CHAPTER 5

RANGE USE BY THE CARACAL IN THE KGALAGADI TRANSFRONTIER PARK

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ABSTRACT

Two female and three male caracals *Caracal caracal* were radio-collared in the Kgalagadi Transfrontier Park and their ranges were calculated. Only three of the caracals produced sufficient data points for satisfactory harmonic mean and kernel analysis of their range sizes, but those of the other two were analysed with the minimum convex polygon procedure. The three statistically verifiable ranges were for two males and a female. The range sizes of males one and two, when calculated with the kernel method, were 312.8 and 92.3 km^2 respectively for 95 % of the points, and that of female one was 66.9 km^2. Range estimates of male three and female two could not be determined statistically. The reasons for the discrepancies in the range sizes are discussed, along with possible reasons for them. Nevertheless the ranges for caracals in the Kgalagadi Transfrontier Park are considerably larger than those calculated for caracals elsewhere in southern Africa.

Keywords: Caracals, *Caracal caracal*, radio-tracking, minimum convex polygon, kernel analysis, harmonic mean

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INTRODUCTION

The orientation of animals in relation to each other is determined by the availability of resources within the habitat in which they occur. The resources in question are not only those of food and shelter, but also the proximity of potential mates. Dispersion of animals in an environment tends to maximise the reproductive success of the individual (Davies 1991). In the case of solitary predators where the male plays no parental role, it seems that the ranges of the females are related to food resource distribution and those of the males to mate acquisition (Davies 1991, Bailey 1993). To maximise reproductive success a male's range tends to overlap with the ranges of a number of females. Ranges of solitary predators are strongly influenced by habitat quality, sex and age. In areas characterised by low prey densities, predators are likely to have larger ranges than in areas that have an abundance of prey (Bailey 1993).

Lawrence (1998) defined the range of an animal as that area within which an animal seeks its food. However, generally the broader definition is accepted that the range is that area in which an animal normally lives. The concepts of territoriality and range are often, mistakenly, used interchangeably. A territory is part or all of a range, being defined as that area within a range that is actively defended by the occupier against animals of the same species (Lawrence 1998). Burt (1943) distinguished between an animal's range and its territory as follows: a range is that area that an animal occupies, whereas a territory is an area within the range that is actively and aggressively defended. Pitelka (1959) suggested that the territory of an animal is that area within an animals' range that is used exclusively by that animal. It is the concept of range rather than territory that is the focus of the present study.

In many cases, intra-specific overlaps in range use occur, because many animals do not occupy exclusive ranges (Smith 1990). Burt (1943) summed up the concept by defining the range of an animal as that area that an animal utilises for its basic life requirements of feeding, breeding, and resting.

The range of an animal is not a simple uni-dimensional area because animals use the space within the boundary of their range disproportionately at different times. Areas of high utilisation within the range are known as core areas of use (Samuel, Pierce & Garton 1985). The identification of a core area of use within a range is important because it contributes to the understanding of the ecological factors that dictate range use. Core areas of use generally contain home sites, refuges and dependable food sources (Burt 1943; Kaufmann 1968; Ewer 1962). It is accepted that while ranges may overlap, core areas of use never do so (Ewer 1962). The core areas of use are also used more intensively than what might be expected under an equal-use pattern (Samuel *et al.* 1985).

The basic hypothesis that is investigated here is that the range size of the caracal *Caracal caracal* in arid areas where the prey base is variable and the hunting cover is sparse (Kruuk 1986), is indeed larger than that of caracal elsewhere, as has been suggested by Gittleman & Harvey (1982) and Bothma & Le Riche (1994). This hypothesis has been supported in other felids by research on the bobcat *Lynx rufus* (Litvaitis *et al* 1986), Canadian lynx *Lynx canadensis* (Sandell 1989) and leopard *Panthera pardus* (Bothma *et al.*1997). The following two specific key questions were examined here:

1. What is the range size of the caracal in this arid region?
2. Do the ranges of caracals near the Namibian border in the Kgalagadi Transfrontier Park extend across the border into Namibia?

STUDY AREA

This study was done in an area along the Namibian border near Mata-Mata in the southwestern portion of the Kgalagadi Transfrontier Park. For logistic reasons it was decided to confine the research activities to an area that extended 60 km north from the Mata-Mata rest camp along the Namibian border (20° 00' E longitude), to approximately 20 km into the interior of the Kgalagadi Transfrontier Park.

The Kalahari Gemsbok National Park was proclaimed in 1931, but it only became a reality in 1935 when a number of farms along the southern bank of the Aoub River were acquired. Today, the Park exists in much the same ecological state as it was then (Van Wyk & Le Riche 1984). An agreement to formally combine the Kalahari Gemsbok National Park (South Africa) with the bordering Gemsbok National Park (Botswana) to form the Kgalagadi Transfrontier Park was signed by representatives of the governments of South Africa and Botswana in 1999. This agreement was ratified at an amalgamation ceremony that was held on the 12 May 2000 (Donaldson 2000).

The Mata-Mata area lies in the Shrubby Kalahari Dune Bushveld of the Savanna Biome (Low & Rebelo 1996). This is an arid savanna with temperatures varying from –10° C to 45° C in the shade with an annual mean rainfall of 153.47 mm occurring mainly in the summer. The landscape is one of undulating dunes with sparse vegetation at altitudes varying from 1000 to 1100 m above sea level (Low & Rebelo 1996).

The vegetation is characterised by the trees *Acacia erioloba*, *Acacia haematoxylon* and *Boscia albitrunca*, a shrub layer of *Grewia retinervis* and *Rhus tenuinervis*, and a well-developed grass layer consisting mainly of *Stipagrostis amabilis*, *Eragrostis lehmanniana, Aristida meridionalis, Schmidtia kalihariensis* and *Centropodia glauca* (Low & Rebelo 1996). There is little variation in the soil forms because the area is predominantly covered by aeolian sand overlying calcrete (Low & Rebelo 1996).

The Kgalagadi Transfrontier Park forms the southern part of the unique greater Kalahari ecosystem. Because of the arid nature of the area, many of the plants there are ephemeral. After sufficient rain, these plants germinate quickly to complete their life cycle in a short time (Eloff 1984).

Because of the harshness of the environment, the southern Kalahari is an area that is only sparsely inhabited by humans. This above any other factor contributes to the uniqueness of the area, and it enhances the value of the area for field research in wildlife management and conservation.

METHODS

Three adult male and two adult female caracals were captured with cage traps from July 2000 to April 2002, and were fitted with 250 g Telonics radio-collars transmitting in the 148.80 to 148.89 MHz. ranges. Three individuals (male 1, male 2 and female 1) provided sufficient data points for meaningful statistical analysis of their range sizes with the harmonic mean and kernel methods. The other two individuals (male 3 and female 2) only generated sufficient data points to calculate range size with the minimum convex polygon method. Nevertheless, these results are given here for comparative purposes only. No attempt was made to measure range overlaps because not all the caracals in a particular area could be monitored.

All the captured caracals were judged to be adults by inspection of their teeth (Stuart 1982) and because they had achieved a weight consistent with an adult (Bernard & Stuart 1987). Notwithstanding the adult status attributed to all three male caracals, it is probable that male 3 was a young adult because his movements indicated that he was still attempting to establish a permanent range. The difference in body weight and canine length (Table 1) between male 1 and male 2 indicates that male 2 was a younger individual, weighing less and with less evidence of wear on the canine teeth than in male 1.

