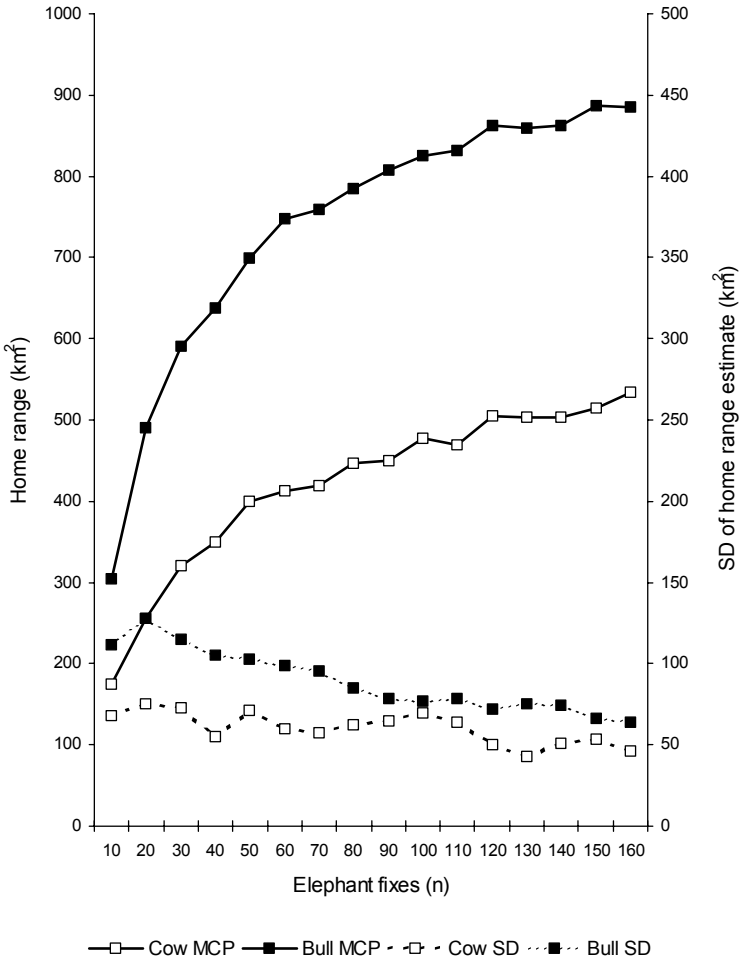


Figure 3. Calculated 100% minimum convex polygon home-ranges (and their standard deviation) of five male and five female elephants from the southern Kafue population. The analysis is the result of a bootstrap analysis, using different sub-sets of the data and clearly shows the effect of both the number of fixes and sex on the calculated home-ranges.

Our data suggest that, while the 100% MCPs of bulls are larger than cows, more fixes may be needed to reach a certain percentage of the maximum predicted home-range. Thus after 60 elephant fixes, the calculated home-ranges were 85% and 77% of the maximum predicted home-ranges, for males and females respectively. While we did not test to see whether this disparity was statistically significant, it was certainly smaller than the differences recorded between seasons after a given number of fixes. This suggests that, while male elephants may have larger home-ranges than females, the number of fixes needed to establish these

differences do not differ with gender. We also found that 120 fixes were necessary to generate a home-range estimate within 95% of the asymptotic home-range calculations for these Kafue animals (Table 2).

Table 2. The effect of the number of elephant fixes on the home-range size of five male and five female elephants in southern Kafue National Park, in relation to their home-range size recorded after 160 fixes.

	Bulls		Cows	
Number of fixes (n)	100% MCP (km^2)	% maximum calculated MCP	100% MCP (km^2)	% maximum calculated MCP
10	304	34	175	33
20	491	56	256	48
30	590	67	320	60
40	637	72	349	65
50	699	79	400	75
60	747	85	413	77
70	760	86	420	79
80	785	89	446	84
90	808	91	450	84
100	825	93	477	89
110	832	94	469	88
120	862	98	505	95
130	859	97	503	94
140	863	98	503	94
150	886	100	515	96
160	884	100	534	100

Conservation area and home-range

We expected that elephants from more arid cluster would have larger home-ranges than those from more mesic areas. This we did indeed find to be true when examining differences in the home-ranges of cows from Etosha and Kafue National Parks (Fig. 4). We have already demonstrated (above) little difference in the number of fixes needed to estimate at least 95% of the total predicted home-range of individuals within a conservation area, based on either season or gender, at least for southern Kafue National Park.

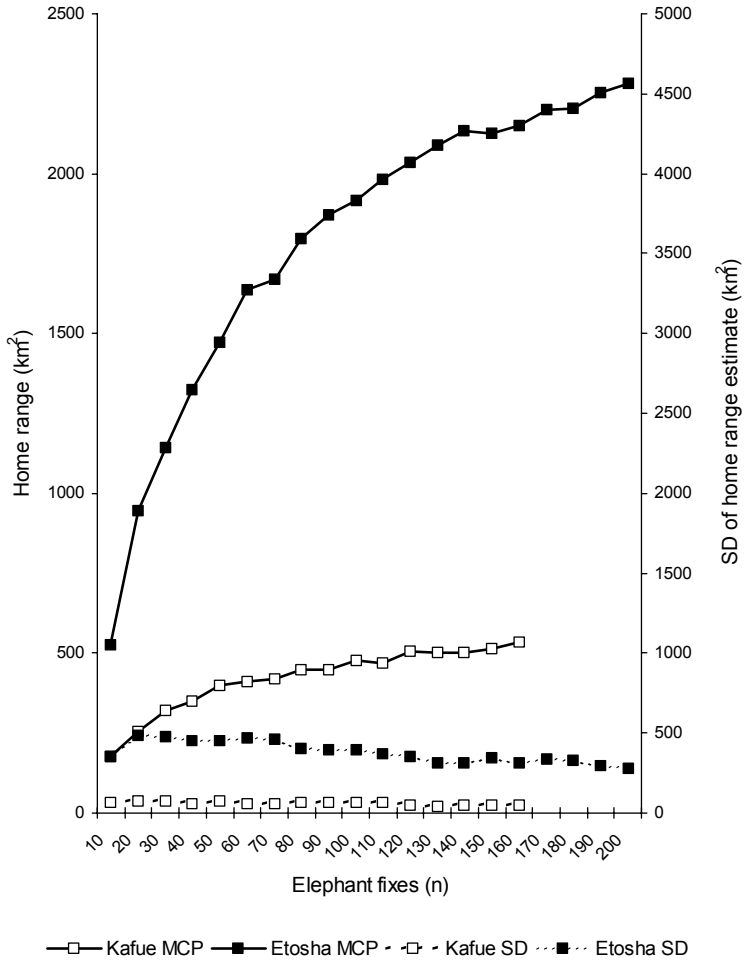


Figure 4. Calculated 100% minimum convex polygon home-ranges (and their standard deviation) of female elephants from the southern Kafue(n=5) and Etosha (n=6) populations. The analysis is the result of a bootstrap analysis, using different sub-sets of the data and clearly shows the effect of both the number of fixes and locality on the calculated home-ranges.

The same could not, however, be said between different conservation areas. When we compared the home-ranges of elephants from Etosha (six cows) and southern Kafue (five cows) during the 2003 dry season (May-November 2003) 95% of the estimated home-range of Kafue's elephants could be predicted after 120 fixes (Fig. 4, Table 3). Only 89% of the estimated home-range of Etosha's elephants could be predicted after this number of fixes. For Etosha's cows, 170 fixes were needed to calculate 95% of their estimated home-ranges. This is reflected in the cumulative home-range figure for these cows (Fig. 4), which do not demonstrate a clear asymptote, even after 200 fixes.

Table 3. The effect of the number of elephant fixes on the home-range size of female elephants in Etosha and Kafue National Parks, in relation to their home-range size recorded

	Bulls		Cows	
Number of fixes (n)	100% MCP (km^2)	% maximum calculated MCP	100% MCP (km^2)	% maximum calculated MCP
10	175	33	525	23
20	256	48	948	42
30	320	60	1143	50
40	349	65	1323	58
50	400	75	1474	65
60	413	77	1635	72
70	420	79	1668	73
80	446	84	1795	79
90	450	84	1869	82
100	477	89	1917	84
110	469	88	1982	87
120	505	95	2036	89
130	503	94	2087	92
140	503	94	2134	94
150	515	96	2127	93
160	534	100	2152	94
170			2198	96
180			2206	97
190			2252	99
200			2280	100

Regional rainfall patterns

For all clusters, rainfall was greatest during the summer months. We therefore analysed data for the period extending from July–June (Figs. 5–8; Table 4). This prevents the splitting of summer rainfall periods between two calendar years. As expected, rainfall increased eastwards across an east-west gradient (Fig. 9). The co-efficient of variation of rainfall (an indicator of rainfall predictability) did not show a similar trend (Fig. 9). The co-efficient of variation of rainfall was, however, much greater in the western Kunene Region (Namibia) than at any other site (Table 4).

Rainfall increased dramatically from a minimum of only 68mm/ year at Sesfontein in the western Kunene Region to 249mm/ year in the eastern Kunene Region (Namibia). Rainfall continued to increase eastwards through the elephant clusters, with the Luangwa cluster receiving the greatest yearly precipitation. Of all our sites, Nyika National Park (Malawi) received the highest yearly rainfall (Table 4). Two sets of rainfall data are available for areas in the vicinity of Lower Zambezi National Park (Zambia). While rainfall data for Chipepo were as we expected, those for Lusitu suggest lower than expected rainfall (Table 4, Fig. 6). Unfortunately only limited rainfall data are available for either of these localities and it is not clear at this

stage what effect the escarpment may have on precipitation. Certainly though, ambient temperatures increase from the Zambezi Valley northwards towards the escarpment (Kinahan, 2004). For its longitude, the Shingwedzi area of Kruger National Park (South Africa) received relatively low and unpredictable rainfall. Rainfall in Maputaland included a winter component that is lacking from any other cluster (Fig. 8).

Examining our rainfall figures, we arbitrarily defined wet season months as those receiving ≥10% of the long-term average annual rainfall. Conversely, dry season months were defined as those receiving <10% of the annual rainfall. Using these criteria, the wet season continued for 4–5 months, depending on location (Table 4). For consistency between sites, we conservatively defined the wet season as the period from December-March for the purpose of this report.

Table 4. Summary of rainfall data within the seven elephant clusters. Data were analysed on a 12 month cycle from July-June, to correspond with the summer rainfall pattern at all study sites. Details are provided of the weather station from which data were collected, together with mean rainfall over this 12 month cycle, the standard deviation of this rainfall between seasons, as well as the co-efficient of variation of rainfall (an indicator of predictability. Where possible data are provided for the last 25 years, and are specified in the table. The duration and period of the wet season are defined by those months receiving more than 10% of the 12 months rain.

Elephant Cluster	Location	Weather Station	Collection period (years)	Mean rainfall (mm)	Rainfall SD (mm)	Rainfall CV (%)	Period of wet season	Duration of wet season (months)
Kunene/ Etosha	Kaokoland	Sesfontein	25	68	67	99	Jan-Apr	4
Kunene/ Etosha	Kaokoland	Hobatare	10	249	94	38	Dec-Apr	5
Kunene/ Etosha	Etosha	Halali	25	376	112	30	Dec-Mar	4
Chobe	Okavaongo (NG 11)	Seronga	20	430	190	44	Nov-Mar	5
Zambezi	Lower Zambezi	Lusitu	7	406	166	41	Dec-Mar	4
Zambezi	Lower Zambezi	Chipepo	10	667	204	31	Dec-Mar	4
Kafue	South Kafue	Ngoma	17	783	234	30	Dec-Mar	4
Luangwa	South Luangwa	Mfuwe	21	802	145	18	Nov-Mar	5
Luangwa	North Luangwa	Marula Puku	7	831	141	17	Dec-Mar	4
Luangwa	Vwaza Marsh	Kazuni	17	900	324	36	Dec-Mar	4
Luangwa	Nyika	Nyika	25	1240	362	29	Dec-Mar	4
Limpopo	Limpopo National Park	Shingwedzi	25	471	260	55	Nov-Mar	5
Maputaland	Tembe Elephant Park	Sihangwane	25	800	448	56	Nov-Mar	5
Maputaland	Maputo Elephant Reserve	Changalane	25	756	242	32	Nov-Mar	5

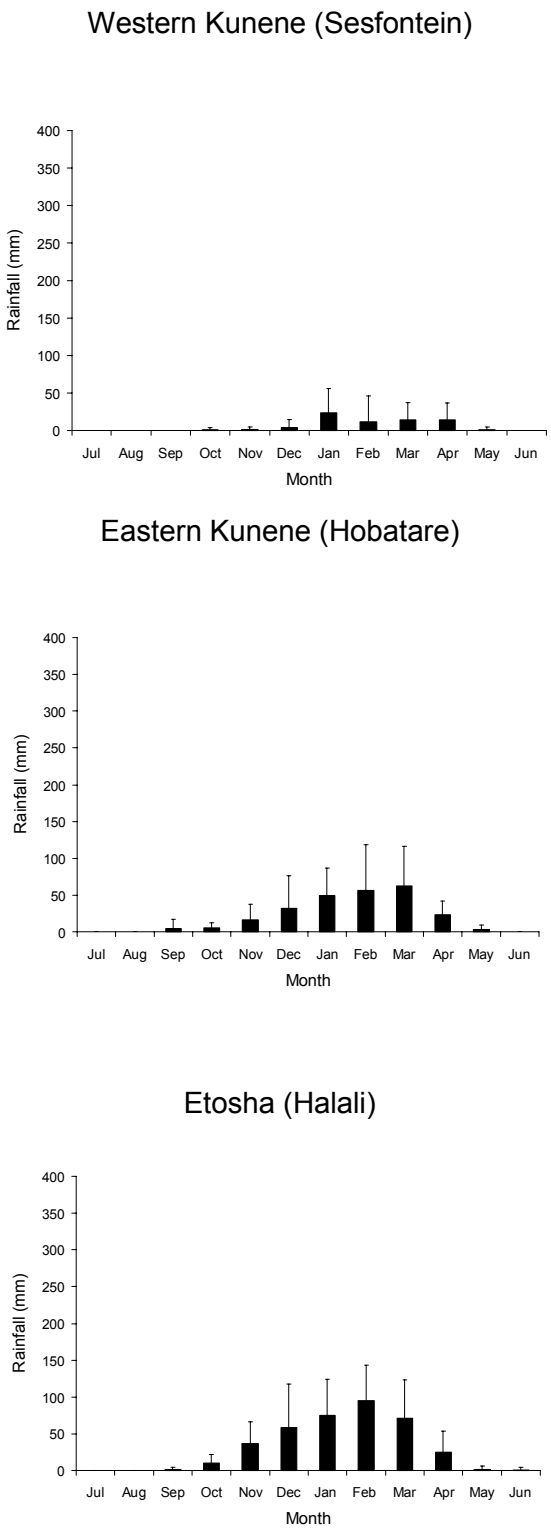
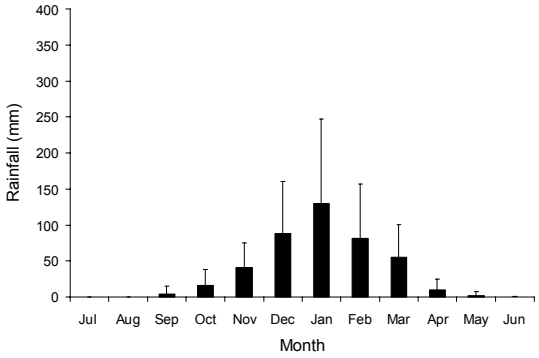
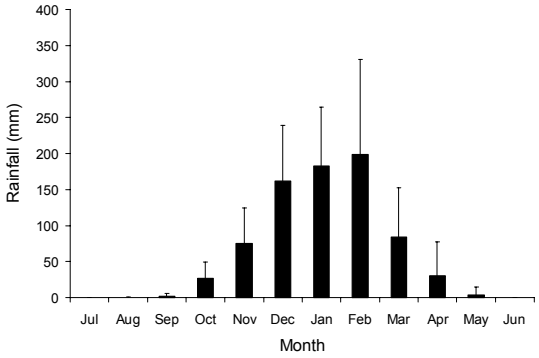


Figure 5. Mean monthly rainfall (±SD) for sites in the Etosha cluster. These include Sesfontein and Hobatare, in the Kunene Region, Namibia. Sesfontein rainfall only available from 1978-2004, Hobatare from 1992-2004. No data available for 2000-2001 for either site. (Data courtesy K. Legget). Mean monthly rainfall (±SD) at Halali, Etosha National Park over the last 25 years, from 1979–2004.

