Home ranges of cheetahs (*Acinonyx jubatus*) outside protected areas in South Africa

Kelly Marnewick[1,2]* & Michael J. Somers[1,3]

[1]*Centre for Wildlife Management, University of Pretoria, Pretoria, 0002 South Africa*

[2]*Carnivore Conservation Programme, Endangered Wildlife Trust, Private Bag X11, Modderfontein, 1645 South Africa*

[3]*Centre for Invasion Biology, University of Pretoria, Pretoria, 0002 South Africa*

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As many carnivores occur outside protected areas, they are vulnerable to anthropogenic threats. In South Africa, the largest proportion of the distribution range of cheetahs (*Acinonyx jubatus*) is outside protected areas along the northern border of the country. Lions (*Panthera leo*) and spotted hyaenas (*Crocuta crocuta*) have been extirpated from these areas, leaving the depauperate carnivore guild dominated by cheetahs, leopards (*Panthera pardus*) and brown hyaenas (*Hyaena brunnea*). To determine how cheetahs use these areas, tracking collars were fitted to nine individuals from September 2003 to July 2009 in the Thabazimbi area, Limpopo, South Africa. Local Convex Hulls (αLoCoH) were used to determine home range sizes and 50 and 95 utilization distributions (UDs) were calculated. Male 95UDs ranged from 121.5 km^2 to 607 km^2 while females ranged from 14.7 km^2 to 703.3 km^2. Cheetahs utilized several ranches and mean home ranges sizes were larger than mean ranch size and larger than cheetah home ranges recorded in other southern African countries, with the exception of the more arid Namibia. This study provides valuable and relevant data on cheetahs and aids conservation practitioners in mitigating human–cheetah conflict on South African farmland.

Key words: African carnivores, Local Convex Hulls, conservation threats.

INTRODUCTION

A key function of protected areas is to separate biodiversity elements from processes that threaten them (Margules & Pressey, 2000). The designation of protected areas has seldom been done in a systematic way and as a result, protected areas are not always effective in contributing to biodiversity conservation (Margules & Pressey, 2000). This means that many species which occur outside protected areas in regions of anthropogenic use are vulnerable to the effects of habitat fragmentation (Ranta, Blom, Niemela, Joensuu & Siitonen, 2009) and conflict-related killings (Swanepoel, Lindsey, Somers, van Hoven & Dalerum, 2014) and other threats.

Large carnivores are particularly vulnerable to threats in fragmented landscapes as they have high space requirements, live at low densities and inevitably come into conflict with humans (Purvis, Gittleman, Cowlishaw & Mace, 2000; Cardillo *et al.,* 2005). While protected areas are important for carnivore conservation, they are seldom effective in their conservation (Woodroffe & Ginsburg, 1998). Conservation of carnivores therefore cannot rely solely on protected areas, and needs to be addressed both within and beyond the boundaries of these areas.

In South Africa, the protected area network alone is not sufficient for conserving populations of large carnivores. For example, leopards (*Panthera pardus*) are vulnerable to edge effects (Balme, Slotow & Hunter, 2010), habitat fragmentation and ineffective positioning of protected areas (Swanepoel, Lindsey, Somers, van Hoven & Dalerum, 2013); and only two protected populations of lions (*Panthera leo*) (Kruger National Park and Kgalagadi Transfrontier Park) are classified as viable (IUCN/SSC, 2006), with lions in smaller protected areas being vulnerable to genetic, ecological and stochastic effects (Miller *et al.,* 2013). Ecological niche modelling shows that the protected area network is also not effective in conserving the most suitable habitat for cheetahs (*Acinonyx jubatus*) and African wild dogs (*Lycaon pictus*) in South Africa (K.M., unpubl. data).

The Kruger National Park and the Kgalagadi

*Author for correspondence.
E-mail: kellym@ewt.org.za / kellymarnewick@gmail.com

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Transfrontier Park hold the only substantial populations of cheetahs inside protected areas in South Africa (Lindsey & Davies-Mostert, 2009), with the largest portion of the national cheetah distribution range occurring outside protected areas along the northern border of the country (Marnewick *et al.*, 2007). Lions and spotted hyaenas (*Crocuta crocuta*) have been extirpated from these areas, leaving the depauperate carnivore guild dominated by cheetahs, leopards and brown hyaenas (*Hyaena brunnea*). In these areas, land is privately owned and utilized for wildlife ranching, livestock ranching or a combination thereof. Both livestock and wildlife have an economic value to the landowner; livestock through live sale or the meat industry and wildlife through sport hunting and live sale. Thus when carnivores prey on these animals, conflict results and the suspected carnivore is often killed in retaliation or in an effort to prevent further losses (Thorn, Green, Marnewick & Scott, 2013). Cheetahs are classified as Vulnerable in the South African Red Data Book of Mammals (Friedmann & Daly, 2004) and the South African population is contiguous with the populations in Botswana, Namibia, Zimbabwe and Mozambique (IUCN/SSC, 2007). These factors make the cheetah population outside protected areas important for conservation of the species.