After their release, the radio-collared animals were radio-located on a weekly basis, where possible. The intermittent nature of the consecutive observations ensured that the positional locations were independent of one another and of the disturbance caused to the animal when it was tracked before (Reynolds & Laundre 1990; Swihart & Slade 1985). The tracking regime therefore avoided auto-correlation of positional data and the resultant underestimation of range size (Swihart & Slade 1985). Most locations were obtained by ground tracking, because an aircraft was not available during the final year of the project.

Radio-tracking

Radio-tracking was done primarily from the ground, but it was occasionally supplemented with aerial tracking. Positional fixes were based on the global

Table 1: *The range sizes and age determination of the caracals that were radio-tracked in the Kgalagadi Transfrontier Park from June 2000 to August 2002.*

Collar frequency in MHz	Period collared in months	Gender	Range size in km^2: 95 % MCP estimate	Range Size in km^2: 95 % kernel estimate	Age	Mass in kg	Total body length in mm	Canine length in mm			
								Right upper	Right lower	Left upper	Left lower
148.82	5.00	Male	765.7		Adult	10.0	1150	15.0	12.0	14.5	11.7
148.87	1.00	Female	2.7		Adult	9.5	985	9.2	0.0	10.0	0.0
148.88	12.00	Male	168.8	312.8	Adult	12.5	1100	15.4	13.6	15.6	13.0
148.84	7.00	Male	57.1	92.3	Adult	11.0	1175	17.0	13.4	17.8	13.2
148.89	5.00	Female	62.4	66.9	Adult	8.0	1004	13.4	11.2	12.0	10.5

MCP: Minimum convex polygon method

positioning system (GPS). Traditionally, radio-collared animals are located by triangulation (Lindzey & Meslow 1977, Stuart 1982, Don Bowen 1982, Litvaitis, Sherburne & Bissonette 1986, Moolman 1986, Kaunda 1998, Mizutani & Jewell 1998). However, there are limitations inherent in the use of triangulation as there may be discrepancies between the animal's true position and the position that is eventually calculated for it (Macdonald & Amlaner 1980, Nams & Boutin 1991). To obviate these errors it was decided to visually locate the radio-collared animals first and then to determine their positions with GPS equipment.

Animals were radio-tracked by using the crests of high dunes as vantage points to listen for radio signals. The direction from which the signal was being transmitted was determined by using a directional antenna in conjunction with a magnetic compass, ensuring that other sources of magnetism did not cause false deflection of the compass (Kenward 1987). Due to the nature of the terrain in the Kgalagadi Transfrontier Park it was possible to travel directly towards the radio signal through the veld. That the correct direction was being followed was confirmed by regularly taking further bearings towards the signal from vantage points en route. In principle, as the distance between the receiver and the transmitter decreases the perceived signal strength increases. Once the signal was judged to be within walking range of the vehicle, the radio-collared animal was approached on foot until visual contact with the animal was made. It was preferable to follow this procedure during the heat of the day, because the radio-collared animal was then less likely to flee before a visual location could be confirmed. In cases where animals did flee before a positive visual location could be done, the onset point of a set of fresh tracks was used to indicate the caracal's original position.

Occasionally, aerial tracking was used to supplement ground tracking. Aerial tracking was done from a high-wing Cessna 182 aircraft with directional antennas attached to the wing struts on either side of the aircraft. Radio-tracking followed the conventional method (P. Funston pers comm.[1]; Kenward 1987). After running some tests it was established that radio-locations taken from the aircraft were accurate to within a grid of 10 000 m^2.

Calculation of range size and identification of core areas of use

If an animal's position is sampled at intervals over a period of time, a plot including all those fixes represents the animal's range for that period of time (Kenward 1987). Positional fixes for radio-collared animals were recorded and used to calculate the range of caracals in the Kgalagadi Transfrontier Park.

Three methods of range analysis were applied to the data, a parametric method (the minimum convex polygon method) and two non-parametric ones (the kernel analysis method and the harmonic mean method). The non-parametric methods of data analysis were selected because they do not impose false probabilistic circles or ellipses, or require assumptions of normal distribution on the range data calculations (Zar 1984, Kenward 1987). The data were subjected to these analyses by using two different computer programs because it has been found that different programs give different range size estimates for the same data set, even while applying the same analysis protocols (Gallerani Lawson & Rodgers 1997). Consequently the Ranges V program (Kenward & Hodder 1996) was used as the primary range estimator, and the Animal Movement Extension of the widely used ArcView Global Information System package, (Hooge 1999), as the secondary estimator. .

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Minimum convex polygon method

The simplest and most widely used method of assessing the range size of an animal is the minimum convex polygon method because it is the smallest area polygon that includes all the location points (Worton 1987). The limitations of this method are that the range size is highly correlated with the number of observations, and that it includes areas that are never visited by the animal in question. Therefore the limited sample sizes available here could only be used for rough indications of range size. The method also does not allow the calculation of the intensity of range use because it only takes the outermost locations into consideration (Worton 1987, Gallerani Lawson & Rodgers 1997). The greatest benefit of this method is that it is the only one that is comparable between studies (Harris *et al.* 1990) because all the other range size estimators use a different algorithm for their estimation of range size.

Outlying location points may be a result of occasional excursions outside the range, and the inclusion of these points could exaggerate the size of the range when computed by using the minimum convex polygon method (Mizutani & Jewell 1998). To take this into consideration, a process of peeling is suggested that involves disregarding 5 % of the location plots that lie furthest away from the arithmetic mean centre of the range, and calculating the area of the minimum convex polygon on the remaining 95 % of the locations (Kenward 1987, Mizutani & Jewell 1998, Broomhall 2001). However, removal of any outliers must be done judiciously because their possible biological relevance cannot be underestimated (Linn & Key 1996).

The core area of use of the range has been defined as an area of obvious clumping of locations (Stuart 1982, Moolman 1986, Bothma 1994). Bothma (1994) found that 13 of the 18 locations (72.2 %), for a collared male caracal in the Kgalagadi

Transfrontier Park, were included in the core area. Based on this it was decided to construct 75 and 50 % contours for the current data to give an indication of the core areas of range use.

Harmonic mean method

The harmonic mean method estimates the density distribution of fixes and equates this to the probability of encountering the animal. The resultant contours indicate the centres of activity or core areas of use. The method is therefore useful when determining the intensity of habitat use, but not as useful for determining total range size (Worton 1987, Mituzani & Jewell 1998). This calculation method allows the isolation of more than one centre of activity, which can be beneficial when calculating core areas of use (Harris *et al.* 1990).

The harmonic mean method allows the calculation of ranges that relate closely to the distribution of the location fixes, but it includes areas that are not frequented by the animal. It is therefore advisable to use an 80 % isopleth to give a more accurate estimation of the range (Harris *et al.* 1990).

The harmonic mean method should not be used to compare mean range sizes between studies statistically because the various computer programs use different algorithms and grid cell sizes upon which to base the calculations (Harris *et al.* 1990). Using the harmonic mean method it has been suggested that the 50 % isopleth gives a suitable indication of core areas of use for many species (Harris *et al.* 1990). It was therefore decided to analyse the current data according to this guideline.