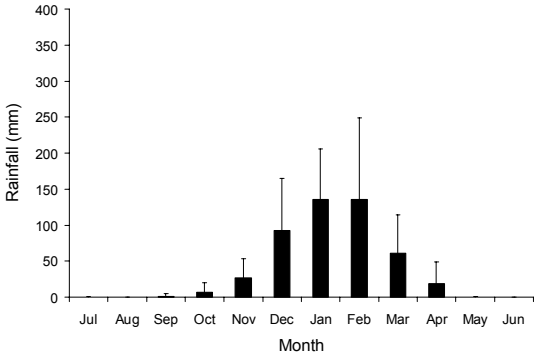
Okavango Panhandle (Seronga)



Kafue (Ngoma)



Zambezi (Lusitu)



Zambezi (Chipepo)

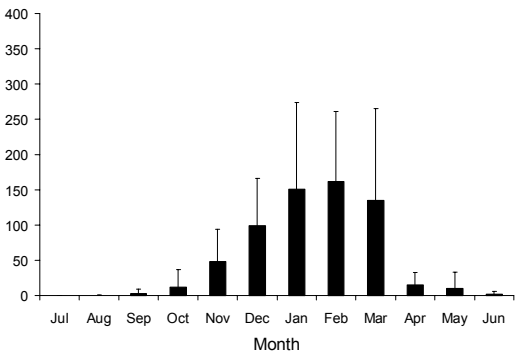


Figure. 6. Mean monthly rainfall (±SD) for sites in the Chobe, Kafue and Zambezi clusters.

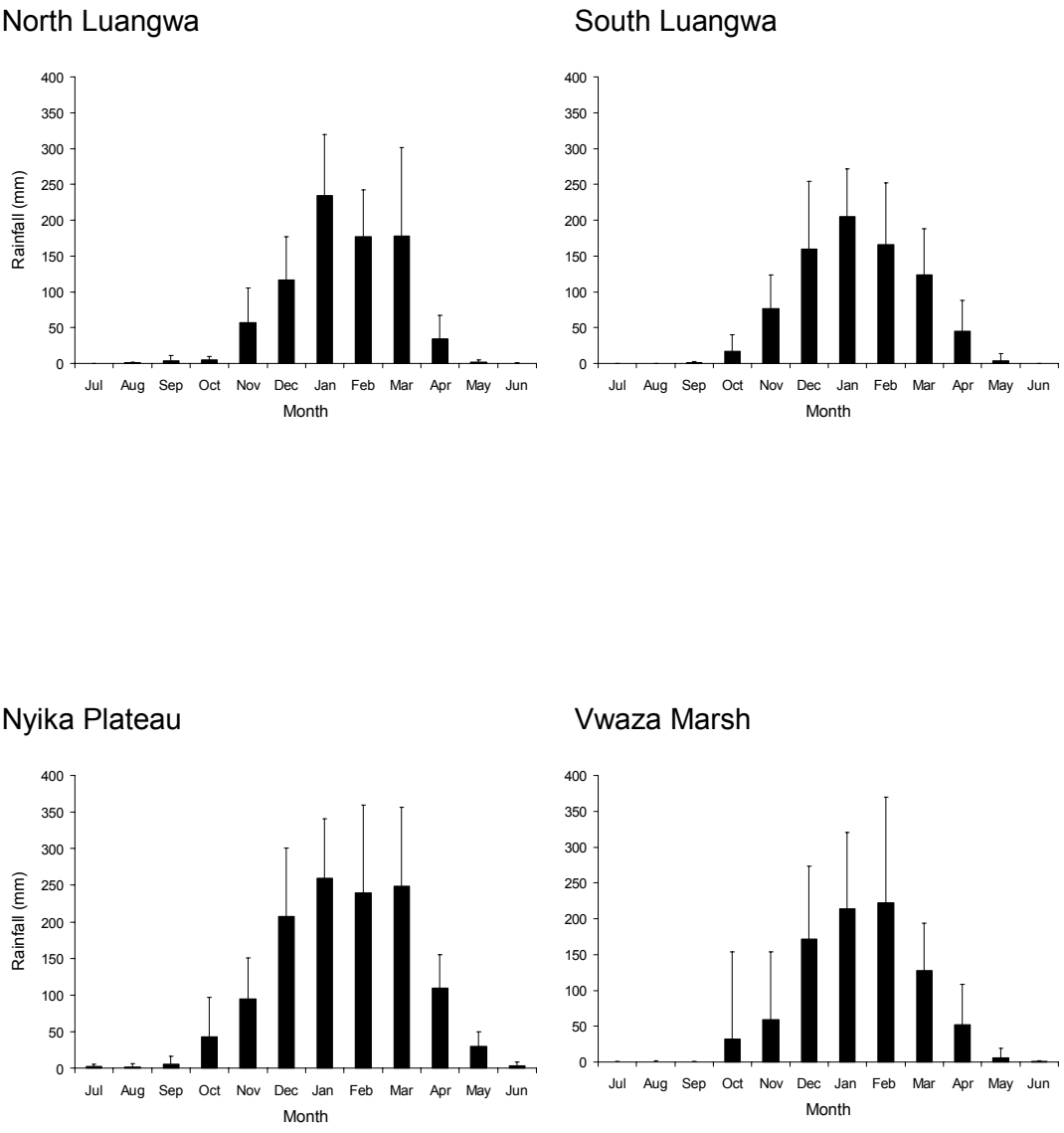
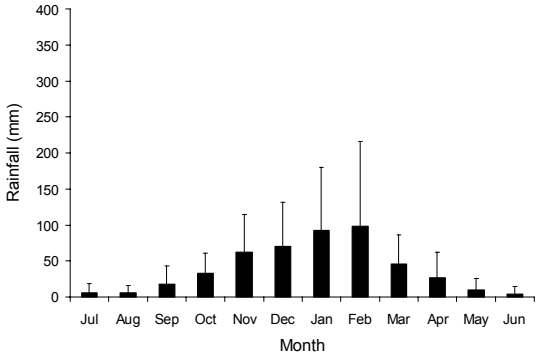
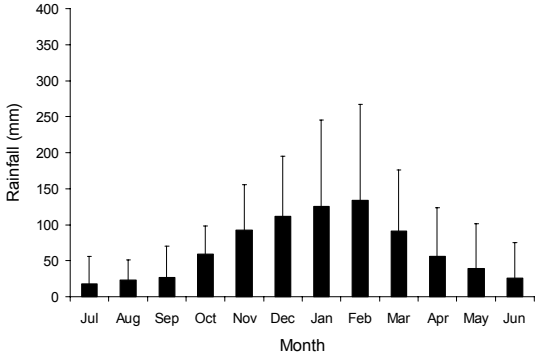


Figure. 7. Mean monthly rainfall (±SD) for sites in the Luangwa cluster.

Limpopo (Shingwedzi)



Maputaland (Tembe Elephant Park)



Maputaland (Maputo Elephant Reserve)

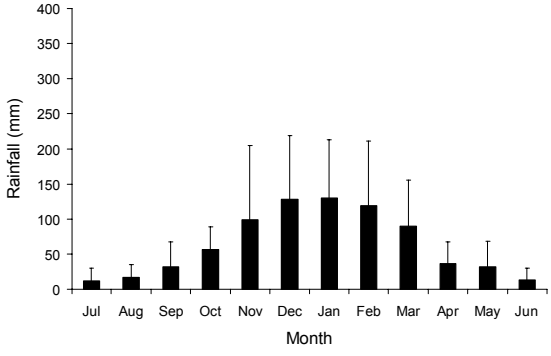
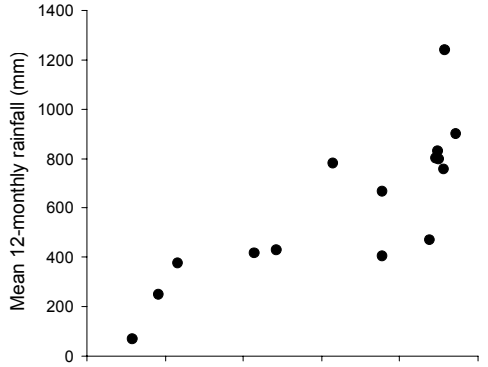


Figure. 8. Mean monthly rainfall (±SD) for sites in the Limpopo and Maputaland clusters.

(a) Rainfall



(b) Rainfall variability

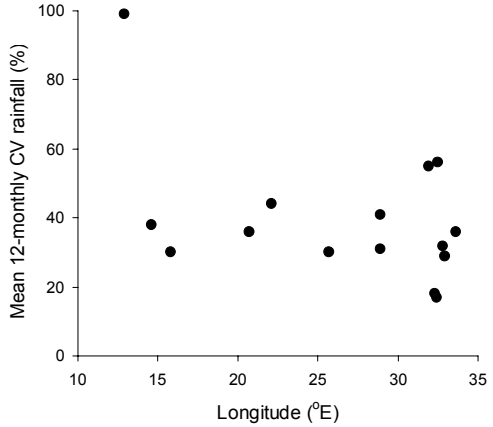


Figure 9. (a) Mean annual rainfall and (b) co-efficient of variability of rainfall for study sites within all clusters along an east-west gradient.

Cluster 1: Etosha National Park and Kunene Region.

Data are available for three elephant satellite-collaring operations within this area. Data for the first two were kindly provided by Dr Keith Legget of the Namibian Elephant and Giraffe Trust, funded through Sida. The third is taken from CERU's research in Etosha National Park, conducted in co-operation with the Etosha Ecological Institute and funded largely by the US Fisheries & Wildlife Service. All collars from two of these operations have expired. The third operation only began during September 2004.

In September 2002 the Namibian Elephant and Giraffe Trust fitted eight satellite collars to elephants in the Kunene Region, Namibia. Six were fitted to males and two to females. The last collar stopped transmitting during August 2004. Complete seasonal records are, therefore, available for the 2003 and 2004 wet seasons, as well as the 2003 dry season. Only limited data are available for the 2002 and 2004 dry seasons. As the first collar failure occurred during April 2003, the number of elephants for which home-range data are available decrease through the study. Elephant collar attrition follows a similar trend in other clusters.

A second batch of collars was attached to individuals in the Kunene Region during September 2004. This involved recollaring four of the original males, as well as a fifth unmarked male. Following Legget (2004), these elephants could be divided into two groups, one of four and the other of five elephants, in the eastern and western Kunene areas. The movements of these elephants are summarised below:

Western Kunene Region

Desert 01 (male) Desert 01 remained in the immediate vicinity of the Hoarusib River. During the 2002 dry season, he ranged from the upper reaches of Hoarusib to the lower end of the Gomatum River (Fig. 10; Table 5). His movements were similar during the 2003 wet season, when his collar failed prematurely.

Desert 02 (male) Desert 02, was a young male estimated at only 12-15 years who moved with his family group (Leggett, pers comm.). His movements are, therefore, more synonymous with those of an adult female than adult male. During the 2002 dry season, he remained in the Hoarusib River moving along the river from 5–70km upstream of its mouth (Fig. 11; Table 5). At the onset of the 2003 wet season, Desert 02 moved upstream approximately 140km from the river mouth, where he stayed until the 2003 dry season. During the 2003 dry season his home-range was similar to the 2003 wet season.

Desert 07 (female) Immediately after collaring Desert 07 moved from the Hoarusib to the Hoanib River, where she ranged through the 2002 dry season (Fig. 11). At the onset of the 2003 wet season, Desert 07 retraced her steps to the Hoarusib River catchment where she remained for the duration of the 2003 wet season. Her wet season range was therefore the largest recorded for any individual (Table 5). Here she ranged from 10–180km upstream of the

river mouth. She remained in the Hoarusib River catchment during the 2003 dry season, ranging less extensively through its catchment area than during the wet season.

Desert 08 (male) During the 2002 dry season Desert 08 moved from the Hoarusib to the Hoanib River (Fig. 10; Table 5). He remained in the Hoanib River until late in the 2003 wet season, when he moved to the plains south of Sesfontein. Early in the 2003 dry season, Desert 08 moved from the Hoanib River back to the Hoarusib River where he ranged from 30-130km upstream of the river mouth. Early in the 2004 wet season, Desert 08 moved from the Hoanib River east to Sesfontein, before turning south to the Sesfontein plains. He then moved eastwards to within 10 km of Hobatere where he remained in the eastern Hoanib River before returning westwards. Desert 08 then crossed back to the Hoarusib River, returning in the 2004 dry season to the Hobatare area and the Hoanib River. The 2004 dry season data contains records from before and after his collar was replaced.

Western Kunene summary

The movements of these four individuals within the western Kunene Region clearly demonstrate the importance of its riverbeds. Individuals apparently forage within their catchment areas, before they are forced to return the rivers to drink every 2-3 days (Leggett, 2004). The movements of Desert 08, in particular, demonstrate the linkage that exits between elephants from this and the eastern Kunene Region.

Eastern Kunene Region

Desert 03 (female) Throughout the study period Desert 03 remained largely within the borders of the Hobatere Game Park and Kaross Game Reserve, part of Etosha National Park (Fig. 11; Table 5). Occasionally she ventured into the eastern section of the Hoanib River. There was no discernible difference between her wet, and dry season ranges, which were the smallest recorded for any within the Kunene Region.

Desert 04 (male) Desert 04's 2002 dry season movements were limited to the areas around Hobatere Game Reserve. At the onset of the 2003 wet season, however, he moved eastward into Etosha National Park (Fig. 10; Table 5). He stayed briefly in Etosha, before heading northwest into the communal areas, where his collar failed prematurely. He was recollared during 2004 and remained in the Hobatere Game Reserve for the 2004 dry season.

Desert 05 (male) During the 2002, 2003 and 2004 dry seasons Desert 05's movements were restricted to the immediate areas surrounding Hobatere Game Reserve (Fig. 10; Table 5). At the onset of the 2003 wet season, Desert 05 moved southeastwards to the Huab River area near Kamanjab, crossing both commercial and communal farmland. He then moved northeast toward Etosha National Park, stopping about 20 km south of the park border, before returning to Hobatere. This wet season movement was repeated in 2004. Home-range use patterns were, therefore, similar for both wet and dry seasons. He was one of the individuals recollared during the 2004 dry season.

Desert 06 (male) During the 2002 dry season, Desert 06 moved in and around Hobatere Game Reserve, to a distance of approximately 15km outside its borders (Fig. 10; Table 5). At the onset of the 2003 wet season he moved 60km southwards from Hobatere into the

Grootberg Mountains. He then returned briefly to Hobatere, before again moving south to the Grootberg Mountains in response to late rains (Leggett, 2004). During the 2003 dry season, Desert 06 initially utilised the Huab River catchment, moving east-west along the Huab River valley, before returning to Hobatere Game Reserve. He was recollared in the 2004 dry season, spending this period in and around Hobatere Game Reserve.

Desert 09 (male) This male was only collared during 2004. He spent the dry season in the vicinity of Hobatere Game Reserve and southwestwards along a tributary of the Ombonde River (Fig. 10).

Eastern Kunene summary

The home-ranges of these individuals indicate that elephants from the Hobatere area overlap with those from both the western Kunene Region and Etosha National Park and northwards (Desert 04) into the communal areas west of Etosha. This refutes Viljoen's contention (1989) that there is no movement of individuals between the Kunene and Etosha elephants. The Kunene region and Etosha represent a viable single elephant cluster. It is highly likely that this cluster links further northwards towards the Angolan border. Viljoen (1989) has documented the movement of a family herd from the Kunene River 195km south to the Hoarusib River. In addition, Lindeque & Lindeque (1991) have noted elephants from Etosha National Park moving to within 20km of the Angolan border. It remains unclear, however, whether there is any eastward movement of individuals along the Kunene River to the Caprivi Strip.

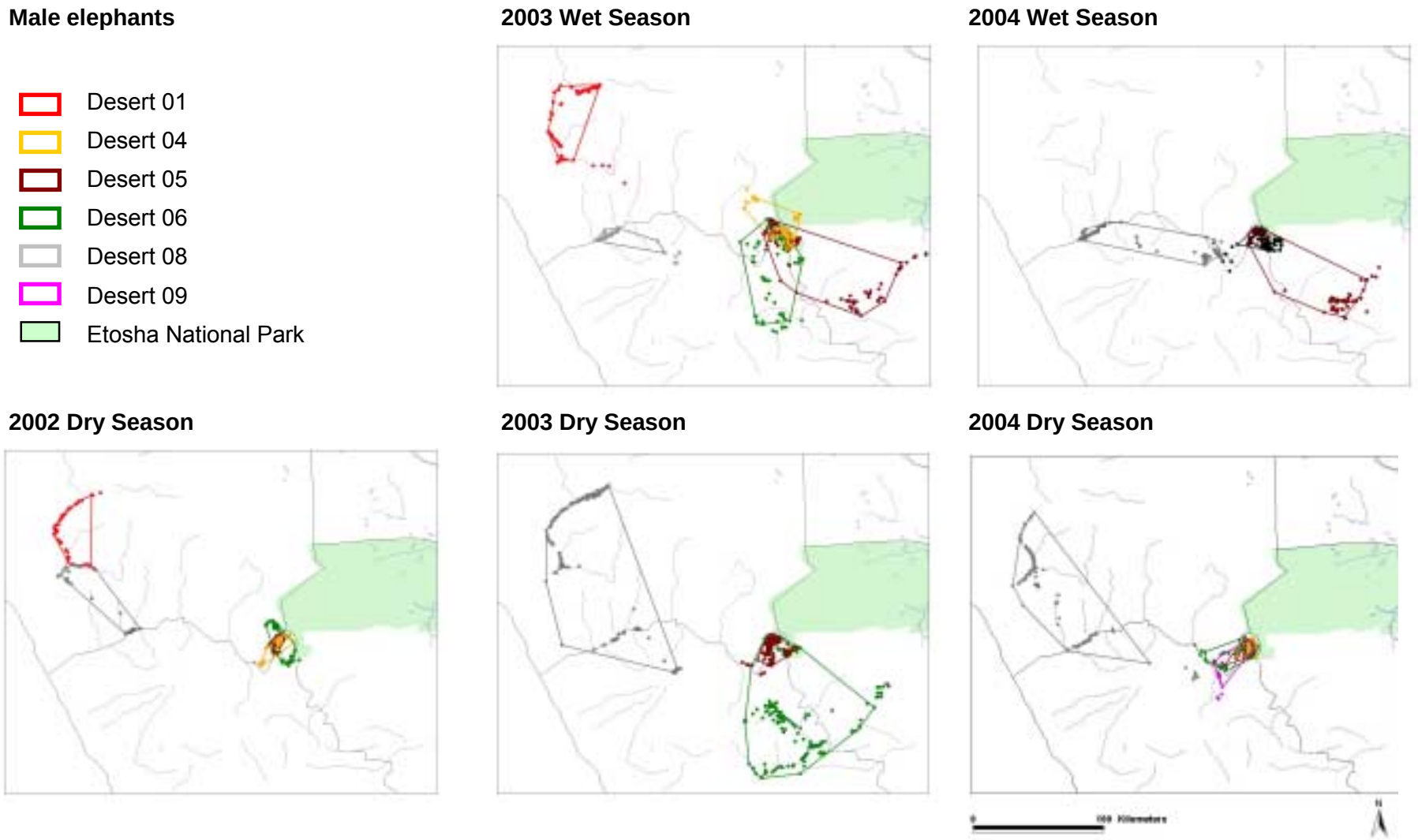


Figure 10. Daily positions and home-ranges (95% MCP) of six male elephants in the Kunene Region, Namibia from the 2002–2004 dry seasons. For more information see Table 5.