Few data exist on cheetahs outside protected areas in South Africa. Some landowners perceive cheetahs to be problematic as they claim cheetahs do not behave naturally in these areas. Ranches are heavily stocked with game and supported by supplying food and water. Because the ranches are fenced and the prey is sedentary, many landowners believe that cheetahs do not use large home ranges as is typical in other areas. This means that the impact of cheetahs on any individual ranch is perceived to be high (K.M., unpubl. data).

These perceptions are important in driving killing of cheetahs and thus their long-term survival outside protected areas. Data relevant to the landowners are required to address these perceptions and to implement cheetah conservation actions. This study therefore attempts to quantify the home ranges of cheetahs outside protected areas on private ranches.

METHODS

Study area

The Thabazimbi District in the Limpopo province was the core study area. The area was selected because previous surveys had been done in the district and a relationship had been developed with the landowners (Marnewick & Cilliers, 2006; Marnewick, Bothma & Verdoorn, 2006; Wilson, 2006). Thus, landowner buy-in had been obtained for the study with the resulting permissions to trap, collar and release cheetahs on several properties. The mean ranch size in the district is approximately 18 km^2 with the main form of land-use being wildlife ranching, or a combination of wildlife and livestock ranching (Wilson, 2006). The area is topographically flat with little change in elevation and few distinguishing geographic features.

The Thabazimbi District lies in the Savanna Biome of South Africa and the main vegetation type is Mixed Bushveld dominated by the red bushwillow (*Combretum apiculatum*), common hook-thorn (*Acacia caffra*), sickle bush (*Dichrostachys cinerea*), live-long (*Lannea discolour*) and marula (*Sclerocarya birrea*) (Low & Rebelo, 1996). Where the soil is more clayey, Clay Thorn Bushveld occurs which is dominated by *Acacia* species (Low & Rebelo, 1996). The area has been historically used for cattle (*Bos taurus*) ranching and the bush is encroached over a large portion of the district (K.M., pers. obs). There are some previously ploughed areas that have since been left fallow. The edges between these areas and the surrounding more dense, bushy areas are generally hard and linear.

The annual, mainly summer, rainfall for the study area varies from 350 mm to 650 mm per year with temperatures ranging from –8°C to 40°C with an annual mean of 21°C (Low & Rebelo, 1996). Human population density is low at 2/km^2 (Statistics South Africa (2001) www.statssa.gov.za accessed on FUNDISA Disk).

Cheetah capture

Cheetahs were trapped from September 2003 to July 2009 using double-door box traps along frequently walked fence lines, at scent marking posts and using live bait. For more detailed information on trapping procedure see Marnewick & Cilliers (2006). Trapped cheetahs were immobilized by a wildlife veterinarian and fitted with tracking collars. All activities involving cheetah handling and research were done under a University of Pretoria Animal Ethics Committee permit (No. EC030-09) and permits issued by the Limpopo Department of Economic Development, Environment and Tourism (the local government conservation authority).

If coalitions were caught then only one member of the group was collared as this group structure is normally stable and these males can be expected to remain together (Caro, 1994). Initially VHF collars (African Wildlife Tracking, Pretoria, South Africa) were fitted and the cheetahs monitored by microlight aircraft. Once the technology was available and affordable, GPS/GSM collars (African Wildlife Tracking, Pretoria, South Africa, and Hot Group, Pretoria, South Africa) were used to obtain more robust data and set to take two to four GPS locations per day; 12:00 and 00:00 for the collars set for two daily locations, and with 06:00 and 18:00 included for the collars with four daily locations. The cheetahs were allowed to recover from immobilization in the trap cage and once fully recovered, were released at the site of capture. Cheetahs were monitored for the extent of their life or the life of the collar. On two occasions, the collars were replaced due to deteriorating batteries by darting the cheetahs from a helicopter. Three female and six male cheetahs were collared. Four of the males were singletons, one from a collation of three and one from a coalition of two, resulting in nine monitoring units (Fig. 1). None of the females had cubs or showed any signs of lactation.

Trapping success was low with approximately 278 trap days required to trap a cheetah, or monitoring unit. Cheetahs were monitored from 28 days to 2119 days depending on the life of the cheetah or the collar (see Table 1). The two male (AM196) and three male (AS68) coalitions were initially monitored using VHF collars resulting in 56 (2.8% of total) and 12 (8.6% of total) data points being obtained, respectively.