The kernel method

The kernel method relies on placing a probability density on each location point. Each probability density is known as a kernel (Worton 1989, Erran Seaman & Powell 1996). The advantages of kernel methods are that they are not based on parametric assumptions and facilitate the smoothing of location data. Additionally, kernel methods have consistent statistical properties (Worton 1989). The selection of a smoothing parameter is important when using the kernel method (Worton 1989), and generally, the least-squares cross-validation approach is considered appropriate (Silverman 1986). A number of options are available when using kernel analysis to investigate range use by animals. In cases where accuracy is not critical, a fixed kernel method gives sufficient information. However, where accuracy is important, such as in arid environments where range size might be used to calculate the size of viable conservation areas, an adaptive kernel method should be used in conjunction with a least-squares cross-validation (Worton 1989). This is the approach that was followed for the analyses that were done in the present study.

Many authors feel that the kernel method with a 95 % isopleth gives a reliable representation of the range size of many species (Jaremovic & Croft 1987, Mizutani & Jewell 1998, Broomhall 2001). It was therefore decided to use this method upon which to base the range size estimates of the caracals (male 1, male 2 and female 1) for which sufficient data points were recorded in the present study to ensure meaningful results.

The 95 % isopleth was used in both the harmonic mean and kernel analyses to remove the effect of outliers on the calculation of range size (Jaremovic & Croft 1987, Mizutani & Jewell 1998, Broomhall 2001). To define the core areas of use, 75 and 50 % isopleths were drawn.

RESULTS

For those caracals for which sufficient locations were obtained to facilitate meaningful analyses (≥ 25 locations) (Mituzani & Jewell 1998, Broomhall 2001) the results appear in Figs. 1 to 6. In addition, the 100 % minimum convex polygon and the peeled (95 %) minimum convex polygon results appear in Fig. 7. Where appropriate, the core areas of use as determined with the harmonic mean method (75 and 50 % isopleths) (Ranges V) appear in Figs. 1, 3 and 5.

Male 1 was located on 40 occasions from 10 August 2001 to 21 August 2002 (Table 1). Synthesis of these data showed that he had a range of 312.8 km^2 (95 % kernel analysis) (Fig. 1), with core areas of use of 94.0 km^2 (75 % harmonic mean) and 51.5 km^2 (50 % harmonic mean) (Fig. 2). The 50 % harmonic mean core area of use equates to 16.5 % of the total range. With the minimum convex polygon method, the 50 % core area of use comprises 22.5 % of the total range area as calculated with the 95 % minimum convex polygon method.

Male 2 was located on 30 occasions. Synthesis of these data gave a range estimation of 92.3 km^2 (95 % kernel analysis) (Fig. 3), with core areas of use of 27.9 km^2 (75 % harmonic mean) and 24.2 km^2 (50 % harmonic mean) (Fig. 4). The core area of use (50 % harmonic mean) equates to 15.3 % of the total range. Based on the minimum convex polygon method, the core area of use represents 40.4 % of the total range.

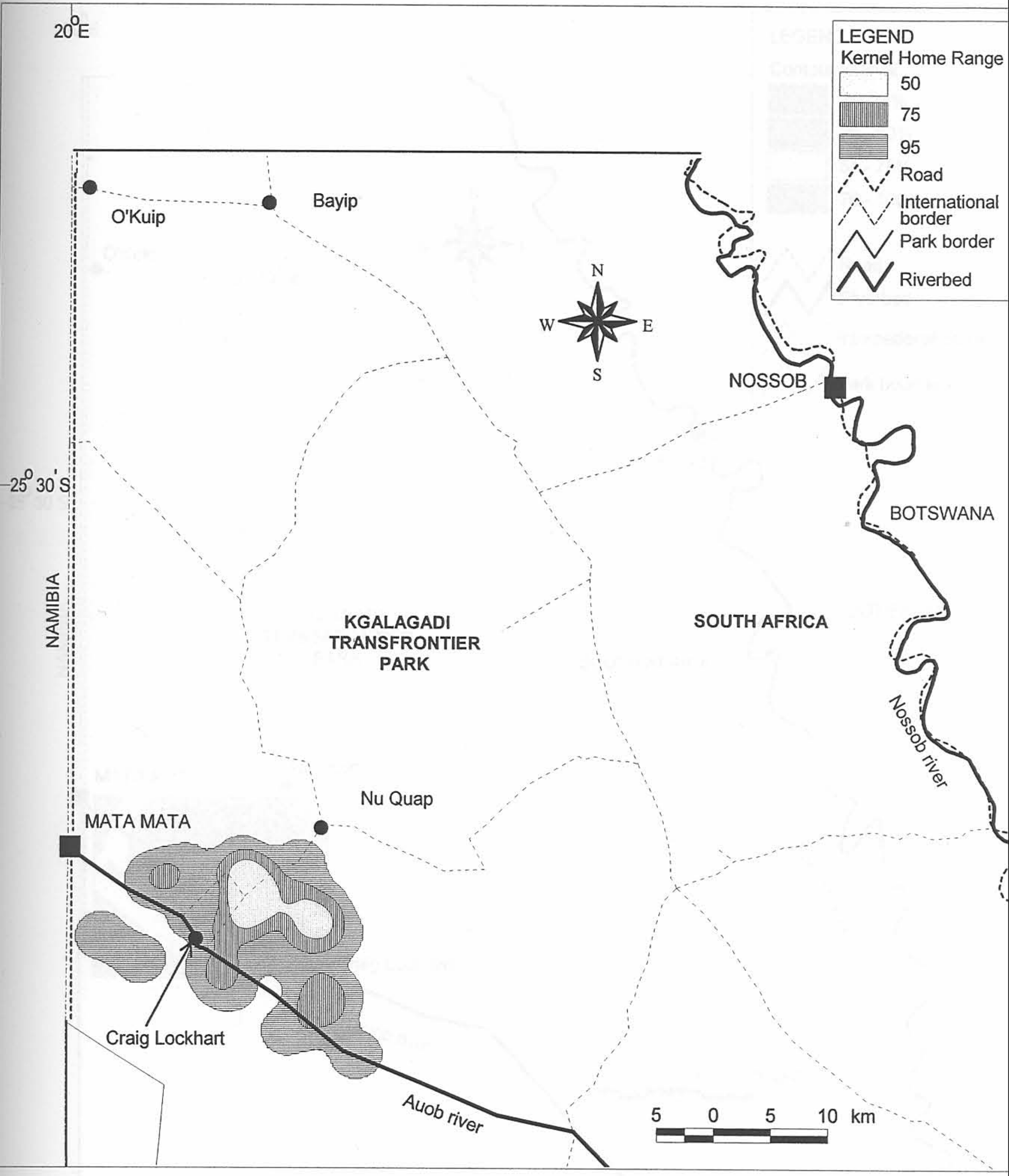


Figure 1: Range use of male 1 using the kernel home range method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.