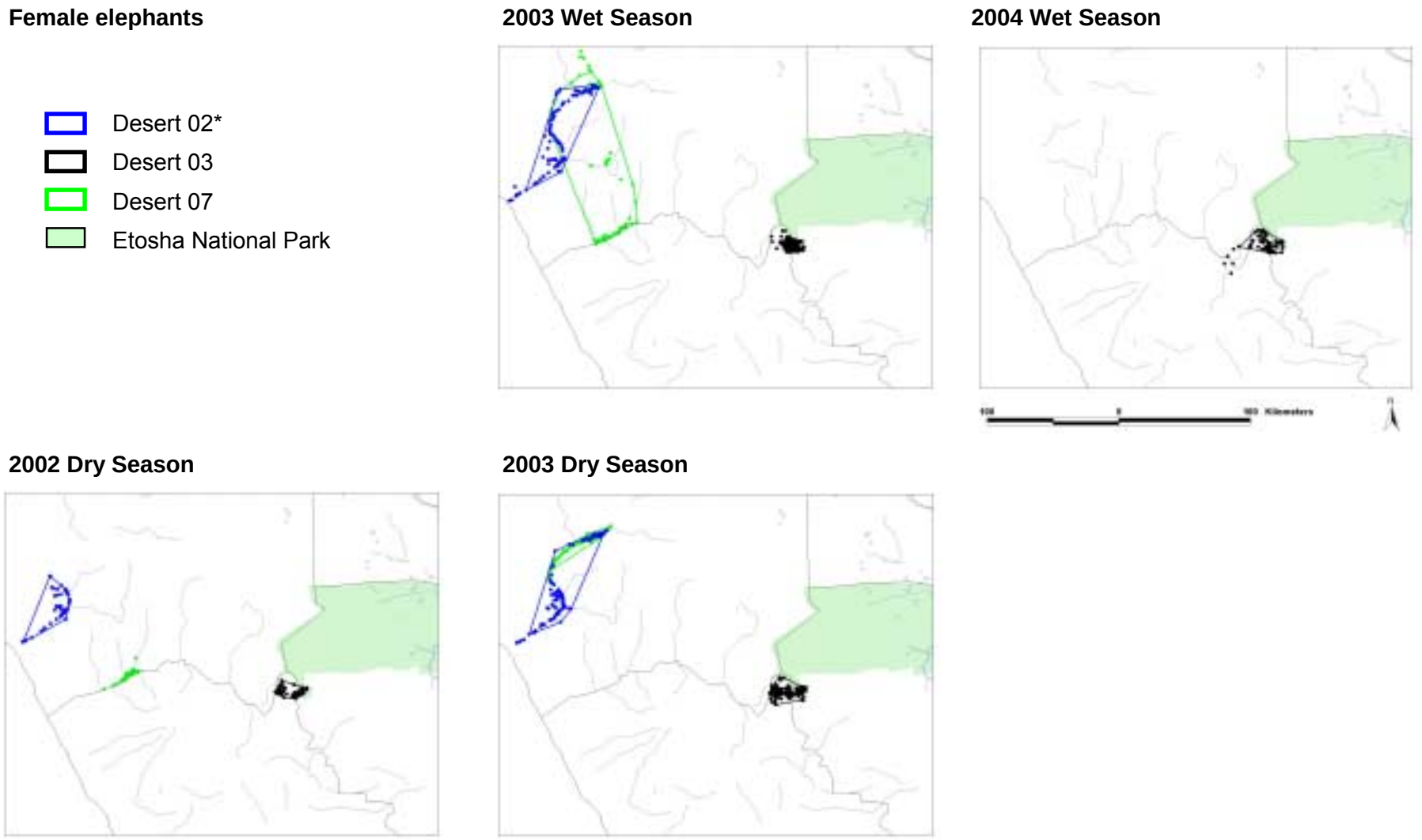


Figure 11. Daily positions and home-ranges (95% MCP) of two female and one juvenile male elephant that moved with his family group (Desert 02) in the Kunene Region, Namibia from the 2002 dry – 2004 wet seasons. For more information see Table 5.
** Desert 02 was young male that moved with his family group. His movements reflect the group's movement, and not that of an adult male.*

Table 5. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for nine elephants in the Kunene Region of the Kunene/Etosha cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Etosha/ Kunene Cluster		2002 Dry Season [a]				2003 Wet Season				2003 Dry Season				2004Wet Season				2004 Dry Season			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Kunene																					
Desert 01	Male	(1044)	(1338)	(149)	(50)	(1399)	(1544)	(210)	(106)												
Desert 02**	Male	(767)	(945)	(111)	(58)	1745	2654	388	135	1767	1758	298	174								
Desert 03	Female	(181)	(274)	(31)	(64)	185	174	19	137	360	315	52	202	(347)	(383)	(53)	(104)				
Desert 04	Male	(239)	(349)	(44)	(34)	(849)	(528)	(71)	(102)									(167)	(242)	(46)	(56)
Desert 05	Male	(89)	(119)	(18)	(59)	3954	2582	352	138	372	231	23	202	2930	2490	430	133	(198)	(234)	(27)	(59)
Desert 06	Male	(392)	(696)	(119)	(63)	2703	1834	185	138	6453	5392	542	222					(585)	(868)	(95)	(57)
Desert 07	Female	(48)	(70)	(11)	(57)	4785	5041	1010	136	309	384	48	199								
Desert 08	Male	(1054)	(1460)	(213)	(62)	465	250	81	133	8087	4669	472	202	1790	1889	320	144	4853	3357	438	164
Desert 09	Male																	(430)	(612)	(69)	(58)
Mean		(477)	(656)	(87)		2306	2089	339		2891	2125	239		2360	2189	375		4853	3357	438	
SD		(418)	(544)	(73)		1856	1811	359		3475	2331	232		806	425	78					
n		8	8	8		6	6	6		6	6	6		2	2	2		1	1	1	

[a] Data only available from Sept – Nov 2002.
** 12–15 year old male moving with family group.

Etosha National Park

A CERU team, supported by members of the Etosha Ecological Institute collared six adult female elephants within the park during November 2002. These were distributed through the central and eastern sections of the park. Complete data sets are therefore available for both the 2003 and 2004 wet seasons as well as the 2003 dry season. Due to collar failures during the 2004 dry season, only limited data are available for three individuals during this period. No functioning collars are presently deployed on elephants in Etosha National Park. Funding for these collars was provided largely by the US Fisheries and Wildlife Service.

Etosha 01 Female Etosha 01 used the southern half of the park extensively. During the 2003 wet season her movements extended west as far as Jakkalswater and east to Gobaub (Fig. 12; Table 6). During the 2003 dry season, however, she no longer made use of the western section of the park, keeping to the central areas of the park south of the pan, largely in the Okaukuejo-Ombika-Aus area, though she did range eastwards as far as Dungaries during an excursion she made in mid November. Her 2004 wet season movements were similar to those in 2003, as she again extended her home-range into the southwestern section of the Park again.

Etosha 02 Etosha 02 exhibited a similar home-range pattern as Etosha 01, with a smaller home-range during the 2003 dry season than the 2004 wet season (Fig. 12; Table 6). Her home-range also extended further westwards during the wet season. During the 2003 dry season she moved through the western section of the park between Duikerdrink and Narawandu. During the dry season her range shifted northwestwards. At this time she ranged between Duiwelsvuur-Ozonjuitji M'bari northeastwards to Panpoint and beyond. Range use was similar for both dry seasons, though she ventured to the northern boundary of the park, west of the Etosha Pan, during the 2004 dry period.

Etosha 03 The range of Etosha 03 bordered the western and southwestern boundaries of Etosha Pan during both wet seasons. Her home-range shrank considerably through the dry seasons to be restricted to the Okaukuejo-Ombika-Aus area along the southwestern fringes of the pan (Fig. 12; Table 6). The home-range of Etosha 03 was similar for both wet and both dry seasons.

Etosha 04 The home-range of Etosha 04 was situated from Klein Okevi, northwards towards Mushara (Fig. 12). While she favoured this area to the east of Etosha Pan, she did range westwards across the pan, particularly during the wet season. These movements suggest that she used similar areas of the park during both wet seasons. Also that her dry season range was smaller than during the wet season. These conclusions should be treated cautiously, as only a limited data set of 69 fixes (2003 wet season) and 27 fixes (2004 wet season) are available for her (Table 6). Only during the 2003 dry season (n=192 fixes) are enough data available to provide a reasonable estimate of home-range size and use.

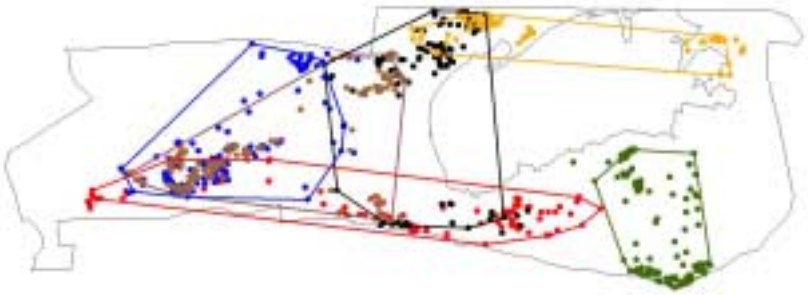
Etosha 05 The home-range of Etosha 05 extended over the central western section of the Park (Fig. 12; Table 6). During the wet season it covered an area from Duikerdrink northeastwards beyond Panpoint, showing a contraction from the wet to the dry seasons. Home-ranges were similar over both years for each season.

Etosha 06 She was the only female not to demonstrate a predictable pattern of home-range use for consecutive dry seasons. Her 2003 wet season home-range included an area of the extending southwards from Goas to the park's southern boundary. She spent considerable time along the boundary fence, but did not cross out of the park. Typical of the other Etosha females, her home-range shrank during the dry season, but was still centred in this southern area, predominantly within 8km of Goas. Her range use pattern was very similar for the 2003 and 2004 wet seasons. During the 2004 dry season, however, she shifted her home-range westwards, from Aus as far Okaukuejo. Her dry season home-ranges were therefore quite different and the extent of this drift is illustrated in Fig. 12.

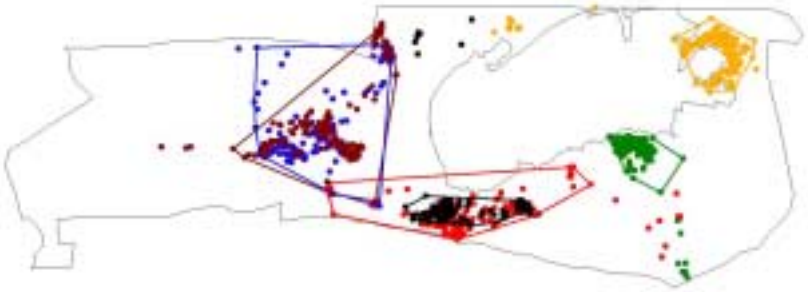
Etosha summary

Dry season home-ranges were much smaller than during the wet seasons. During the dry season cows limited their activities to areas close to water and seldom ventured further than 8km from natural and artificial water points (see van Aarde *et al*., 2004a). Range fidelity was high – for both wet seasons, the ranges of each individual were located in similar regions of the park. With the exception of Etosha 06, dry season ranges fell within wet season ranges. The home-range sizes of these six females were similar during the two wet seasons (Wilcoxon Matched Pairs: $Z_{(0.05, 1)} = 0.52$; $P=0.60$; Table 6), but were significantly smaller during the dry season (Wilcoxon Matched Pairs; $Z_{(0.05, 1)} = 2.20$; $P<0.05$; Table 6). Migratory movements within the Park were strictly seasonal and resulted in an expansion of ranges during the wet seasons. Fences surrounding the Park may have restrained traditional migratory movements. This is evident in both the southeast and north central areas of the park (Fig. 12). At no time did any individual cross the park's fence lines. Historically, elephants moved into the park during the 1950's. Seasonal censuses indicate that in the late 1980s 30–50% of Etosha's elephant population spends 3–5 months of their time outside the park during the wet season (Lindeque & Lindeque, 1991).

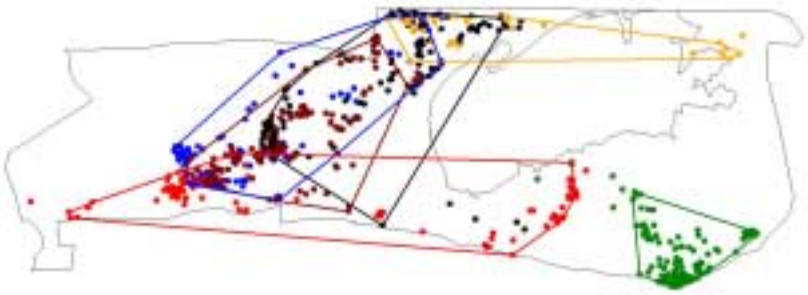
2003 Wet Season



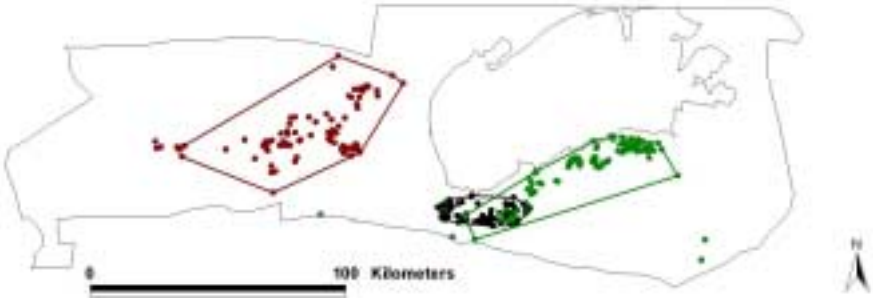
2003 Dry Season



2004 Wet Season



2004 Dry Season



Etosha 01 Etosha 02 Etosha 03 Etosha 04 Etosha 05 Etosha 06

Figure 12. Daily positions and home-ranges (95% MCP) of six female elephants in Etosha National Park during the 2003 and 2004 wet and dry seasons. For more information see Table 6.

Table 6. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for six elephants in the Etosha cluster. Four collars malfunctioned within a month and were replaced by collars on new animals during July 2003. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Kunene/Etosha Cluster		Wet Season 2003				Dry Season 2003				Wet Season 2004				Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Etosha																	
Etosha 01	Female	3581	9059	1674	124	1737	1353	190	200	5132	7721	926	109				
Etosha 02	Female	3351	3230	536	128	2581	1107	228	200	3720	5173	591	99				
Etosha 03	Female	4539	2501	382	127	383	461	67	192	4095	4384	536	129	4095	476	63	109
Etosha 04	Female	1770	3534	539	69	547	734	151	192	1634	5768	921	27				
Etosha 05	Female	3986	4034	626	129	2143	1386	293	200	3044	3827	572	135	2273	2094	307	100
Etosha 06	Female	1664	1803	293	126	349	250	41	200	995	972	95	137	1373	1421	209	117
Mean		3424	4126	702		1290	882	162		2711	3061	401					
SD		1082	2880	558		985	474	96		1576	1831	265					
n		5	5	5		6	6	6		3	3	3					

Cluster 2: Chobe Cluster

Despite its size, being by far the largest of the elephant clusters, the Chobe cluster is under-represented in our home-range analysis. To date only six working collars have been deployed by us within the cluster (four other collars failed after approximately one month). These collars, which are still operational, are fitted to three bulls and three cows. The original collars were fitted during October 2003, but did not provide sufficient data to calculate home-ranges for this dry season (10-33 fixes). Fortunately, these collars did allow us to monitor the sudden change in range use of a these individuals at the end of the dry season. 2004 wet season data are only available for two bulls. With the deployment of four replacement collars in June 2004, full 2004 dry season data sets are available for three bulls and three cows. The original units were fitted with support from the US Fish &Wildlife Services through Conservation International's southern Africa Wilderness Programme and replacement units were funded by the Peace Parks Foundation.