Data analysis

Local Convex Hulls (αLoCoH) (Getz & Wilmers, 2004; Getz, Fortmann-Roe, Lyons, Ryan & Cross, 2007) were used to determine home range sizes, using the computer programme R v 2.10.1 (The R Foundation http://www.R-project.org/). Utilization distributions (the two-dimensional distribution of the position of an animal (Worton, 1989) were considered at two spatial scales where 50 utilization distributions represented core areas and 95 utilization distributions represented total ranges. K, the number of nearest neighbour points used to construct local hulls to obtain a utilization distribution, was calculated using the square root of the total number of data points per animal (Getz *et al.,* 2007).

LoCoHs have been shown to outperform kernels and provide a more accurate representation of the animals' home range, especially in areas with hard boundaries (Getz *et al.,* 2007). Minimum Convex Polygons (MCP) (Jenrich & Turner, 1969) (Hawth's Analysis Tools ARC GIS V 3.27 2006; www.spatialecology.com/htools) were determined and used to allow for comparison with other studies, because the method is widely used (Harris *et al.,* 1990). For area calculations, the data were projected into UTM. Home range size using MCPs was plotted against sequential GPS locations in the software package Abode Beta V2 (Laver, 2005; http://fishwild.vt.edu/abode/abodeweb.html) to visually determine if home ranges reached asymptotes. Relationships between male and female home range sizes, maximum distances moved and proportion between total and core ranges were tested using appropriate statistical tests.

RESULTS

Fate of the collared cheetahs

Two of the females were shot by landowners and one was killed in a road accident. The coalition of three males was shot as was one of the single males, the coalition of two died from what appeared to be natural causes, three single males have unknown fates as the collar downloads stopped. They either died and the collars were destroyed, were out of cell phone reception, or the collars malfunctioned. Five of the nine collared cheetahs died due to anthropogenic causes.

Home range sizes

The home range sizes of all females reached an asymptote. Male home ranges appeared to be larger than female ranges but they did not all reach asymptotes (Fig. 2) and these differences were not significant for the MCP ($t_{(7)} = -0.8$, $P = 0.22$), 95UD ($t_{(7)} = -0.7$, $P = 0.46$) or 50UD ($t_{(7)} = 0.77$, $P = 0.23$). Male 95UDs ranged from 121.5 km^2 to 607 km^2 while females ranged from 14.7 km^2 to 703.3 km^2 (Fig. 3a). The 50UD (Fig. 3b) as a percentage of the 95UD was 18% for females, 10% for males and 12% across all sexes. There was no significant difference between the maximum distances between points for males and females ($t_{(7)} = -1.14$, $P = 0.15$).

DISCUSSION

Owing to the low trapping success of 278 trap nights per cheetah, our sample size was low. The data collected did not allow for analysis of sea-