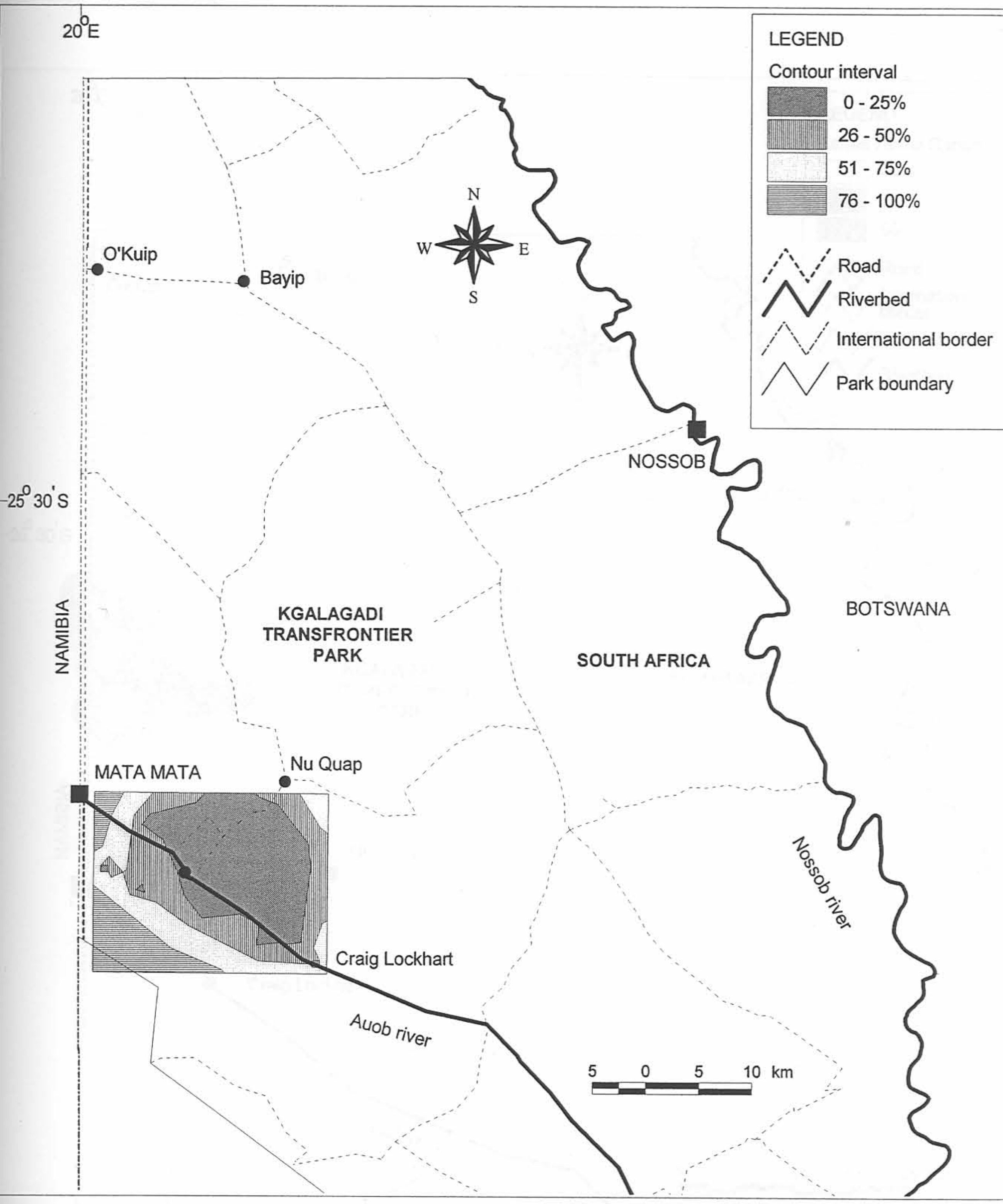


Figure 2: Range use of male 1 using the harmonic mean method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.

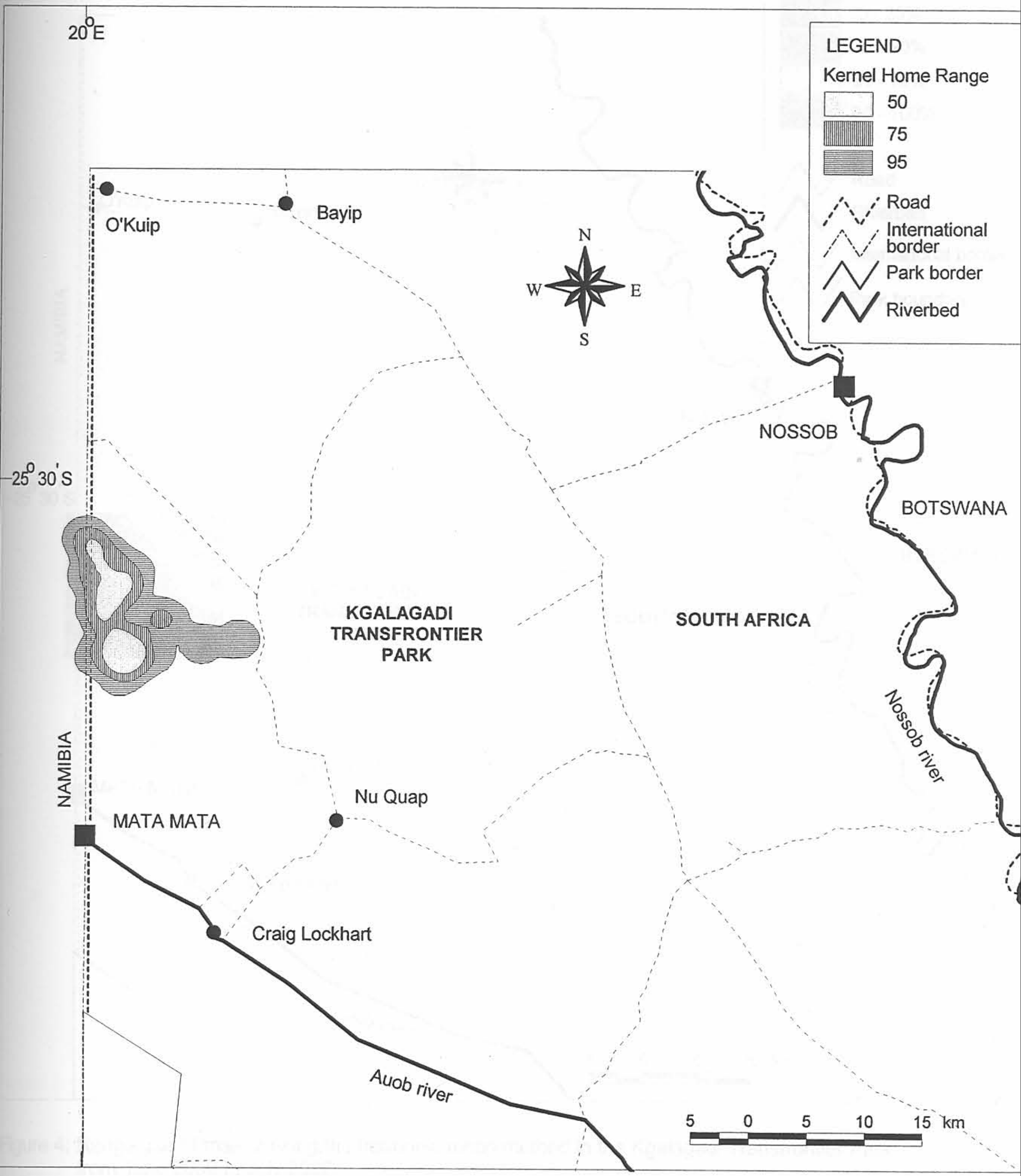


Figure 3: Range use of male 2 using the kernel home range method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.