Bots 01 (female) This female yielded only 26 fixes before her collar failed. During the time it was active, during the 2003 dry season, her activities were centred in the area around Seronga and Eratsha, where she remained until 15 November (Fig. 13; Table 7). She then headed 50 km northwards towards the Caprivi Strip, shifting the centre of her activities. Here she ranged through both NG11 and NG13.

Bots 02 (male) During the 2003 dry season, this male's home-range was centred on the area south of the Kangara-Eretsha road, with a single excursion northwestwards 20km into NG11 (Fig. 13; Table 7). During the wet season he left this area, moving further northwards towards the Caprivi Strip from late February until early April 2004. During this period he ranged through the western sector of NG13, some 50 km north of his dry season range. In April 2004 he returned southwards again to the Eretsha-Katjirarjira area and remained in this area throughout the dry season.

Bots 03 (female) With only 10 fixes from this female it is impossible to say anything constructive with regard to her home-range, except that it followed the Panhandle from Seronga northwestwards to Shauwe (Fig. 13; Table 7).

Bots 04 (female) Female Bots 04 provided limited information before her collar failed. She kept to the area bordering the Panhandle around Mawana until the 13th November. At this time she suddenly left the Panhandle, heading 40 northeastwards towards the boundary of NG11 and NG13. This corresponded almost exactly with the time Bots 01 headed northwards towards the Caprivi Strip (Fig. 13; Table 7).

Bots 05 (male) This male's activities were initially centred on the Seronga area (Fig. 13; Table 7). On the 15th Nov Bots 05 abruptly left this area, heading 45 km northwards towards the boundary of NG11 and NG13 before his collar failed.

Bots 06 (female) During the 2003 dry season female Bots 06 covered a range extending from Shauwe to Eretsha along the Pandhandle (Fig. 13; Table 7). On the 16th November she left this area, heading 45km northeastwards to the boundary of NG11 and NG13. Here she remained into the 2004 wet season, returning to the Seronga area at the end of January 2004, moving through central NG11 before moving northeastwards again in mid March 2004. She ranged through NG13 until June 2004, when she returned to Seronga and remained close to the Panhandle for the remainder of the dry season.

Bots 07 (female) Data are only available for the 2004 dry season. Typical of animals at this time of the year, early dry season movements were restricted to the Panhandle and Delta (Fig. 13; Table 7). Initially she concentrated her movements between Seronga and Eretsha, shifting to the Nagarange-Mawana section of the Panhandle in late August. On the 22nd November she left the Panhandle, moving away northeastwards into NG 13 over a period of three days.

Bots 08 (female) This female's home-range movements were concentrated in the Gunitsuga-Kanagara region for the first few months of the dry season (Fig. 13; Table 7). In late October she left this riverine habitat, moving up to the Shauwe-Mawana section of the Panhandle, from where she was recorded as far away as 25km from the river. On the 21st November she headed up away from the Panhandle northeastwards to the border of NG11 and NG13.

Bots 09 (male) This male started the 2004 dry season close to the Panhandle in the Seronga-Kangare area (Fig. 13; Table 7). He moved up the Panhandle as the dry season progressed, reaching as far as Sangoshe. He suddenly returned southwards 70km in late October and began working his way up the Panhandle again. With one exception, he remained within 20km of the Panhandle during the dry season. Then on the 18th November he moved northeastwards towards NG13, travelling further away from the Panhandle than at any other period in the dry season.

Bots 10 (female) This female concentrated her 2004 dry season movements in the south of the Panhandle until late October, when she moved northwestwards along the Panhandle (Fig. 13; Table 7). Her northward movements took her to within 5km of the Caprivi Strip at the end of October. On the 22nd November she moved away from the Panhandle, crossing into NG13 some 40km away from the river floodplain.

Chobe summary

In summary, despite the short life of four of the six initial collars, it was clear there was an abrupt movement of individuals from the Panhandle towards the Caprivi Strip and NG13 on or around the 15th November 2003. A similar movement pattern was observed during 2004, largely with different individuals. The timing of this event was, however, a week later. The ranging data of individuals suggests that water may limit their ability to utilise the dry regions to the northeast of the Panhandle until ephemeral waterholes fill at the start of the rainy season. We speculate that at this time they respond quickly, expanding their ranges into this area until water availability again restricts range use.

The movement of all females was predictable, as all moved away from the Panhandle for the duration of the wet season. Male movement did not show this consistency. Instead, most males left the Panhandle at the end of the dry season, though several returned before the wet season ended. One (Bots 10) did not even leave the Panhandle. These observations are consistent with the findings of aerial surveys conducted by a CERU team – Mosojane (2004) suggests that the presence of bulls within NG11 was not affected by season, while females were absent from the area during the wet season. Individuals did indeed move into NG13. While they came into close proximity with the Caprivi

Strip, they did not cross this fence line into Namibia. In addition, no individual was tracked crossing to the southwestern bank of the Kavango River.

2003 Dry Season

Males

Females

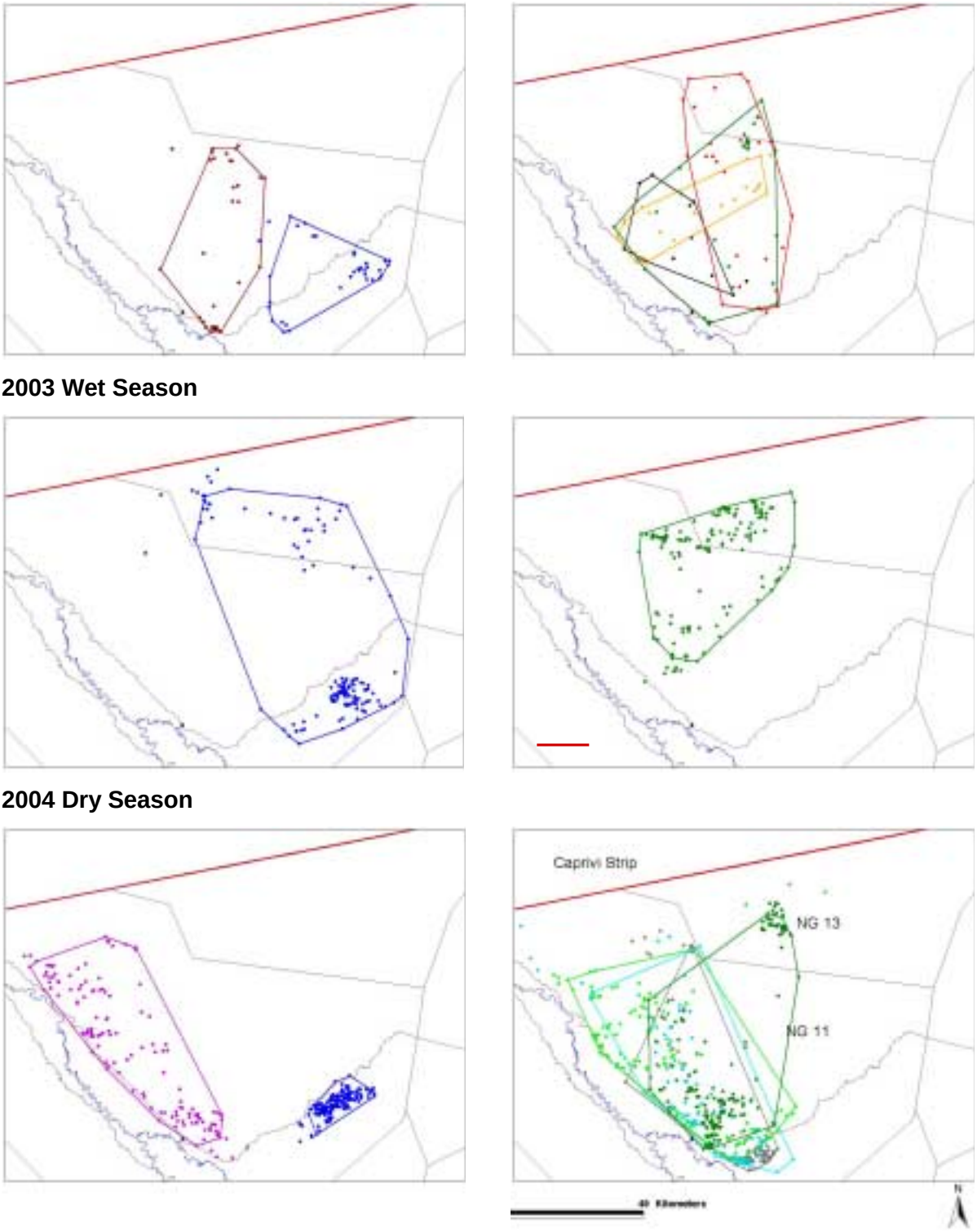


Figure 13. Daily positions and home-ranges (95% MCP) of seven female and three male elephants in the Okavango Panhandle during the 2003 and 2004 wet and dry seasons. For more information see Table 7.

Table 7. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for ten elephants in the Chobe cluster. Four collars malfunctioned within a month and were replaced by collars on new animals during July 2003. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Chobe Cluster		Dry Season 2003*				Wet Season 2004				Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Okavango Panhandle													
Bots01	Female	(1423)	(3019)	(656)	(26)								
Bots02	Male	(624)	(915)	(92)	(33)	2961	1367	156	143	148	148	26	165
Bots03	Female	(524)	(1603)	(635)	(10)								
Bots04	Female	(549)	(1324)	(245)	(26)								
Bots05	Male	(968)	(1610)	(214)	(33)								
Bots06	Male	(1764)	(2694)	(203)	(29)	1385	1535	226	147	1960	1378	198	154
Bots07	Female									2022	2416	642	123**
Bots08	Female									1239	416	99	119**
Bots09	Male									1418	2357	377	131**
Bots10	Female									1765	1347	119	124**
Mean						2173	1451	191		1425	1344	244	
SD						1115	118	50		696	945	229	
N						2	2	2		6	6	6	

* data only available Oct–Nov 2003; ** data only available July–Nov 2003.

Cluster 3: Kafue Cluster

We fitted collars to five male and five female elephants during May 2003. Eight of these collars continue to function properly, while two failed during the 2004 wet season. We expect the remaining collars to fail during the 2005 wet season. The International Fund for Animal Welfare provided funding for these collars. Sufficient fixes were obtained for all operating collars, to provide complete data sets for the 2004 wet season, as well as the 2003 and 2004 dry seasons.

Kafue 1 (female) This female had the smallest home-range of any individual. Through the whole tracking period her movements were concentrated around Ngoma and the open grasslands in the neighbouring Nkala GMA (Fig. 14; Table 8). The only deviation from this trend was some time spent 25km south of Ngoma in the Nanzhila region of southern Kafue during the 2003 dry season.

Kafue 3 (female) During the 2003 dry season Kafue 3's movements were largely restricted to the Ngoma area, particularly the Ngoma Forest, with occasional excursions eastwards into the Nkala GMA. During the 2004 wet season, her home-range extended, though not dramatically, westwards and she also spent more time in the Nkala GMA (Fig. 14; Table 8). While her home-range shrank slightly during the 2004 dry season, she concentrated her activity towards the south and west of Ngoma, moving further westwards than previously recorded.

Kafue 5 (female) This female's home-range was concentrated across a broad band from the boundary of Kafue and Nkala GMA in the east, to within 10km of the park boundary in the west, during both the 2003 dry and 2004 wet seasons (Fig. 14; Table 8). Her home-range did, however, more than halve during the 2004 dry season as she discontinued her westward forays, concentrating her activities instead in the Ngoma area.

Kafue 6 (female) Data are only available for the 2003 dry season, before Kafue 6's collar failed. Her activities during this season were similar to those of a number of other females. Her movements were concentrated in the Ngoma region, as well as the neighbouring Nkala GMA (Fig. 14; Table 8).

Kafue 8 (female) The home-range of female Kafue 8 extended over a 40km long east-west strip passing through Ngoma and extending 10km into the Nkala GMA (Fig. 14; Table 8). Home-range size showed little variation, but was slightly larger during the 2003 dry season than either of the other monitoring periods.

Kafue 2 (male) Kafue 2's movements were restricted to the Ngoma area and Nkala GMA through the 2003 dry season. During the 2004 wet season he extended his range considerably, down through the Nkala River, making extensive use of the southwest area of the park and into the neighbouring Mulobezi GMA, 80km from Ngoma (Fig. 14; Table 8). With the onset of the 2004 dry season his movements were almost exclusively restricted to the park. He did not return to the Ngoma region, but wandered extensively through the Nanzhila region south of Ngoma. Correspondingly his 2004 dry season home-range (CHECK) was considerably larger than during 2003 95% KER = 373km^2).

Kafue 4 (male) Kafue 4 consistently roamed over the smallest area of any male (Fig. 14; Table 8). During the 2003 dry season his movements were concentrated in the Nkala GMA and areas south of Ngoma extending down towards the Nanzhila region. With the onset of the 2004 wet season his home-range expanded. He made less use of the Nkala GMA, moving more extensively through the Nanzhila region, as well as areas south of Ngoma. His home-range shrank again during the 2004 dry season and while his activities covered similar areas to the 2003 wet season, he also appeared to utilise areas southwest along the Nkala River.

Kafue 7 (male) The 2003 dry season home-range of Kafue 7 extended from Nkala GMA, southwestwards through Ngoma and into the Nanzhila region of Kafue (Fig. 14; Table 8). While using extensively the same area, his home-range extended slightly westwards, as well as northeastwards towards the shore of Lake Itezhi Tezhi through the 2004 wet season. His 2004 dry season home-range was similar to that of 2003, though smaller, as it did not extend as far southwards into the Nanzhila region.

Kafue 9 (male) During the 2003 dry season male Kafue 9 ranged extensively through the Nanzhila region, as well as northeastwards towards Ngoma, with occasional excursions into the Nkala GMA (Fig. 14; Table 8). During the 2004 wet season his range shifted westwards slightly and he was even recorded moving into the Mulobezi GMA. His home-range would probably have increased further during this wet season, but his collar failed before this could be firmly established.

Kafue 10 (male) This male wandered extensively through southern Kafue and its neighbouring GMAs (Fig. 14; Table 8). During the 2003 dry season his movements were concentrated in the Nkala GMA to the east of Ngoma, and southwestwards along the Nkala River. Kafue 10's home-range shifted markedly southwest during the 2004 wet season. He stopped visiting the Nkala GMA, concentrating much of his activity in the Mulobezi GMA and Nanzhila region of the park. This wet season home-range was the largest recorded for any individual. During the 2004 dry season his home-range shrank considerably and was comparable in size and location to his 2003 dry season home-range.

Southern Kafue summary

The presence of five collared males and females in the cluster, allowed us to make valid statistical comparisons between the home-ranges of males and females. The only significant differences we observed were for male home-ranges, that were significantly larger than females during the 2004 wet season (Mann-Whitney U test: n=4,5, Z=2.20, P<0.05; Table 9). In addition, 2004 dry season home-ranges were smaller than 2004 wet season ranges (Wilcoxon Matched Pairs test: n=8, Z=2.52, P<0.02; Table 9). No other gender, or season specific differences existed in home-range size. Thus, while male home-ranges increased substantially during the wet season, those of females did not. Male and female wet season home-ranges did not differ significantly in size.

In summary, no elephants we tracked in southern Kafue moved northwards beyond the southern shore of Lake Itezhi Tezhi towards the central or northern sectors of the Park. The wet season home-ranges of females were considerably smaller than those of males. Female activity was concentrated in the Ngoma area

and the Nkala GMA, while the Nanzhila region was visited periodically. These finding are supported closely with the localities of elephant herds encountered in southern Kafue during both a rapid population assessment conducted by helicopter during May 2004 (van Aarde et al, 2004b), as well as a fixed wing aerial survey during September 2004 (van Aarde et al., 2004c).

During the wet season, males used the southern section of the park more extensively. The home-ranges of a number of males increased southwestwards through the Nanzhila region, up the Nkala River into the Mulobezi GMA. During the dry season the home-ranges of males shrank, when they also used the Nkala GMA. Individuals did not, however, use either the Sichifulo or Bilili Springs GMAs, to the south and southeast of Kafue respectively.

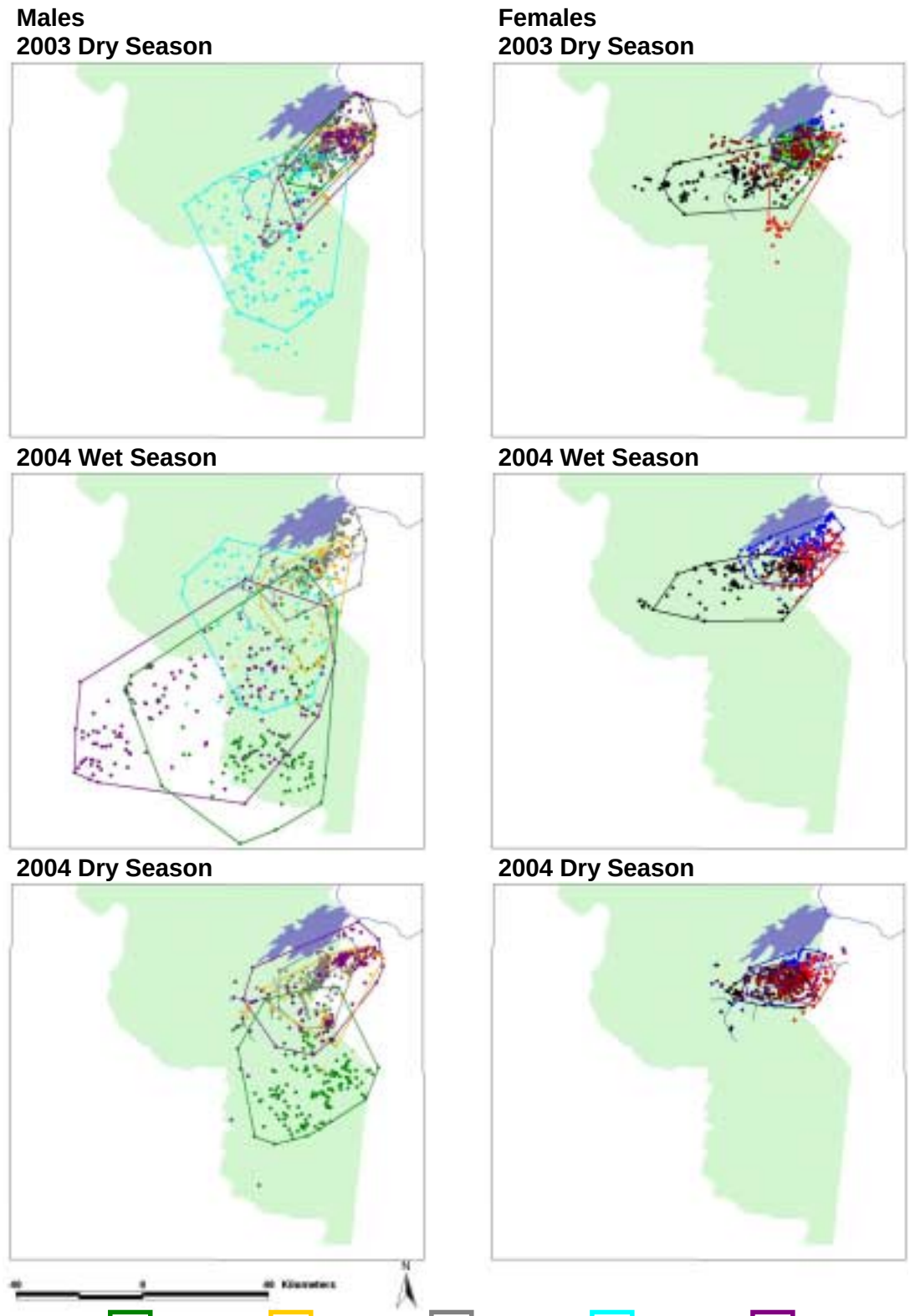


Figure 14. Daily positions and home-ranges (95% MCP) of five female and five male elephants in southern Kafue National Park from the 2003 to 2004 dry seasons. For more information see Table 8.

Table 8. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for ten elephants in the Kafue cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Kafue Cluster		Dry Season 2003				Wet Season 2004				Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Ngoma													
Kafue 01	Female	377	358	41	182	185	236	34	139	182	147	15	181
Kafue 02	Male	433	373	22	182	3738	3963	423	134	1523	1370	158	176
Kafue 03	Female	155	180	33	181	374	425	77	139	300	195	24	158
Kafue 04	Male	238	139	15	181	717	614	49	140	613	252	26	178
Kafue 05	Female	802	968	178	181	780	620	63	138	242	250	20	86
Kafue 06	Female	236	274	32	154								
Kafue 07	Male	593	521	51	181	735	622	92	132	480	190	16	173
Kafue 08	Female	432	364	19	181	219	239	23	140	189	214	25	169
Kafue 09	Male	1962	2564	394	181	(1822)	(2527)	(358)	(97)				
Kafue 10	Male	622	361	41	180	3893	4754	549	137	1112	351	42	175
Mean		585	610	83		1330	1434	164		580	371	41	
SD		523	724	119		1552	1824	203		491	408	48	
n		10	10	10		8	8	8		8	8	8	

Table 9. Summary 97% KER home-range data for male and female elephants in southern Kafue National Park. Data compare seasonal home-ranges. The mean values are followed by one standard deviation of the mean.

	Home-range (km^2)	
Season	Males	Females
2003 Dry	348±133	467±133
2004 Wet	2488±774	380±774
2004 Dry	540±197	201±197

Cluster 4: Zambezi Cluster

The Lower Zambezi cluster included six cows that were collared in Lower Zambezi National Park (Zambia) during August 2004. The collaring operation was co-funded by the National Postcode Lottery of the Netherlands and Peace Parks Foundation. Data are, therefore, only available for these cows for the 2004 dry season.

Zambezi 01 With the exception of one record in the Sapi Safari Area, this female remained within Zambia during the 2004 dry season. She never moved more than 4.5km from the Zambezi River (Fig. 15; Table 10). Her movements were concentrated along the 30km riverfront of Lower Zambezi National Park, though she moved westwards 26km into the neighbouring Chiawa GMA during the last week of November.

Zambezi 02 The movement of this cow was almost identical to that of Zambezi 01. With the exception of one record in the Sapi Safari Area, she too remained north of the Zambezi River, not moving more than 4km from its banks (Fig. 15; Table 10). Her movements were concentrated within the Lower Zambezi National Park, though she moved 11km out of the park into Chiawa GMA during the last week of November.

Zambezi 03 For the majority of the dry period this female remained within Lower Zambezi National Park, concentrating her movements along a 25 km stretch of the river (Fig. 15; Table 10). On the 12th November, however, she suddenly crossed the Zambezi River into Mana Pools National Park. Over seven days she travelled westwards more than 80km following the riverbank to the Chirundu area. Here the main Lusaka-Harare road crosses the Zambezi River. She did not cross this highway, but remained in this area for the remainder of the dry season.

Zambezi 04 This female confined her movements to the northern side of the Zambezi River, opposite Mana Pools National Park (Fig. 15; Table 10). Similar to the other females, she remained close to the river within Lower Zambezi National Park until the middle of November, when she headed westwards 22km into the Chiawa GMA.

Zambezi 05 This female used the Chiawa GMA more extensively than the others cows, ranging through the area during August, before moving into Lower Zambezi National Park (Fig. 15; Table 10). She remained in the park until 22nd November when, at the same time as four of the five other females, she returned to the Chiawa GMA. At no time was she found more than 6km away from the Zambezi River.

Zambezi 06 This female was the only individual to confine her movements to Lower Zambezi National Park (Fig. 15; Table 10). Here she ranged largely in the region north of the Sapi Safari Area, though she wandered more extensively along the Zambezi River in November than during the preceding months.

Zambezi Summary

Females within this cluster remained ranged largely within Lower Zambezi National Park. They showed a synchronous movement out of the park during late November. Unlike other areas, when individuals tend to move away from water at this time, the Lower Zambezi females remained close to the Zambezi River.

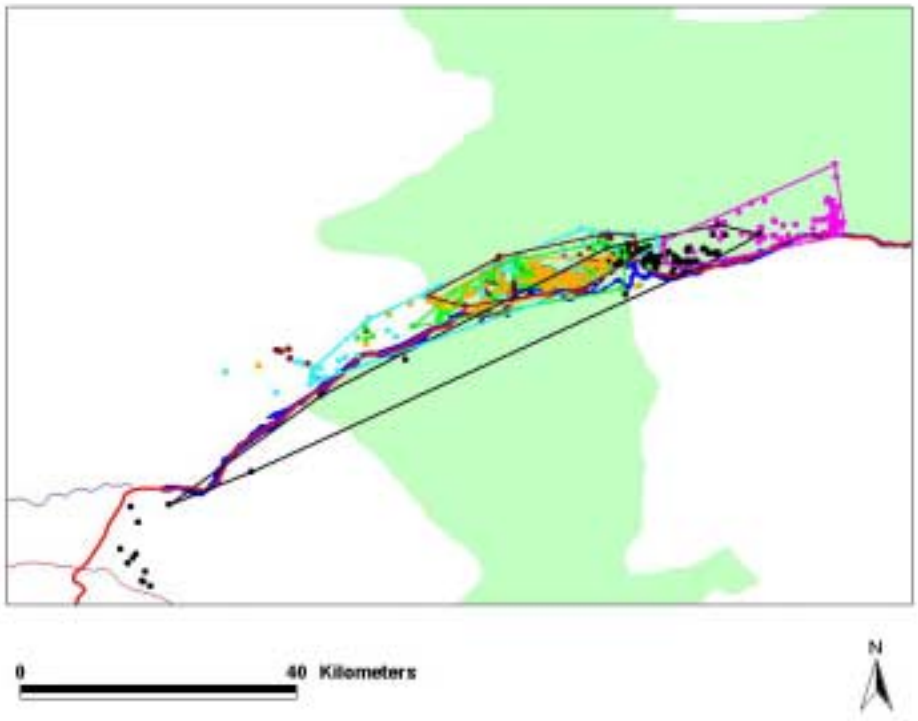


Figure 15. Daily positions and home-ranges (95% MCP) of five female elephants in the Lower Zambezi-Mana Pools area during the 2004 dry season. For more information see Table 10.

Table 10. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for six elephants in the Zambezi cluster. Data only available for Aug–Nov 2004. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistics (mean, SD, n) provided for all valid data.

Zambezi Cluster		Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Zambezi 01	Female	(127)	(167)	(28)	(93)
Zambezi 02	Female	(207)	(294)	(46)	(93)
Zambezi 03	Female	(953)	(872)	(187)	(94)
Zambezi 04	Female	(319)	(420)	(135)	(98)
Zambezi 05	Female	(219)	(774)	(107)	(81)
Zambezi 06	Female	(290)	(324)	(27)	(93)
Mean		(353)	(475)	(88)	
SD		(302)	(283)	(66)	
n		(6)	(6)	(6)	

Cluster 5: Luangwa Cluster

Luangwa and Munyamadzi

The Luangwa cluster includes three collars that were attached to elephants in North Luangwa National Park that were largely co-funded by the National Postcode Lottery of the Netherlands and Peace Parks Foundation. These were fitted during August 2004. A further five collars were deployed during October 2004 in South Luangwa National Park and the Munyamadzi GMA, that bridges the two parks. Funding for this operation was provided by the Conservation Foundation Zambia. All collars in this area were fitted to females.

N Luangwa 01 During the limited period for which we have information, this female remained on the forest plain at the base of the Muchinga Escarpment, in the northeast of the park (Fig. 16; Table 11). Her home-range stretched over a distance of 30km.

N Luangwa 02 This cow ranged along a 20km stretch of the Luangwa River in the northeast of the park (Fig. 16). During the study period she never moved further than 5km from the river. While predominantly ranging on its north bank, her movements also took her into the Musalangu GMA on its southern banks.

N Luangwa 03 Despite being the most westerly of the North Luangwa cows, well away from the Luangwa River, this female was never far from water (Fig. 16). She kept close to the tributaries of the Mulandashi River throughout the dry season to the north and northeast of Kutandala Camp.

S Luangwa 01 This female's movements were restricted almost entirely to the Munyamadzi GMA. Here she ranged over a relatively small area to the east of the GMA, with a single fix recorded in North Luangwa (Fig. 16).

S Luangwa 02 During October 2004 this female remained close to the Luangwa River in the Munyamadzi GMA (Fig. 16). Her movements took her through the Luambe and Lumimba National Park and GMA. During November, she moved southwards into the northeastern corner of South Luangwa National Park, in the vicinity of the Mwamba River. Given these movements, our limited data indicate a much larger home-range area than any of the other females in this cluster (Table 11).

S Luangwa 03 This female ranged to the east of the Luangwa River, in an area that stretching eastwards towards the Nchindeni Hills. Her movements were largely within the Lupande GMA (Fig. 16). They also took her to the confluence of the Luangwa and Kapamba Rivers within South Luangwa National Park.

S Luangwa 04 Centred in the vicinity of Flatdogs Camp, female S Luangwa 04 ranged along the Luangwa River through South Luangwa National Park during October 2004 (Fig. 16). In November, she spent more time on the east of the river within the Lupande GMA.

S Luangwa 05 Female S Luangwa 05 remained within South Luangwa National Park. Her movements were centred in the region of Mchenja and Mwamba Camps, extending northwestwards along a tributary of the Luangwa River.

Luangwa Summary

Females within this cluster appeared to remain close to water. Unlike several other areas, there was no abrupt movement away from such water sources during November. This suggests, perhaps, that no substantial rainfall fell at this time. Alternatively, that preferred habitats are close to water. Females in South Luangwa were seen crossing eastwards outside the park into the Lupande GMA. Only limited movements were observed by females within Munyamadzi GMA, though they did cross into both North and South Luangwa.

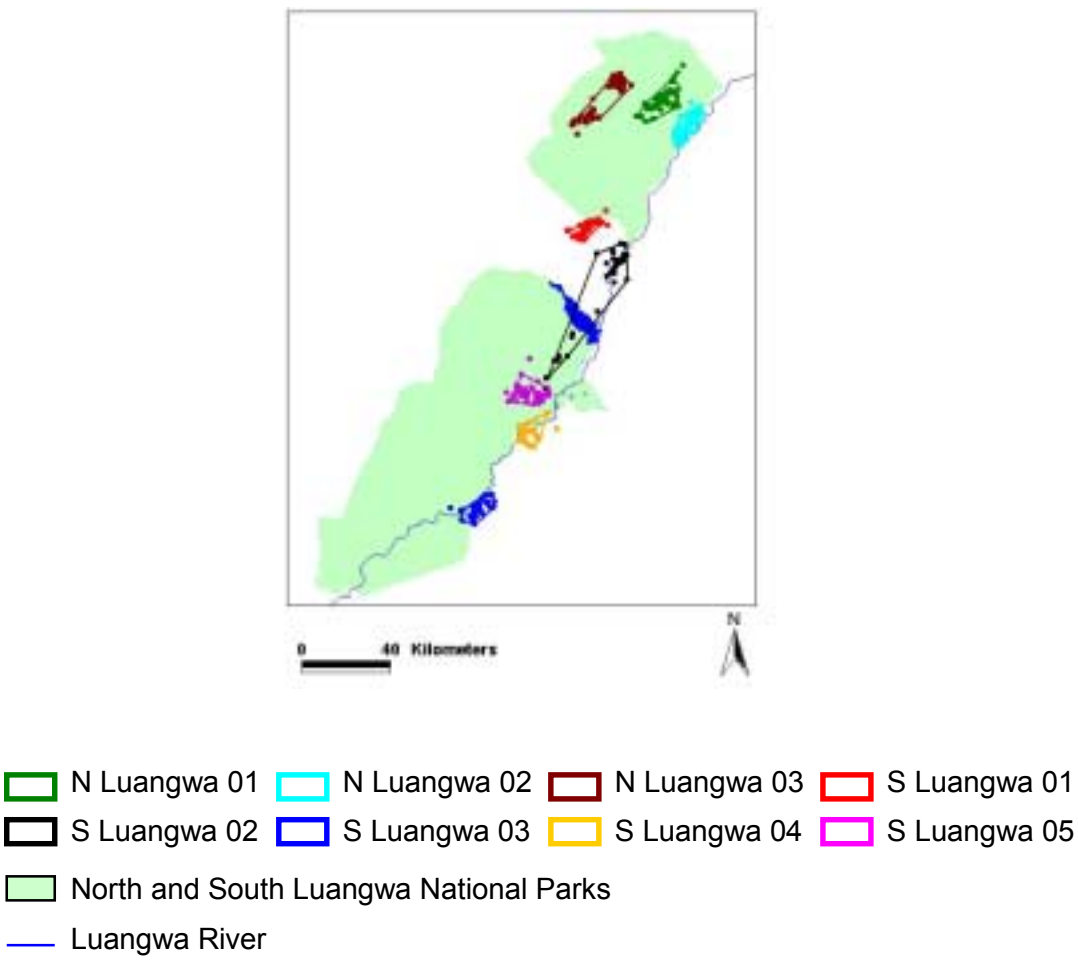


Figure 16. Daily positions and home-ranges (95% MCP) of eight female elephants in the Luangwa-Munyamadzi area during the 2004 dry season. For more information see Table 11.

Table 11. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for eight elephants in the Luangwa cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data. Data only available for North Luangwa animals for Aug–Nov 2004 and for South Luangwa animals for Oct–Nov 2004.