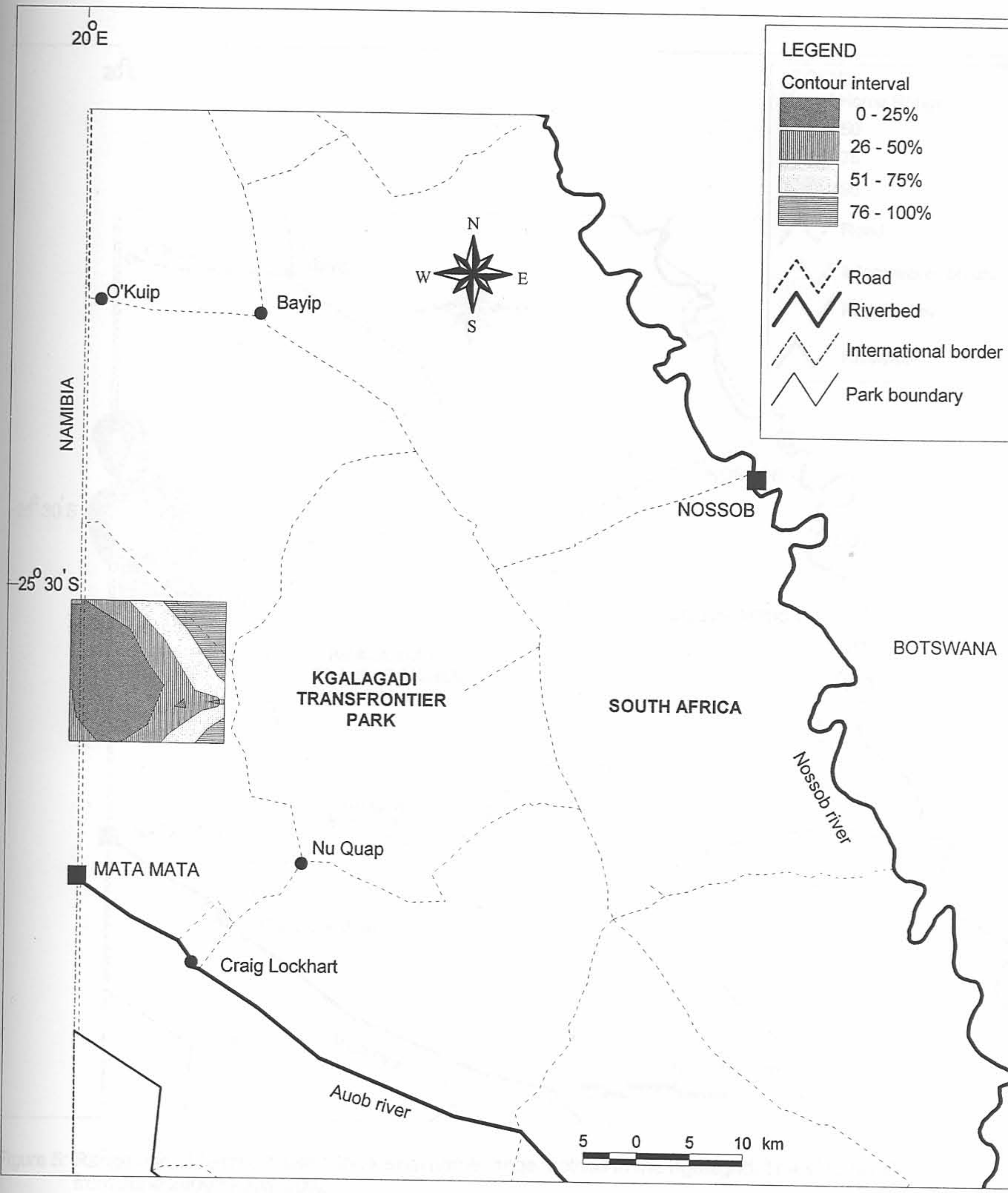
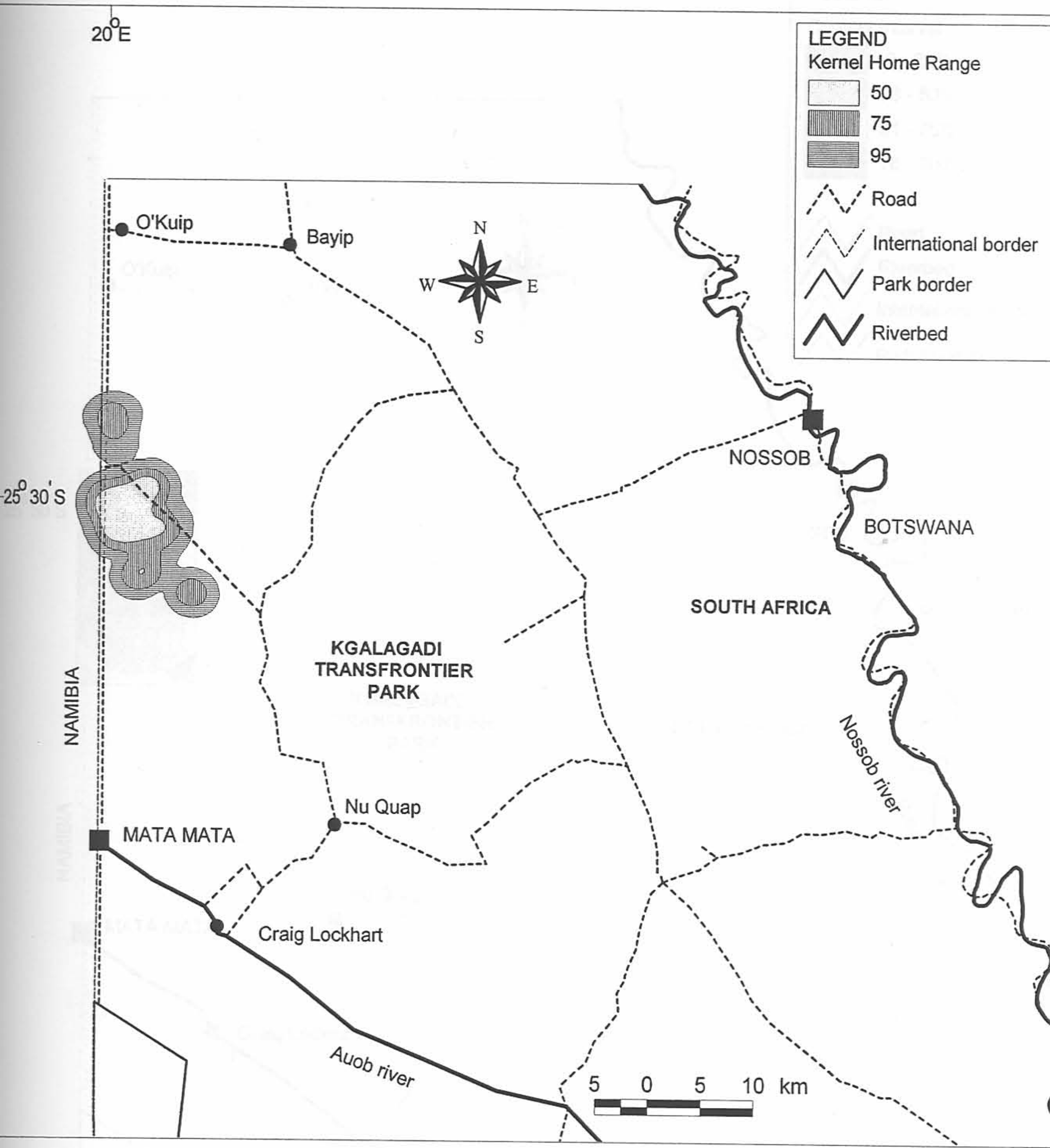


Figure 4: Range use of male 2 using the harmonic mean method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.



gure 5: Range use of female 1 using the kernel home range method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.

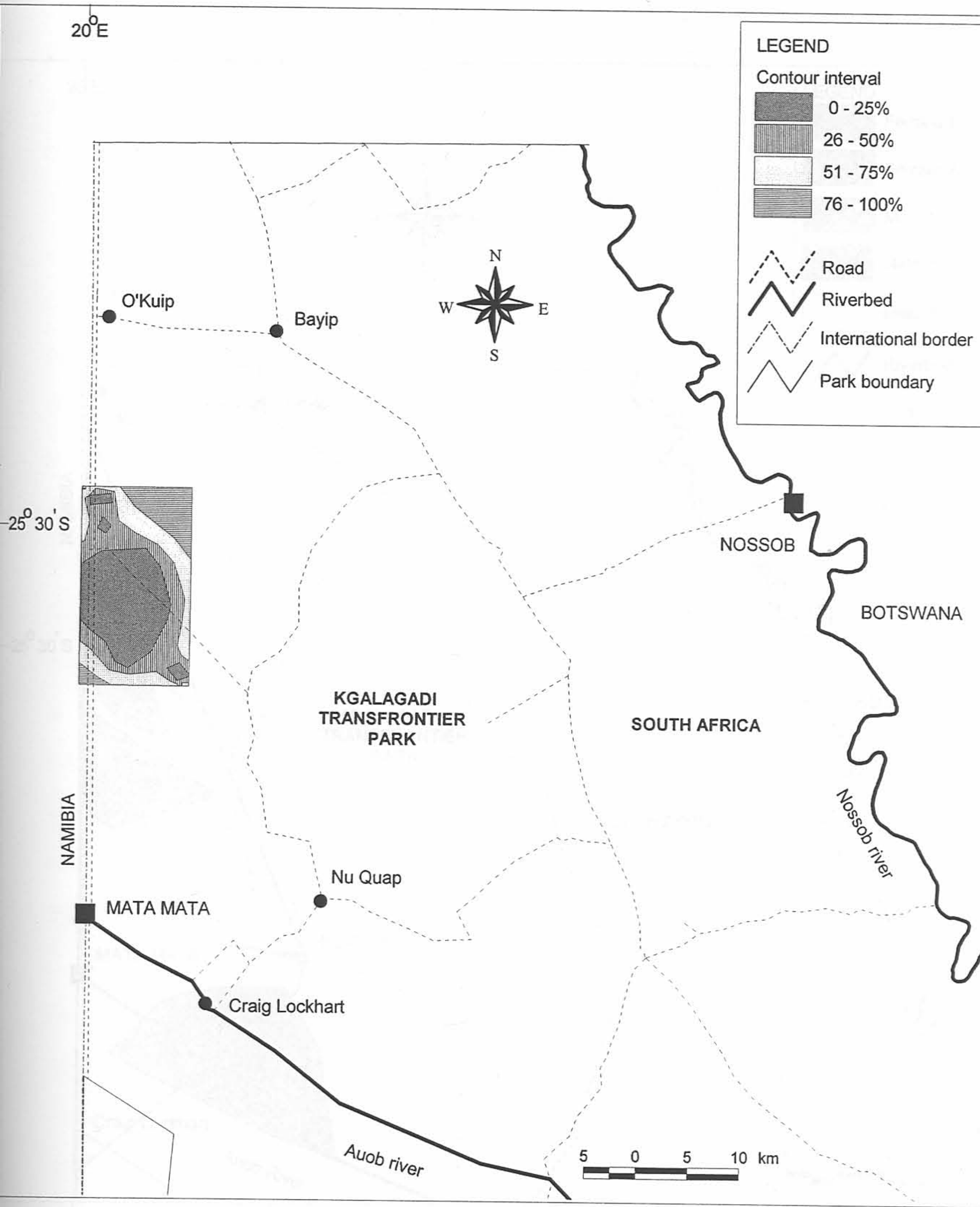
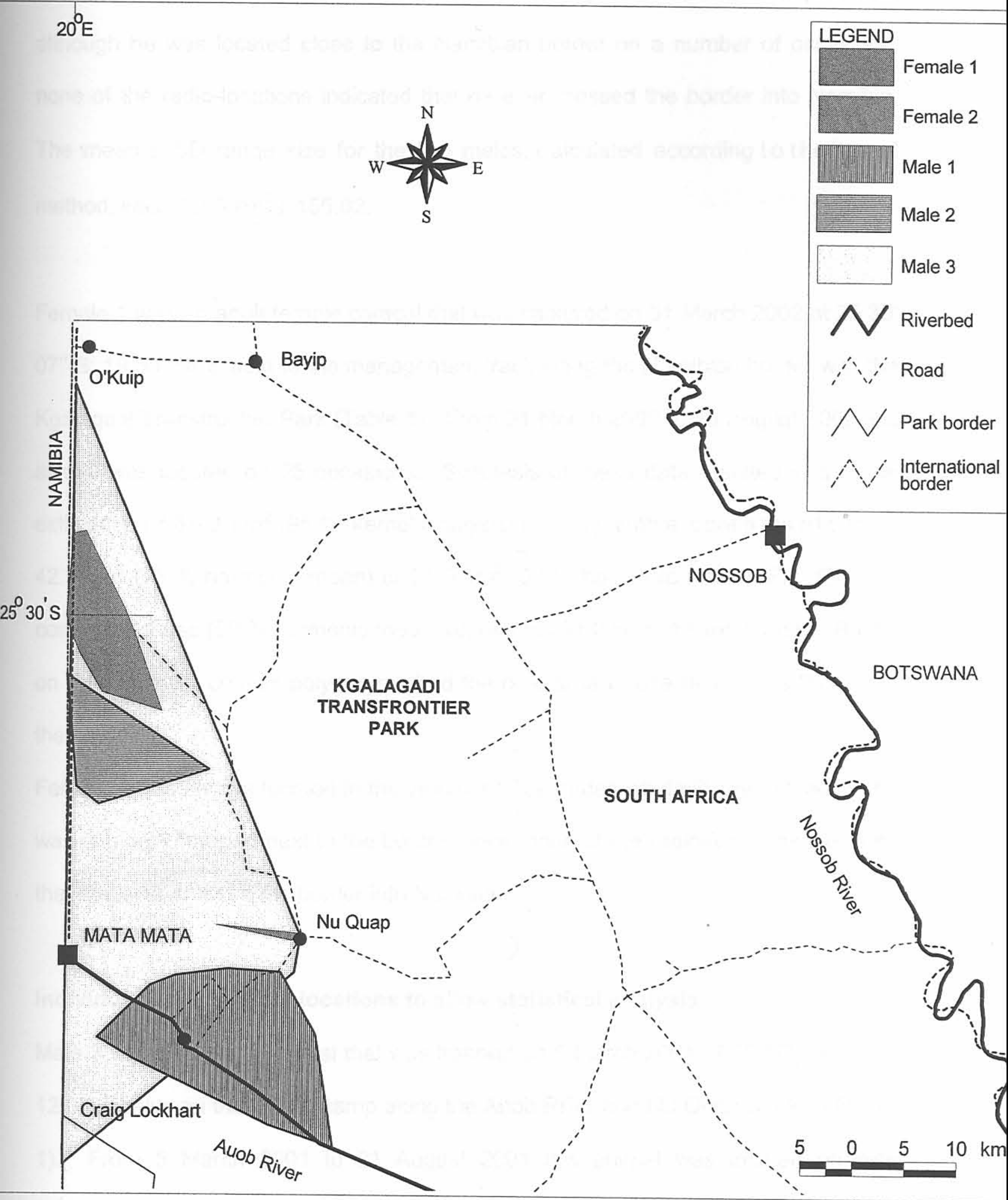


Figure 6: Range use of female 1 using the harmonic mean method in the Kgalagadi Transfrontier Park from June 2000 to July 2002.



gure 7: Range use of all radio-collared caracal determined by the minimum convex polygon method in the Kgalag Transfrontier Park from June 2000 to July 2002.