Luangwa cluster		Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
N Luangwa 01	Female	(187)	(247)	(27)	(72)
N Luangwa 02	Female	(119)	(179)	(30)	(95)
N Luangwa 03	Female	(221)	(284)	(36)	(94)
Mean		(175)	(237)	(31)	
SD		(52)	(53)	(4)	
n		(3)	(3)	(3)	
S Luangwa 01	Female	(74)	(127)	(14)	(44)
S Luangwa 02	Female	(645)	(1037)	(164)	(41)
S Luangwa 03	Female	(114)	(211)	(35)	(37)
S Luangwa 04	Female	(109)	(156)	(18)	(44)
S Luangwa 05	Female	(153)	(264)	(44)	(42)
Mean		(219)	(359)	(55)	
SD		(240)	(382)	(62)	
n		(5)	(5)	(5)	

Kasungu National Park

Three collars, one on a male and two on females, were fitted to animals at Kasungu National Park, Malawi. Collars were attached during August 2004. The costs of collaring were largely co-funded by the National Postcode Lottery of the Netherlands and the Peace Parks Foundation.

Kasungu 01 (male) With the exception of one fix during August, this male's home-range was restricted to the national park (Fig. 17). His movement outside the park took him 4km east of the Lisutu Gate on 22nd August. Otherwise, he remained within the south-central area of the park, particularly the Lingazi River, it tributaries and the dambos that radiated from this watercourse.

Kasungu 02 (female) This female's home-range was similar to Kasungu 01's (Fig. 17). She did, however, move north to a tributary of the Liziwazi River briefly during November. She was recorded close to the Limamba River in Augsut for a single fix. On 22nd August she was recorded outside the park, close to its boundary, 3.5km north of Lisutu Gate.

Kasungu 03 (female) Kasungu 03 moved mainly along the Lingazi River and around the Lifupa Lodge area (Fig. 17). She made two excursions outside the park during August, with recordings 14km south and 3km northeast of the Lisutu Gate on 17th and 22nd August respectively.

Kasungu Summary

The movement of the three individuals collared in Kasungu National Park was limited to the south-central section of the park over the limited duration of our study. It is not clear why all three individuals should venture outside the park on the same data, 22nd August, returning the next day. While our initial reaction was that this was an anomaly of the satellite-tracking system, such as eastward shift in fixes was not observed for other collared elephants on the same day.

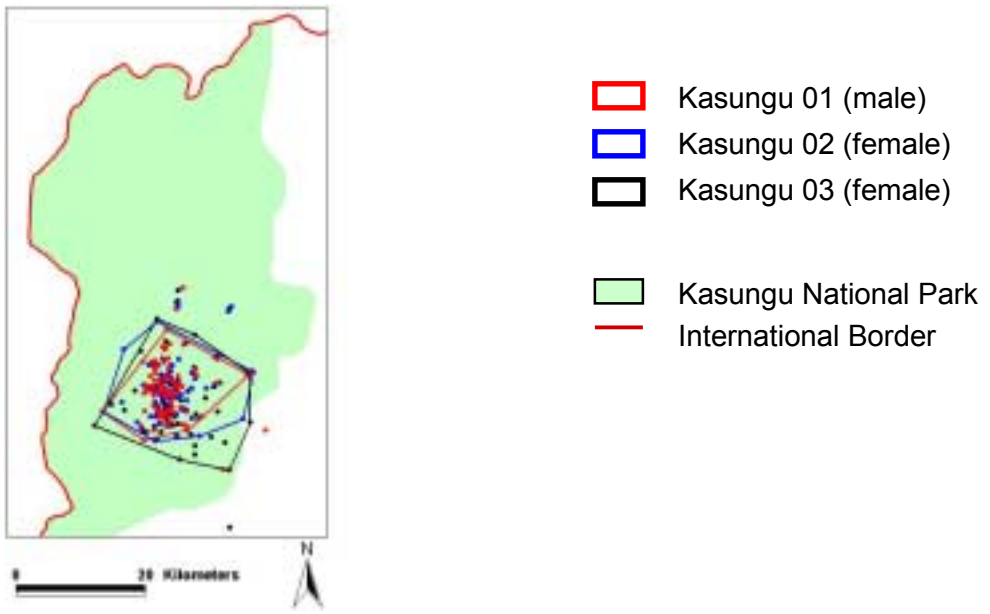


Figure 17. Daily positions and home-ranges (95% MCP) of one male and two female elephants in Kasungu National Park during the 2004 dry season. For more information see Table 12.

Table 12. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) nine elephants at Kasungu, Vwaza Marsh and Nyika in the Luangwa cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data. Data only available for Aug–Nov 2004.

Luangwa cluster		Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Kasungu 01	Male	(200)	(178)	(32)	(90)
Kasungu 02	Female	(276)	(177)	(23)	(86)
Kasungu 03	Female	(344)	(247)	(23)	(91)
Mean		(273)	(201)	(26)	
SD		(72)	(40)	(5)	
n		(3)	(3)	(3)	
Vwaza 01	Male	(175)	(559)	(161)	(72)
Vwaza 02	Female	(318)	(660)	(144)	(88)
Vwaza 03	Female	(327)	(1968)	(418)	(40)
Vwaza 04	Female	(485)	(559)	(131)	(85)
Mean		(326)	(937)	(214)	
SD		(126)	(689)	(137)	
n		(4)	(4)	(4)	
Nyika 01	Female				
Nyika 02	Male				
Mean					
SD					
n		(2)	(2)	(2)	

Vwaza Marsh Game Reserve

Four individuals were collared at Vwaza Marsh Game Reserve, one male and three females. Collars were attached during August 2004. Limited home-range data are, therefore, only available for part of the 2004 dry season. Costs associated with collaring were largely co-funded by the National Postcode Lottery of the Netherlands and the Peace Parks Foundation.

Vwaza 01 (male) August 2004 was the only month in which Vwaza 01 used the floodplain of the South Riuru River. He was recorded along its entire length, along the park boundary, from Zaro in the west to Lake Kazuni in the east (Fig. 18). He never crossed south of the river into the adjacent farmland. During September and October he moved away from the floodplain, concentrating his movements further northwards in the Lasantha Hills. On 3rd November he suddenly left this area, heading towards the western boundary of the park in the Kalindamawi area. On 7th November satellite reception was lost for the remainder of the dry season. Home-range data for this male is, therefore, incomplete and our calculated home-range area should be treated with caution (Table 12).

Vwaza 02 (female) From August–October this female concentrated her movements along the South Rukuru River. in the central southern section of the park. Her movements extended from here towards the base of the Lasantha Hills. On the 15th November Vwaza 02 left this area and moved to the western boundary of the park in the Kalindamawi area (Fig. 18). Here she even crossed the international boundary, roaming 2km outside the reserve and into the Lundazi Forest Reserve of Zambia.

Vwaza 03 (female) This females movements were similar to those of Vwaza 02 (Fig. 18). From August–October this female concentrated her movements along the South Rukuru River, moving no more than 2.5km away from the river. On the 16th November she moved to the western boundary of the park in the Kalindamawi area.

Vwaza 04 (female) The ranging of Vwaza 04 was consistent with that of the other females. Initially, she concentrated her movements along the South Rukuru River, always keeping to its northern bank within the reserve (Fig. 18). On the 14th November she left this area, travelling over the course of two days to the western boundary of the park in the Kalindamawi area. Here she even roamed up to 2km into Zambia's Lundazi Forest Reserve.

Vwaza Marsh Summary

Towards the end of the dry season collared elephants made extensive use of the South Rukuru River and its northern floodplain. They did not, however, cross south of the river into agricultural land. There was a sudden, synchronised movement of collared females to the western side of the park during mid November. This paralleled the range shift of the male, which we recorded a week earlier. Individuals were then recorded moving outside Vwaza Marsh, crossing the international border into Lundazi Forest Reserve in Zambia.

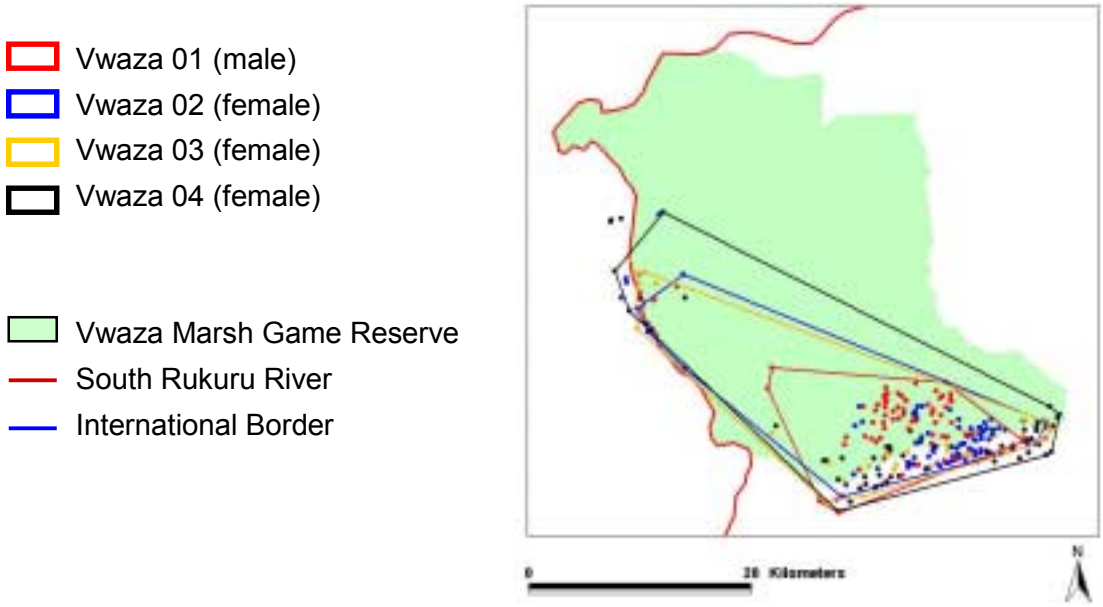


Figure 18. Daily positions and home-ranges (95% MCP) of one male and three female elephants in Vwaza Marsh Game Reserve during the 2004 dry season. For more information see Table 12.

Nyika National Park

Two individuals were collared at Nyika National Park (Malawi), one male and one female. Collars were attached during August 2004. Limited home-range data are, therefore, only available for the 2004 dry season. The costs of collaring were largely co-funded by the National Postcode Lottery of the Netherlands and the Peace Parks Foundation.

Nyika 01 (female) This female initially ranged through the densely vegetated valleys 5-15km northwest of Chilinda (Fig. 19). She avoided the open upland grasslands. In late October she moved from this area to an area of woodland 10km east of Chilinda, remaining there for the rest of the dry season. At no time did she leave the park's boundaries.

Nyika 02 (male) This male's movements were quite different to Nyikas 01's. Through August and early September he moved through a wide arc to the north of Chilinda (Fig. 19). By mid September he settled into an area of woodland 10-15km to the southwest of Chlinda in the Sangule region, where he remained for the rest of the dry season.

Nyika summary

It would be premature to make any statements regarding the ranging behaviour of these two individuals. They did, however, shift the centres of their ranges partway through the dry season. Neither was observed leaving the park.

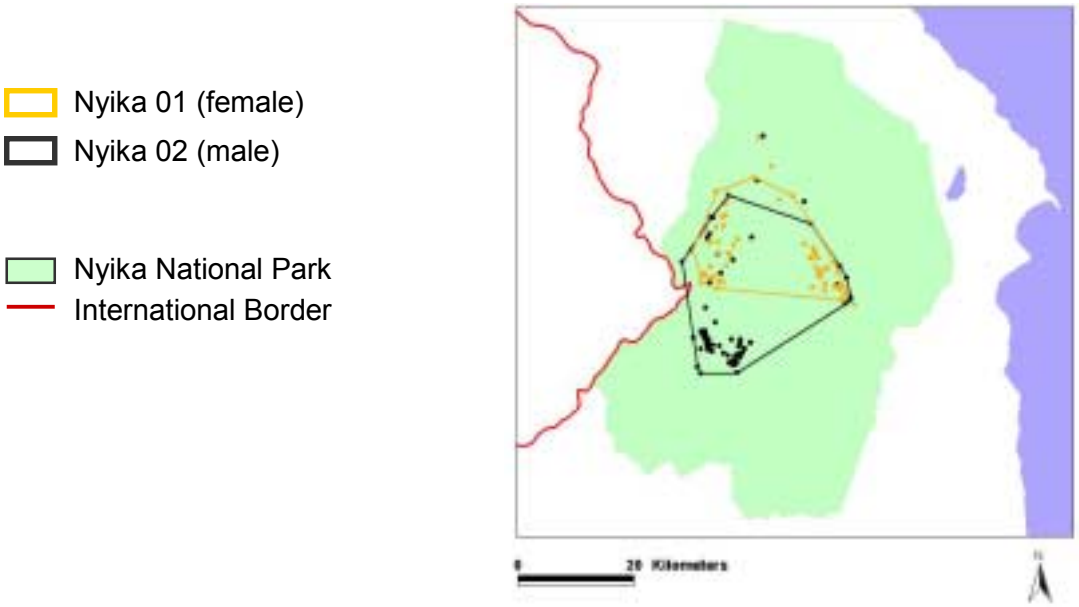


Figure 19. Daily positions and home-ranges (95% MCP) of one male and two female elephants in Nyika National Park during the 2004 dry season. For more information see Table 12.

Cluster 6: Limpopo Cluster

For logistical reasons, elephant capture was staggered in this cluster. Female KNP 01 was captured on the Lebombo Mountains south of Shingwedzi during 2002. Since then her movements were limited to a fenced off sanctuary within the Limpopo National Park. Individuals KNP 02, 03, 05 and 06 were collared during September 2003. KNP 04 was collared later, during November 2004. One of the males (KNP 06) was captured north of Shingwedzi in the Kruger National Park and the other male (KNP 05) near the Kruger boundary fence in the Limpopo National Park. Three cows (KNP 02, 03 and 04) were all captured in the Limpopo National Park, north and south of the Shingwedzi River and close to the boundary fence.

Funding for this cluster was largely co-funded by the National Postcode Lottery of the Netherlands and Peace Parks Foundation. Logistical support was provided by the South African National Parks.

KNP 01 (female). This female was confined to the wildlife enclosure to the west of Massingir Dam, in Limpopo National Park (Fig. 20). Consequently, her home-range was restricted by the enclosure's fence lines. This can clearly be seen in her range use – while apparently increasing from the 2003 dry season to the 2004 wet season (Table 13) – though more fixes were available for this time), its area reflects the shape of wildlife enclosure.

KNP 02 (female) Female KNP02 ranged through the Limpopo National Park (Fig. 20). Her home-range spanned a distance of 70km, bordered to the south by the wildlife enclosure, the west by the boundary fence with the Kruger National Park and to the north and east by the Shingwedzi River. The core of her home-range shifted southwards from the 2003 dry to the 2004 wet season, though little difference was observed between her 2004 wet or dry season home-ranges (Table 13).

KNP 03 (female) The ranging behaviour of this female was similar to that of KNP 02 (Fig. 20). The fence line of the Kruger National Park, wildlife enclosure and Shingwedzi River also bounded her range. She too shifted her dry season home-range southwards from 2003 to 2004. During the 2004 wet season, however, she crossed the boundary into Kruger National Park. She remained here for two weeks, in an area immediately south of Shingwedzi Rest Camp, before returning to Mozambique. KNP 03's 2004 wet season home-range was larger than that of any other female (Table 13). Her collar failed during June 2004.

KNP 04 (female) As this cow was collared later than the other individuals, home-range data are only available for the 2004 wet and dry seasons (Fig. 20). The size of her home-range was similar between these two seasons (Table 13). Again, the wildlife sanctuary, Kruger National Park fence line and the Shingwedzi River bounded her home-range. Her home-range did, however, shift southwards between the two seasons.

KNP 05 (male) This male was unusual, in that his home-range was smaller in the wet season than the two dry seasons (Fig. 20, Table 13). During the 2003 dry season the core of his home-range was similar to that of the collared females, except for a single excursion he made northwestwards from the Shingwedzi towards the Limpopo River. His home-range was again comparable to that of the collared females during the 2004 wet season, though he moved up to 15 km eastwards from the Shingwedzi River. His home-range expanded again during the

2004 dry season as he briefly reached the Limpopo River during both May and September, before returning to the Shingwedzi River. At no time did he cross the boundary from between the Kruger and Limpopo National Parks.

KNP 06 (male) Unlike the other collared animals, KNP 06's movements were largely restricted to Kruger National Park (Fig. 20). The one important exception was during February 2004 when he crossed the fence line to an area south of Massingir Dam for three days, before returning to Kruger. His home-range extended from Massingir Dam, through the Letaba area northwards towards the Shingwedzi River. He spent much of his time near the Shingwedzi River and eastwards towards the boundary of the Limpopo National Park. He ranged far more extensively than any of the collared females, while seasonal home-range areas were comparable with those of KNP 05 (Table 13).