Male 2 seemed to orientate his range on the vicinity of the Driefendas pan, and although he was located close to the Namibian border on a number of occasions, none of the radio-locations indicated that he ever crossed the border into Namibia. The mean ± SD range size for the two males, calculated according to the kernel method, was 202.5 km^2 ± 155.92.

Female 1 was an adult female caracal that was captured on 31 March 2002 at 25 30' 07" S: 19 59' 56"E next to the management track along the Namibian border with the Kgalagadi Transfrontier Park (Table 1). From 31 March 2002 to 19 August 2002 this animal was located on 25 occasions. Synthesis of these data resulted in a range estimation of 66.9 km^2 (95 % kernel analysis) (Fig. 5), with a core area of use of 42.2 km^2 (75 % harmonic mean) or 21.5 km^2 (50 % harmonic mean) (Fig. 6). The core area of use (50 % harmonic mean) represents 31.0 % of the total range. Based on the minimum convex polygon method the core area of use represents 26.4 % of the range.

Female 1 was always located in the vicinity of Driefendas windmill, and although she was originally trapped next to the border fence, none of the radio-locations indicated that she ever crossed the border into Namibia.

Individuals with too few locations to allow statistical analysis

Male 3 was a 10.0 kg caracal that was trapped on 5 March 2001 at 25 46' 14" S: 20 12 07 E between the giraffe camp along the Auob River and Nu Quap windmill (Table 1). From 5 March 2001 to 21 August 2001 this animal was located on nine occasions. Due to the low number of locations, the only appropriate method for range analysis was the minimum convex polygon method. According to this method the range size of male 3 was 765.7 km^2 (95 %) (Fig.7). The resultant core areas of use, derived by constructing 75 and 50 % contours, were 118.2 and 21.7 km^2 respectively. Male 3 was eventually shot by a Namibian farmer when it crossed into Namibia from the Kgalagadi Transfrontier Park.

Female 2 was a 9.5 kg caracal captured at Nu Quap windmill (25 46' 17" S: 20 12' 09" E) on 15 June 2001 (Table 1). During the period from 15 June 2001 to 19 July 2001 this animal was located on seven occasions. This animal died on 19 July 2001 and the collar was retrieved. The condition of the collar on recovery suggests that another predator had killed the caracal. The minimum convex polygon method (95 %) was applied to this small sample and gave a range size of 2.7 km^2 (Fig.7). The resultant core areas of use were 0.3 and 0.2 km^2 respectively when the 75 and 50 % minimum convex polygon contours were calculated. For the period that female 2 was collared, she remained in a small area in the vicinity of the Nu Quap windmill.

The ranges and core areas of use for male 3 and female 2 are represented in Tables 2 and 3 for completeness only but they should not be considered representative of the mean range size and core areas of use of caracals in the Kgalagadi Transfrontier Park, nor were they used for this purpose.

Namibian farmers bordering the Kgalagadi Transfrontier Park shot three research animals that were originally captured and radio-collared in the Kgalagadi Transfrontier Park. It is therefore clear that the caracals do cross into Namibia from the Kgalagadi Transfrontier Park. Due to the loss of these animals it was not possible to assess whether the movement of caracals into Namibia was due to stock raiding or whether it simply indicated that the ranges extended beyond the borders of the Park, as do those of leopards (Bothma *et al.* 1997).

DISCUSSION

Because of the small sample size and the highly variable results (Table 2) it was decided to discuss the range of each caracal independently. Moreover, the ranges of the animals that generated meaningful results when using statistical methods are discussed separately from those upon which it was only possible to perform minimum convex polygon analyses.

Male 1 was collared for the longest period of time, and hence he produced in the highest number of location points. This animal also had the largest range of all the animals that could be located on sufficient occasions to facilitate statistical analysis of the range data. After collaring, the animal remained in a stable range area, to the extent that after locating the animal on six separate occasions it was possible to go to one of two vantage points within the range and be sure of picking up a signal from the animal. All attempts to locate the animal were successful. This animal was never located in the vicinity of the Namibian border. Although the possibility exists that the animal made excursions to areas outside the stable range area, no such behaviour was detected by radio-tracking.

When the range of male 1 is compared with that of the male studied by Bothma & Le Riche (1994) in the Kgalagadi Transfrontier Park there is an obvious difference in range size. The range of an adult male caracal as calculated by Bothma & Le Riche (1994) was 308.0 km^2 when calculated according to the minimum convex polygon method using 100 % of the locations. In comparison the male 1 had a range of 194.3 km^2 (Ranges V) or 194.2 km^2 (Animal movements) when calculated according to the minimum convex polygon method. This is 63.1 % of the range size of the adult male caracal that Bothma & Le Riche (1994) studied. Kernel analysis (95 %) of the range

Table 2: *Range sizes calculated by two range programs as applied to data collected for caracals in the Kgalagadi Transfrontier Park from June 2000 to August 2002.*

Item	Range method	Male 1	Male 2	Female 1	Male 3	Female 2
		Range size in km^2				
Animal number:		Male 1	Male 2	Female 1	Male 3	Female 2
Collar frequency:		148.88	148.84	148.89	148.82	148.87
Gender:		Male	Male	Female	Male	Female
Number of radio locations:		40	30	25	9	7
Ranges V	MCP 100	194.3	71.3	66.7	765.7	2.7
	MCP 95	168.8	57.1	62.4	765.7	2.7
	MCP 75	97.1	39.8	32.3	118.2	0.3
	MCP 50	37.9	23.1	16.5	21.7	0.2
	Harmonic 100	283.0	120.0	95.7	-	-
	Harmonic 95	219.3	51.0	89.8	-	-
	Harmonic 75	94.0	27.9	35.3	-	-
	Harmonic 50	51.5	14.1	20.8	-	-
	Kernel 100	400.1	161.6	102.8	-	-
	Kernel 95	312.8	92.3	66.9	-	-
	Kernel 75	139.3	44.2	42.2	-	-
	Kernel 50	55.7	24.2	21.5	-	-
Movement	MCP 100	194.2	71.3	66.6	765.6	2.7
	MCP 95	-	-	-	-	-
	MCP 75	-	-	-	-	-
	MCP 50	-	-	-	-	-
	Kernel 95	268.9	120.3	138.1	-	-
	Kernel 75	88.4	56.1	69.2	-	-
	Kernel 50	29.1	23.1	26.6	-	-
	Harmonic 100	-	-	-	-	-
	Harmonic 95	-	-	-	-	-
	Harmonic 75	-	-	-	-	-
	Harmonic 50	-	-	-	-	-

Ranges V: Kernel analysis using a tail weighted adaptive kernel and least-squares cross-validation of male 1 estimates the range of this caracal at 312.8 km^2 which is 61.0 % larger than the range estimated according to the minimum convex polygon method. Different environmental conditions, and hence food resources, may have played a role here.

Male 2 generated sufficient locations to allow for meaningful statistical analysis and had a range of 71.3 km^2, when calculated according to the 100 % minimum convex polygon method. This equates to 23.1 % of the range size recorded by Bothma & Le Riche (1994) and 36.7 % of the size of the male 1.