There was little evidence for an expansion of his home-range during the wet season, while his dry season range was concentrated northeast of the Shingwedzi River. During the 2003 dry season, he left this area during late September and travelled southwards towards the Letaba River before returning to the Shingwedzi area a month later. Here he remained into the 2004 wet season, before moving relatively slowly southwards again during January 2004 to the Letaba area (and as far as the Massingir Dam as mentioned above), returning over a period of only a few days to Shingwedzi during mid-March. He remained in this area until 20th Oct 2004 when he moved southwards again towards the Letaba area, looped back to the Shingwedzi River and returned to the Letaba area for the remainder of the dry season. His home-range may, therefore, best be described as centring on the area east of the Shingwedzi River with frequent excursions southwards towards the Letaba River during both the wet and dry seasons.

Limpopo summary

In agreement with Grainger *et al.* (2005), we found no clear seasonal or sex-specific differences in home-range use for this cluster. On occasion, individuals were observed crossing between the two parks, despite the fence line. Elephants apparently avoided the area immediately north of Massingir Dam, which contains a number of villages. The home-range of the female in the elephant sanctuary was the smallest recorded. She also ranged through the entire enclosure, suggesting her home-range was restricted relative to that of other individuals.

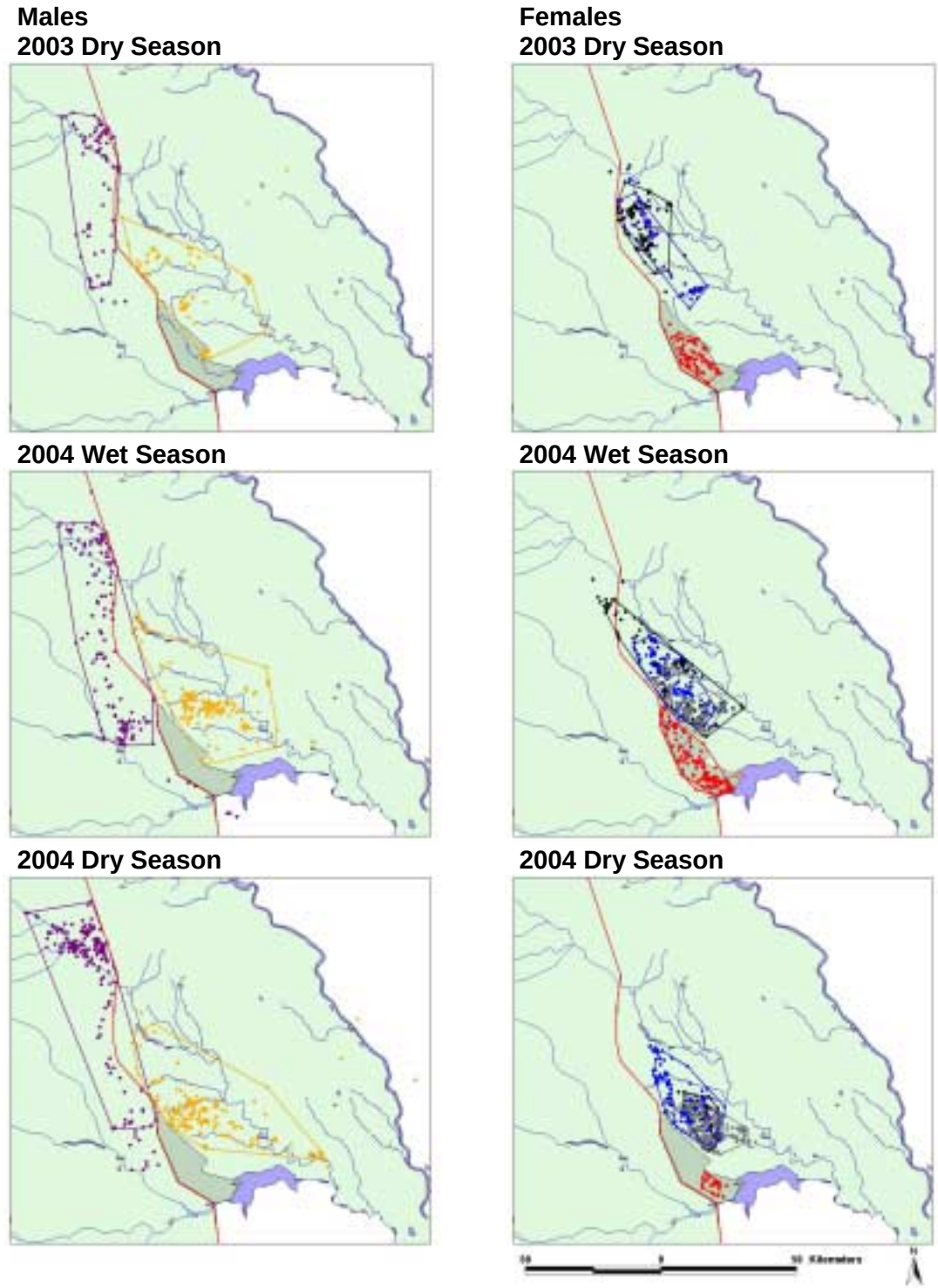


Figure 20. Daily positions and home-ranges (95% MCP) of four female and two male elephants in the Limpopo National Park (Mozambique) and Kruger National Park (South Africa) during the 2003 and 2004 wet and dry seasons. For more information see Table 13.

Table 13. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for six elephants in the Limpopo cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Limpopo Cluster		Dry Season 2003*				Wet Season 2004				Dry Season 2004			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Kruger/Limpopo													
KNP01	Female	(150)	(241)	(49)	(84)	300	442	57	137	(33)	(65)		(5)
KNP02	Female	(422)	(673)	(93)	(83)	452	687	138	140	483	522	43	178
KNP03	Female	(408)	(478)	(74)	(84)	773	1253	152	140	(172)	(283)	(43)	(44)
KNP04	Female					324	418	73	130	321	439	117	176
KNP05	Male	(1235)	(1442)	(186)	(84)	1442	879	134	140	1601	1343	151	169
KNP06	Male	(882)	(996)	(188)	(85)	1544	2728	454	142	1659	1119	175	188
Mean		(619)	(766)	(118)		806	1068	168		1,016	856	121	
SD		(433)	(468)	(65)		559	870	145		712	444	58	
n		(5)	(5)	(5)		6	6	6		4	4	4	

*Data only available Sept–Nov 2003

Cluster 7: Maputaland Cluster

CERU's satellite tracking programme commenced during September 2000. Within this cluster, the elephant population has artificially been divided into two fragments. One exists within Tembe Elephant Reserve (South Africa), the other in Maputo Elephant Reserve and the Futi Corridor (Mozambique). The Futi Corridor follows the drainage line of the Rio Futi from Tembe Elephant Park into Maputo Elephant Reserve. The Tembe Elephant Park population has been fenced in since 1989. Human settlement, the Indian Ocean and the Tembe Elephant Park fence constrain movement of the Maputo Elephant Reserve population.

Satellite transmitters were deployed on two cows and one bull in Maputo Elephant Reserve, as well as two bulls in the Futi Corridor. We also collared three cows and one bull in Tembe Elephant Park. Funding for this tracking was provided by the US Fish & Wildlife Services, Wildlifewins, the Mozal community Development Trust and the Peace Parks Foundation.

Maputo Elephant Reserve and Futi Corridor

Futi 13 (male) This male moved extensively through the Futi Corridor, always east of the Rio Maputo, as well as within Maputo Elephant Reserve. No clear expansion and compression of his home-range was apparent from the seasonal data (Fig. 21, Table 14). During the 2000 dry season he moved from the Futi Corridor into the central areas of Maputo Elephant Reserve (to the north of Lago Munde) for October, before moving to the west of the reserve along the Rio Futi in November. His movements were concentrated in the Futi Corridor during the 2001 wet season, contining into the dry season. Late in the 2001 dry season, during October and November, he returned to the central regions of Maputo Elephant Reserve. This male's 2002 wet season range was very similar to the previous wet season, excepting that he travelled further south down the Futi Corridor to within 3km of Tembe Elephant Park.

Futi 18 (male) The wet season movements of Futi 18 were restricted to the Futi Corridor. His 2002 wet season range area was substantially greater than during 2001. This could be attributed to an extra movement southwards to the boundary of Tembe Elephant Reserve during 2002, though not during 2001. During the wet season, he avoided Maputo Elephant Reserve. Dry season movements, however, took this male to Maputo Elephant Reserve, where he spent time from mid-July to mid-August 2001 in the northwest of the reserve in the area of riverine vegetation along the Rio Futi, east of Logo Tzembesanhe and Bella Vista. Again, he moved into Maputo Elephant Reserve during the 2002 dry season, spending a period from mid-May to late June in an area north of Lago Munde before moving southwestwards back into the Futi Corridor. He returned to the same area of MER for a few days in late September, before returning to the Futi Corridor. Due to his movements into the MER, his dry season home-ranges tended to be larger than during the wet season.

Maputo 21 (male) This male ranged extensively through Maputo Elephant Reserve and the Futi Corridor (Figure 21). Consequently his home-range during the 2001 dry season was the largest recorded for any of these collared individuals (Table 14). During the 2000 dry season his movements were concentrated along the Rio Futi, largely within Maputo Elephant Reserve. In the 2001 wet season his home-range shifted almost completely as he moved

southwards, remaining close to the Rio Futi in the Futi Corridor. He travelled extensively through the 2001 dry season, predominantly along the Futi Corridor, until mid-July. From mid-July onwards he made extensive use of Maputo Elephant Reserve, both along the riverine vegetation to its west, and the areas adjacent to the lakes in the east. His large home-range during this season can be attributed, in part, to a sudden departure from MER as he travelled rapidly to the boundary of Tembe Elephant Park from 8th–11th October, before returning equally as rapidly back to MER. With the exception of this excursion, he spent the dry season from mid-July onwards exclusively in the MER though his movements had taken him to the boundary of Tembe Elephant Park in early May too.

Maputo 19 (female) This female used the MER predominantly during the 2000 dry season, visiting both the riverine vegetation along the Rio Futi, as well as utilising the area to the west of Lago Munde in the central MER (Fig. 22). During late November she left the MER, moving southwards into the Futi Corridor, where she remained until the middle of February 2001, when she again returned to MER. She remained within the reserve through remainder of the study period, concentrating her movements between the eastern banks of the Rio Futi and Lago Munde to the east.

Maputo 20 (female) With the exception of the 2002 dry season, the home-range of Maputo 20 was smaller than Maputo 19 (Table 14). Her movements were entirely restricted to MER, and concentrated between the eastern banks of the Rio Futi and Lago Munde to the east (Fig. 22).

Maputo Elephant Reserve/ Futi Corridor Summary

During the dry season Maputo Elephant Reserve was utilised by all our study elephants. Movements tended to focus on the Rio Futi, as well as the reedbeds adjacent to the lake systems. During the wet season, males in particular utilised the Futi Corridor. Every male ranged to, or very close to, the border of Tembe Elephant Park. Individuals avoided the Rio Maputo and certainly never crossed over to its west bank. No clear difference could be detected in the seasonal home-range sizes of individuals (Table 14).

Tembe Elephant Park

Tembe 16 (male) This was the only male to be fitted with a functional male in Tembe Elephant Park. His seasonal home-range sizes are considerably smaller than those for males in the Futi Corridor/ Maputo Elephant Reserve. Movements were largely restricted to the southwestern half of the park and away from the Rio Futi or Muzi Swamps in the east (Fig. 21). His home-range appeared to expand during the 2001 wet season, compared to the dry seasons, though almost double the number of fixes were recorded during this season too, perhaps explaining this discrepancy. Home-range use covered a different area to that of females.

Tembe 14, 15 and 17 (females). Home-range use was very similar for these three females. All concentrated their ranging behaviour in the eastern and northeastern sections of the park (Fig. 22). These ranges corresponded to the areas through which the Rio Futi flows into the Futi Corridor, as well as the Muzi Swamps. Their home-ranges were the smallest recorded for any individual in this entire study (Table 14).

Tembe Summary

The ranges of elephants in Tembe Elephant Park were the smallest recorded for any individuals in this study. In fact, with the exception of Lake Manyara National Park, ranges noted for elephants in Tembe Elephant Park are the smallest on record for this species (Whyte, 2001; Osborn, 2004). Water (rainfall) and food availability are key determinants of home-range shape and size (Douglas-Hamilton, 1973; Leuthold, 1977; Dunham, 1986; De Boer et al., 2000). In Tembe Elephant Park, however, water is linearly distributed through the park and these elephants could have extended their ranges with increasing water scarcity. We ascribe the tiny ranges of these elephants to their confinement within an artificially fenced boundary. It is clear that elephants from the Futi Corridor move to this boundary fence and that these two sub-populations would better be managed as a single unit.

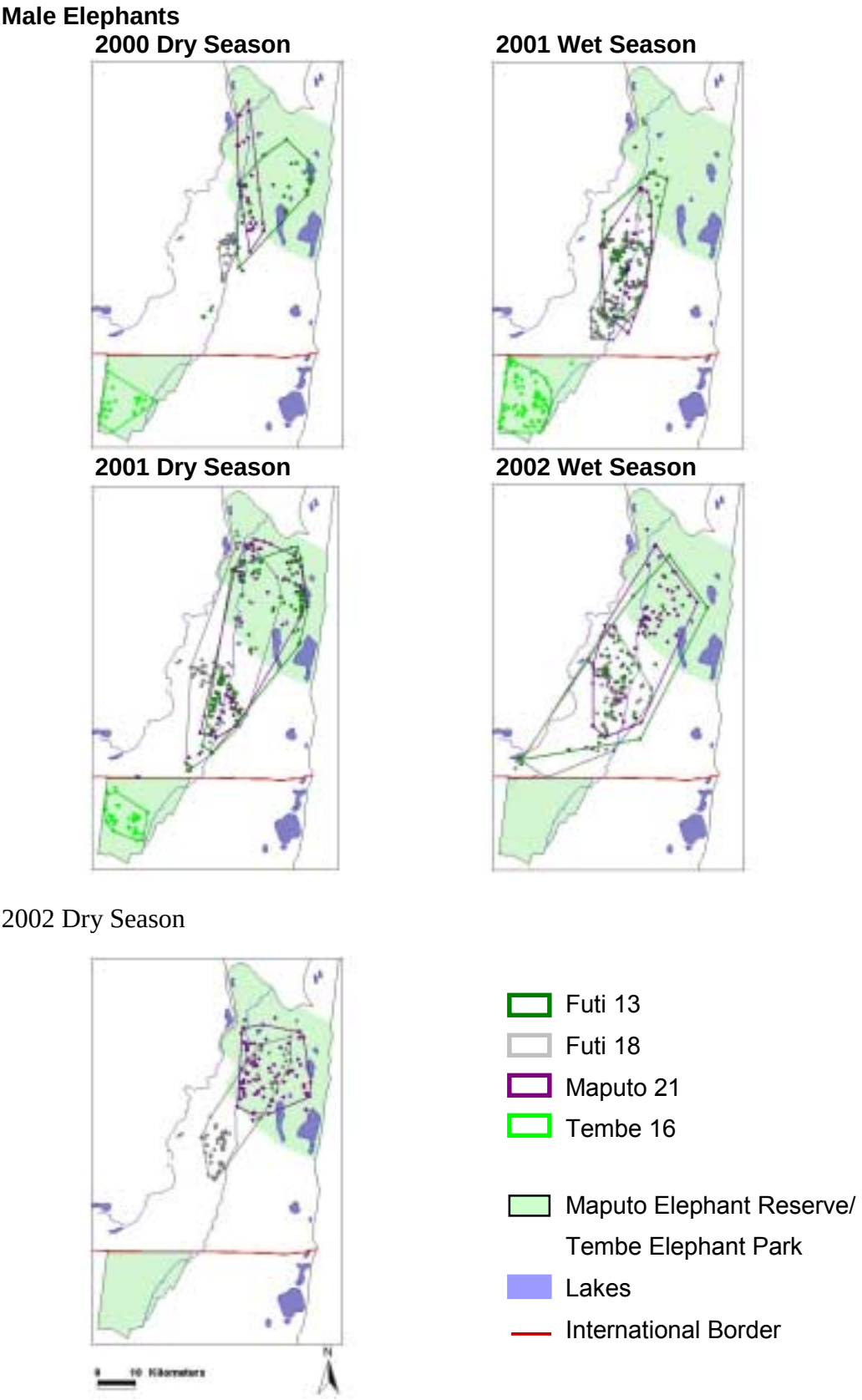


Figure 21. Daily positions and home-ranges (95% MCP) of four male elephants in Maputaland, including Tembe Elephant Park, the Futi Corridor and Maputo Elephant Reserve from the 2000–2002 dry seasons. For more information see Table 14.