Although male 2 had a considerably smaller range than male 1 on two occasions when radio-tracking was attempted, no signal was detected. On all occasions when this male was successfully radio-located, a signal was detected from one of three high vantage points within the defined range. It is possible that on those occasions when this animal could not be detected, he may have been on excursions outside the known area of its range. The reasons for these excursions may be that he was trying to extend his range. Another possibility is that he had gone across the border into Namibia. This does not, however, explain why a signal was not detected, because vantage points along the border were used for radio-tracking purposes. Kernel analysis (95 %) resulted in a range size estimation of 92.3 km^2 that is 29.4 % larger than the range estimated according to the minimum convex polygon method for male 2.

Female 1 provided sufficient locations to allow for meaningful results from statistical analysis of the range size. She was frequently recorded in the vicinity of the Namibian border. As no other females were trapped and collared in the Kgalagadi

Transfrontier Park, it is impossible to compare these results with that of other females. The kernel method (95 %) estimated the female's range at 66.9 km^2, which is to all purposes identical to that when estimated by the minimum convex polygon method (66.7 km^2).

The young Male 3 was limited to a core area of use (minimum convex polygon 75 %) of 118.2 km^2 for the first month after capture (Table 1). Thereafter he moved over large distances which made regular radio-tracking impossible. This animal first moved northwest from where he was captured near Nu Quap (25 46' 15" S: 20 12' 05" E) to an area near Driefendas windmill (25 28' 20" S: 20 01' 01" E) a distance of 40 km. Over a period of two months he then moved 36 km further to the north and was located near O'Kuip (25 16' 28" S: 20 00' 57" E). He was finally shot in Namibia on a farm 25 km south of Mata Mata rest camp at 25 57' 53" S: 19 59' 50" E. It is believed that this animal was moving out of its natal range and was trying to establish a range of its own as is known to happen in larger predators (Bothma 2002). The range of 765.7 km^2 (100 % minimum convex polygon) for the period over which he was tracked would then not have been stable. This range is 248.6 % larger than the range established for an adult male caracal in the same area by Bothma & Le Riche (1994) and 576.7 % larger than the mean male range (100 % minimum convex polygon) of the other males in this study.

Female 2 was located within a small area for a period of a month. On capture, this animal seemed to be in a good physical condition. It was obvious that she was old because there was evidence of extensive tooth wear (Table 1). This female remained in a range of 2.7 km^2 (100 % minimum convex polygon). However on the 19 July 2001 the collar was located 300 m from Nu Quap Windmill, and it was evident from the condition of the collar that the caracal had died and had been consumed by another predator. Therefore this range area is not indicative of the mean range size of female caracals in the Kgalagadi Transfrontier Park.

Comparison with other studies

When compared with other studies of caracal ranges (Table 3) it is evident that even when the minimum convex polygon method is applied for comparative purposes, the range sizes of caracals in the Kgalagadi Transfrontier Park are far larger than those in other areas. The only study area that has revealed a larger range size for an individual male caracal was in Saudi Arabia, a true desert with a concomitant low prey density. The peeled range (95 % minimum convex polygon) for the individual in Saudi Arabia was 865.4 km^2. The 100 % minimum convex polygon method for the animal in Saudi Arabia gave a range of 1116.0 km^2 (Van Heezik & Seddon 1998).

Rodents form a significant portion of the diet of a caracal (Stuart 1982, Moolman 1986, Avenant 1993). The relatively smaller range size of males 1 and 2 (Tables 1 and 2), when compared with the results from Bothma & Le Riche (1994), could be related to the higher prey abundance as a result of two consecutive years of rainfall far above the mean for the study area during the study period. Rodent populations tend to track increased rainfall closely, with a gradual build-up and rapid decline (Nel *et al.* 1984). The population densities of small predators tend to change in synchrony with prey population dynamics (Brand *et al.* 1976). The ranges of small predators tend to expand as prey densities decline (Ward & Krebs 1985, Litvaitis *et al.* 1986).

There is no evidence from other studies that the range size of female caracals is related to the range size of male caracals according to a specific ratio. However,

Source	Study area	Animal	Gender	Number of locations	MCP 100 (km^2)	MCP 95 (km^2)
Stuart (1982)	Caledon	1	male	67	48.0	-
	Caledon	2	male	4	N.A.	-
	Eastern Robertson Karroo	3	female	43	11.8	-
	Eastern Robertson Karroo	4	female	17	26.7	-
	Eastern Robertson Karroo	5	female	12	22.4	-
	Coastal sandveld	6	female	25	11.9	-
Norton & Lawson (1984)	Stellenbosch	1	male	63	65.0	-
Moolman (1986)	Mountain Zebra National Park	1	male	28	16.7	-
	Mountain Zebra National Park	2	male	30	16.0	-
	Mountain Zebra National Park	3	male	35	15.8	-
	Mountain Zebra National Park	4	male	66	12.2	-
	Farm next to Mountain Zebra National Park	5	male	41	30.6	-
	Farm next to Mountain Zebra National Park	6	male	26	21.5	-
	Farm next to Mountain Zebra National Park	7	male	23	5.1	-
	Mountain Zebra National Park	8	female	46	6.5	-
	Mountain Zebra National Park	9	female	45	6.3	-
	Mountain Zebra National Park	10	female	27	5.1	-
	Mountain Zebra National Park	11	female	24	3.9	-
Bothma & Le Riche (1994)	Kgalagadi Transfrontier Park	1	male	18	308.0	-
Avenant & Nel (1997)	West Coast National Park	1	male	298	27.5	-
	West Coast National Park	2	male	352	26.4	-
	West Coast National Park	3	female	52	5.6	-
	West Coast National Park	4	female	558	8.9	-
	West Coast National Park	5	female	375	7.7	-
van Heezik & Seddon (1998)	Saudi Arabia	1	male	74	1116.0	865.4
Melville (current study)	Current study	1	male	40	194.3	168.8
	Current study	2	male	30	71.3	57.1
	Current study	3	male	9	765.7	765.7
	Current study	4	female	25	66.7	62.4
	Current study	5	female	7	2.7	2.7

MCP: Minimum convex polygon method

Sandell (1989) suggests that in solitary carnivores, the ranges of males are approximately 2.5 times that of females. There is evidence, however, that the ranges of female caracals are considerably smaller than those of males (Stuart 1982, Moolman 1986, Avenant & Nel 1993). This seems to be true for the Kgalagadi Transfrontier Park too, but this observation is only based on one female that provided sufficient locations to allow statistical analysis of her range use. Male 2 had a range size similar to that of female 1, but it is thought that this was due to his still being young and subdominant, whereas male 1 was considered to be mature and dominant. The differential range size of these two individuals agrees with Sandell's (1989) contention that dominant males roam over larger areas than subdominants.

CONCLUSIONS

It is clear, even from such a small sample, that the range sizes of caracals in the Kgalagadi Transfrontier Park are considerably larger than those recorded for caracals elsewhere in South Africa. This supports the hypothesis that in arid areas with low prey densities, the ranges of caracals are larger than those in more mesic regions with higher prey densities (Gittleman & Harvey 1982). This has implications for conservation in arid areas because it indicates that larger areas are required to sustain viable predator populations in arid areas than in more mesic regions.

To gain further insight into the range use and range size of caracal in the Kgalagadi Transfrontier Park it would be necessary to capture and collar a larger sample of both male and female caracals, both in the interior of the Park and along the border with Namibia. The only way to gauge how far caracals from the Park move into Namibia and *vice versa* is to persuade farmers in the vicinity to cooperate more actively with research attempts. Based on current data, the population of caracals in the

Kgalagadi Transfrontier Park is contiguous with that of Namibia and should be managed as a megapopulation.

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