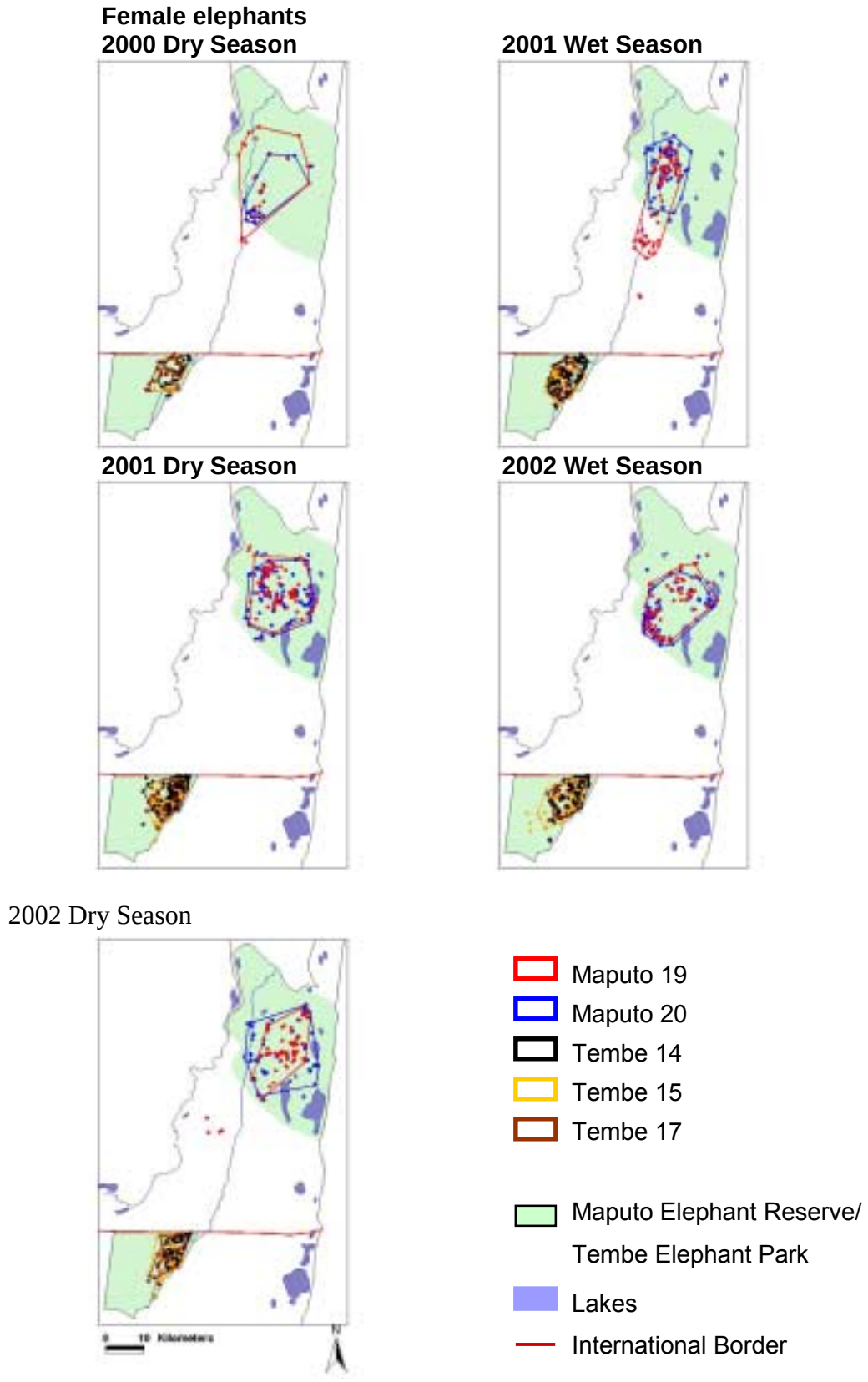


Figure 22. Daily positions and home-ranges (95% MCP) of five female elephants in Maputaland, including Tembe Elephant Park, the Futi Corridor and Maputo Elephant Reserve from the 2000–2002 dry seasons. For more information see Table 14.

Table 14. Summary of home-range data (95% minimum convex polygon: 95% MCP; 95% kernel: 95% KER; 50% kernel: 50% KER) for nine elephants in the Futi Corridor, Maputo Elephant Reserve and Tembe Elephant Park within the Maputaland cluster. Data in brackets represent individuals providing insufficient data (<120 fixes) to contribute to the home-range analysis. Summary statistic (mean, SD, n) provided for all valid data.

Maputaland Cluster		2000 Dry Season				2001 Wet Season				2001 Dry Season				2002 Wet Season				2002 Dry Season			
Elephant ID	Sex	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n	95% MCP (km^2)	95% KER (km^2)	50% KER (km^2)	n
Futi 13	Male	(319)	(791)	(134)	31	380	537	66	72	728	1253	254	103	948	586	53	63				
Futi 18	Male	(31)	(86)	(13)	30	211	378	68	77	750	921	103	98	580	505	76	79	332	551	80	66
Maputo 21	Male	(138)	(505)	(85)	26	298	586	119	59	700	1361	237	80	668	951	100	75	331	479	65	85
Maputo 19	Female	(325)	(571)	(101)	25	163	344	68	63	251	298	47	76	218	338	66	63	190	294	37	68
Maputo 20	Female	(160)	(203)	(22)	25	158	181	21	80	256	295	26	104	213	263	25	82	314	490	78	64
Mean		(195)	(431)	(71)		242	405	69		537	825	134		525	529	64		278	421	60	
SD		(126)	(285)	(52)		95	162	35		260	509	106		314	269	28		77	110	21	
n		(5)	(5)	(5)		5	5	5		5	5	5		5	5	5		3	3	3	
Tembe 16	Male	(108)	(166)	(27)	30	173	257	18	83	89	119	22	47								
Tembe 14	Female	(34)	(79)	(12)	28	69	114	17	85	77	115	18	105	68	101	7	83	41	59	5	65
Tembe 15	Female	(45)	(88)	(6)	25	62	79	10	84	78	98	8	104	89	134	17	79	75	108	11	91
Tembe 17	Female	(51)	(85)	(20)	26	53	70	6	62	52	73	11	82	58	77	4	60	54	100	22	61
Mean		(59)	(104)	(16)		89	130	13		69	95	12		72	104	9		64	104	16	
SD		(33)	(41)	(9)		56	87	6		15	21	5		16	29	7		15	6	8	
n		(4)	(4)	(4)		4	4	4		3	3	3		3	3	3		2	2	2	

Synthesis

This report represents the preliminary synthesis of CERU's research into home-range use by elephants. It contains information from all seven of the recognised elephant conservation clusters. To date complete information are only available for the Etosha and Maputaland elephant populations. Daily information downloads are still being received from most elephants. For some of these individuals not even a full seasons data are available.

Our data certainly appear contradictory, with information from one cluster conflicting with that of another. For instance, while female home-ranges increased during the wet season in Etosha, they remained constant in size in Kafue. In the Okavango Panhandle, it appears that females may remain further from permanent water for longer periods than males in the dry season. In Kafue, however, it is the males that increase their home-ranges during the wet season. While the number of individuals in each conservation area limits the interpretation of the data at hand, the availability of information from such a large number of individuals from different conservation areas is critical to our understanding of ranging behaviour across southern Africa.

CERU's next step is to move from a descriptive appraisal of home-range use, to applying this data within an ecological framework. Currently we are compiling digital landscape maps for each study site. This will allow us to progress towards examining home-range use within a landscape framework. In this way we can identify elephant-selected habitats, both within and outside recognised conservation areas. It will also allow us to examine the effect of human-induced landscape fragmentation on habitat selection. Eventually it should allow us to predict landscape use in relation to such key environmental variables as water availability, habitat preferences and human disturbance. The importance of the different patterns of range use we have observed for different areas is crucial. It allows us to work towards a space-use model that we hope can be generalised to all areas and is not case-specific. This has always been a shortcoming of previous elephant studies, which tend to be based at a single location.

Recommendations

While this report summarises the present standing of our home-range database, it also allows us to address examine some of our shortcomings. This will allow us to move forwards more productively in the future. Listed below are concerns we have that need to be addressed:

1. Collars are best fitted at the beginning or end of the dry season. Collars fitted in the middle of this period do not provide sufficient data to include in daily home-range analysis. Collars fitted early in the dry season still allow time for a good representative data set to be collected for the dry season. Units fitted late in the dry season (*e.g.* the collars fitted to animals in Kaudom Game Reserve during late October) provide effective home-range information from the beginning of the following wet season.
2. It became apparent when trying to collect rainfall data, that such basic information is not available for all collaring localities. It is also evident from our report that, in many localities, elephants exhibit sudden long distance movements during November. This may be in response to localised rainstorms (see Leouthold, 1977; Viljoen, 1989). Thus, it is essential we can access reliable daily weather records from all areas where collars are deployed, at least for the 2-year collaring period. Establishing automated weather stations in localities where the collection of weather data is unreliable may best facilitate this.
3. A large number of satellite collars have been deployed on elephants through southern Africa. It is our responsibility, both ethically and economically, to see to the removal of these units once they expire. Animals may still be tracked at this time, using the built in radio transmitters. This must be considered as part of the original budgeting process. To date only a limited number of collars have been removed from elephants in the Etosha and Limpopo clusters. The Namibian Elephant and Giraffe Trust have seen to the removal of their collars. CERU intend to retrieve as many of the collars as possible.

Key gaps within the collaring network

This report serves to synthesise CERU's current elephant ranging data. It also allows us to identify key gaps within our elephant ranging network. Thus, further research can be prioritised with respect to understanding the movement patterns in areas earmarked for TFCAs. These priorities are evaluated below:

Kunene/ Etosha Cluster. It is obvious from our research, as well as that of the Desert Elephant and Giraffe Foundation, that the Etosha and Kunene populations are capable of inter-linking. We also know that individuals from Etosha may move northwards towards the Angolan border (Lindeque & Lindeque, 1991). Also, that ranges of individuals from the Kunene River overlap 195km southwards with those frequenting the Hoarusib River. It is not clear how this population may link eastwards

along the Kunene or northwards into Angola. Given the importance of river systems, that we demonstrate throughout this report, it makes sense to examine the Kunene River as an elephant corridor. The situation in Angola is unknown, as no systematic survey has been conducted of its elephant population (Blanc *et al*., 2003). However, the Parque Nacional do Iona that lies north of the Kunene River has been classified as non-range (Blanc *et al*., 2003).

Chobe Cluster. As we report in the cluster analysis, the Chobe cluster is underrepresented in our home-range analysis. It does, however, contain the most elephants, with an estimated population of around 120,000. The importance, from an elephant conservation perspective, may not be in conserving elephants within the cluster. Rather, it may be in identifying areas that could act as population sinks for its burgeoning population. Elephants from Botswana are known to range into Angola, Zambia, Zimbabwe and Namibia. The corridors elephants use in connecting between these countries need urgent and critical evaluation at several sites within the proposed Okavango-Upper Zambezi TFCA Zone (as defined by Hall-Martin and Modise, 2002). The collaring of several elephants at sites along the Caprivi strip will benefit the project greatly.

Kafue Cluster. Indications are that individuals from southern Kafue do not move northwards from the Ngoma area. CERU's aerial surveys suggest few elephants are present in central Kafue, with populations present from Chunga northwards into the park. CERU is presently negotiating with IFAW to motivate for the deployment of collars in this northern Kafue area.

Zambezi Cluster. As collars were only attached during August 2004, few data are available for the Zambezi Cluster. All collars were attached to individuals in Lower Zambezi National Park. It is not clear why the Tete Province of Mozambique, which borders this area, is not included within this cluster. Elephants are believed to move between Zimbabwe, Zambia and Mozambique along the Zambezi Valley (Blanc et al., 2003). The western Tete Province includes an estimated population of over 2000 elephants (Blanc et al., 2003) and stretches to within 18km of the Luangwa cluster. We have requested funding from USFWS for six collars in Mana Pools region.

Luangwa Cluster. North and South Luangwa Parks are well-covered by the present collaring efforts. In fact the data we have for January 2005 show individuals crossing from South to North Luangwa. There is little evidence to date to suggest that

individuals from Kasungu or Nyika will link with other populations. The ranges of elephants from both populations appear to be restricted to these parks. Early observations are more promising for Vwaza Marsh, where several individuals have briefly crossed over into Zambia and back.

Limpopo Cluster. The ranges of individuals from the Limpopo cluster show movement of both males and females between Kruger and Limpopo National Parks. The TFCA that has been developed in the region is both large and structurally complex. More emphasis, however, needs to be placed on the north of this TFCA. Here the Wngwe communal land in Zimbabwe and the Jumbo region in South Africa link Kruger National Park to Zimbabwe's Gonarezhou National Park. Human settlement is ongoing within Gonarezhou and this will certainly affect the ranging of elephants in this National Park, an issue that needs to be critically addressed. The collaring of several elephants living in the northern part of Kruger and the abutting parts of Zimbabwe will yield valuable information within the context of our present efforts.

Maputaland Cluster. The collars deployed in this cluster clearly show the range restrictions imposed by Tembe Elephant Park. They also demonstrate the connectivity between Tembe and Maputo Elephant Reserve via the Futi Corridor. At this stage, the major benefit of any new collars would be to examine the efficacy of the new elephant fence line.

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References

ARGOS (2000) *Users guide: satellite data collection and location system.* Service Argos, Toulouse.

Blanc, J.J., Thouless, C.R., Hart, J.A., Dublin, H.T., Douglas-Hamilton, I., Craig, C.G. & Barnes, R.F.W. (2003). *African Elephant Status Report 2002: an update from the African Elephant Specialist Group.* IUCN/SSC African Elephant Specialist Group. IUCN Gland, Switzerland and Cambridge, UK.

De Boer, W.F., Ntumi, C.P., Correia, A.U. & Mafuca, M., (2000) Diet and distribution of elephant in danger: the Maputo Elephant Reserve, Mozambique. *African Journal of Ecology* **38**: 188 – 201.

Douglas-Hamilton, I., (1973) On the ecology and behaviour of the Manyara elephants. *East African Wildlife Journal* **11**: 401 – 403.

Dunham, K.M., (1986) Movements of elephant cows in the unflooded middle Zambezi Valley, Zimbabwe. *African Journal of Ecology* **24**: 287– 291.

Girard, I., Ouellet, J-P., Courtois, R., Dussault, C. & Breton, L. (2002). Effects of sampling effort based on GPS telemetry on home-range size estimations. *Journal of Wildlife Management* **66**: 1290–1300.

Grainger, M, van Aarde, R.J. & Whyte, I. (2005). Landscape heterogeneity and the use of space by elephants in the Kruger National Park, South Africa. *In review*.

Hall-Martin, A.J. (1987). Role of musth in the reproductive strategy of the African elephant (*Loxodonta africana*). *South African Journal of Science* **83**: 616–620.

Hall-Martin, A.J. & Modise, S. (2002). Existing and potential transfrontier conservation areas in the SADC region. Unpubl. report, Peace Parks Foundation, Stellenbosch.

Hays, G.C., Åkesson, S., Godley, B.J., Luschi, P. & Santidrian, P., (2001) The implications of location accuracy for the interpretation of satellite – tracking data. *Animal Behaviour* **61**: 1035 – 1040.

Hooge, P. N. & Eichenlaub, B. (1997). *Animal movement extension to Arcview. ver. 1.1.* Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, AK, USA

Kenward, R.E. (2001). *A manual for wildlife radio tagging.* Academic Press, London.

Kinahan, A. (2004). Ambient temperature as a determinant of landscape use and habitat selection of elephants in Lower Zambezi National Park, Zambia. Unpubl. trip report, CERU, University of Pretoria.

Leggett, K. (2004). *Annual Report (July 2003 – June 2004).* Unpubl. Report, Namibian Elephant and Giraffe Trust, Outjo.

Leuthold, W. (1977) Spatial organization and strategy of habitat utilization of elephants in Tsavo National Park, Kenya. *Zeitschrift fur Saugetierkunde* **42**: 358 – 379.

Lindeque, M. & Lindeque, P.M. (1991). Satellite tracking of elephants in northwestern Namibia. *African Journal of Ecology* **29**: 196–206.

Mosojane, S. (2004) Human-elephant conflict along the Okavango Panhandle in northern Botswana. Unpubl. project report, CERU, University of Pretoria.

Osborn (2004). The concept of home-range in relation to elephants in Africa. *Pachyderm* **37**: 37–44.

Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J. & Gitzen, R.A. (1999). Effects of sample size on kernel home-range estimates. *Journal of Wildlife Management* **63**: 739-747.

van Aarde, R.J., Kilian, W. & Versfeld, W. (2004a). *The dynamics of savannah elephants in Etosha National Park in northern Namibia.* Unpubl. final report 2004 to USFWS, CERU, University of Pretoria.

van Aarde, R.J., Jackson, T.P., Ferreira, S., Kinahan, A. & Shrader, A. (2004b). *The dynamics and integrity of savanna elephants in the Kafue National Park, Zambia.* Unpubl. progress report January – July 2004 to IFAW, CERU, University of Pretoria.

van Aarde, R.J., Guldemond, R. & Lehman, E. (2004c) *Elephant census of the southern portion of the Kafue National Park, Zambia.* Unpubl. report, CERU, University of Pretoria.

Viljoen, P.J. (1989). Spatial distribution and movements of elephants (*Loxodonta africana*) in the northern Namib Desert region of the Kaokoveld, South West Africa/Namibia. *Journal of Zoology (London)* **219**: 1–19.

Whyte, I. (2001) *Conservation Management of the Kruger National Park Elephant Population.* Unpubl. PhD Thesis, University of Pretoria.

Worton, B.J. (1995). Using Monte Carlo simulation to evaluate kernel-based home-range estimators. *Journal of Wildlife Management* **59**: 794–800.