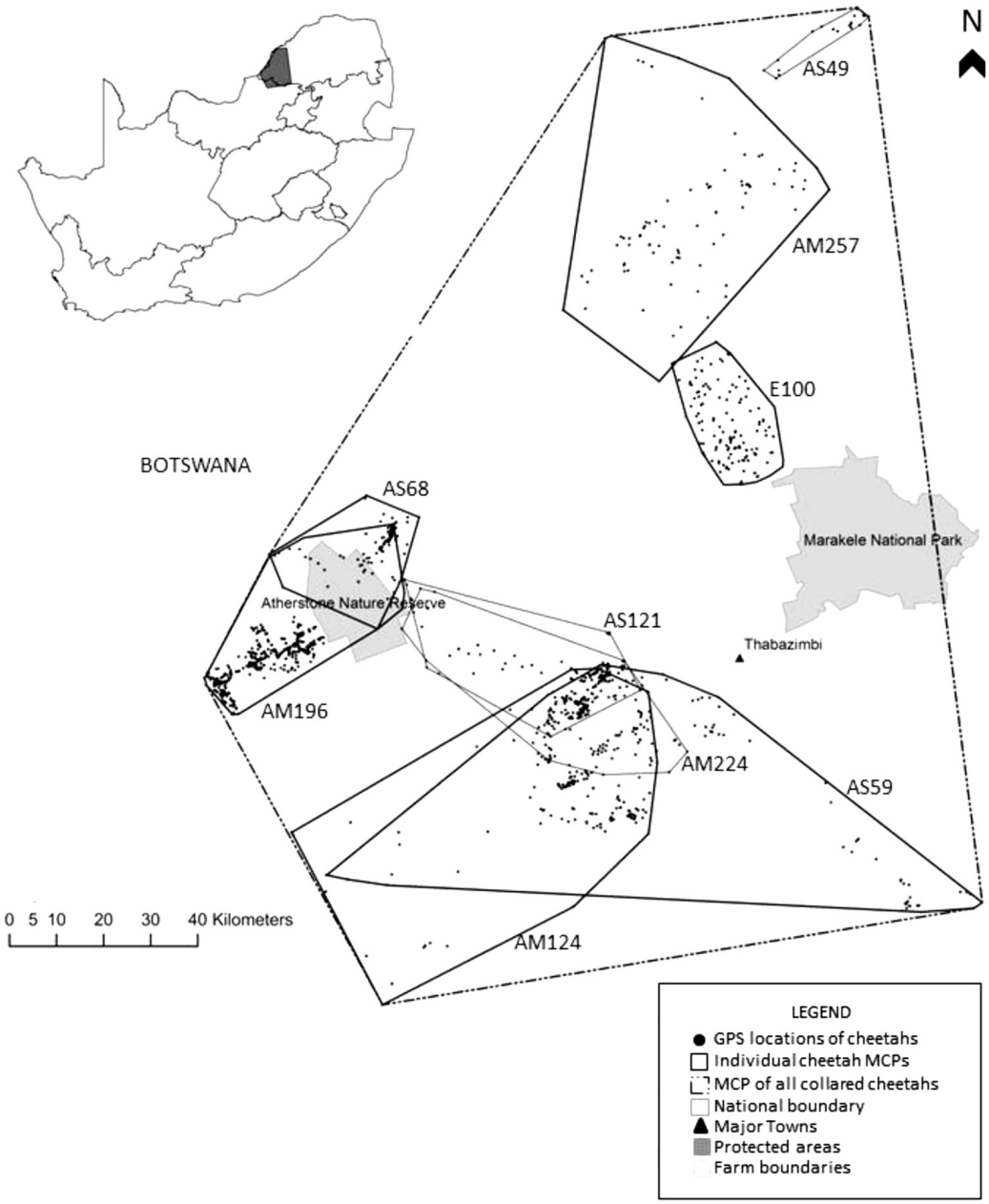

Fig. 1. The study area in Limpopo province, South Africa, where free-roaming cheetahs were collared. MCPs for each cheetah are shown along with protected areas, farm boundaries and major towns.

sonal range use as only the coalition of two males were monitored for longer than one year. However, this study is still valuable in assessing cheetah movement in a ranching area and provides new information to assist conservation practitioners in conflict mitigation and conservation researchers on the effort required to derive robust home range estimates for cheetahs (*c.* 343 locations).

Cheetahs in Thabazimbi have large home ranges similar to cheetahs outside protected areas in other southern Africa countries. All studies on cheetahs outside protected areas show larger home ranges than cheetahs in the Kruger National

Table 1. Details of cheetahs collared on livestock and wildlife ranches in the Thabazimbi District, Limpopo province, South Africa.

Animal ID	Social	Sex	Date start	Date end	Fate	No. days	No. locations	95UD	50UD	MCP	No. Hulls	k-value	Max distance between points (km)
AS59	Single	Male	2006/08/03	2006/10/13	Shot	71	150	607.0	86.6	2761.8	12	18	122
AM124	Single	Male	2006/07/14	2007/03/21	Unknown	250	394	506.2	42.0	2172.0	20	70	76
AM224	Single	Male	2007/06/15	2007/10/16	Unknown	123	43	314.2	44.8	824.2	7	18	57
AM257	Single	Female	2007/05/18	2007/11/15	Road kill	181	90	703.3	102.0	1717.3	9	12	65
AS49	Single	Female	2007/12/12	2008/01/09	Shot	28	31	14.7	0.2	61.1	6	10	21
AS68	Coalition of three	Male	2004/05/03	2008/02/09	Shot	1377	140	171.2	4.2	367.1	12	30	28
E001	Single	Female	2007/09/20	2008/04/17	Shot	211	167	183.23	56.485	315.6	13	16	28
AS121	Single	Male	2008/07/04	2008/11/21	Unknown	140	196	192.0	11.7	631.0	14	30	48
AM196	Coalition of two	Male	2003/09/18	2009/07/07	Dead – natural	2119	1954	121.5	0.0	662.0	44	60	45
Averages standard error presentedin brackets													
Males	Males	Males	2003/09/18	2009/07/07		680 (± 352)	96 (±68)	318 (±80)	32 (±13)				
Females	Females	Females	2007/05/18	2008/04/17		140 (±57)	480 (±299)	300 (±207)	53 (±29)				
All	All	All	2003/09/18	2009/07/07		500 (±245)	352 (±203)	312 (±79)	39 (±13)				

k-value: The number of nearest neighbours minus one out of which convex hulls were created.
UD: Utilization distribution.
MCP: Minimum convex polygon.

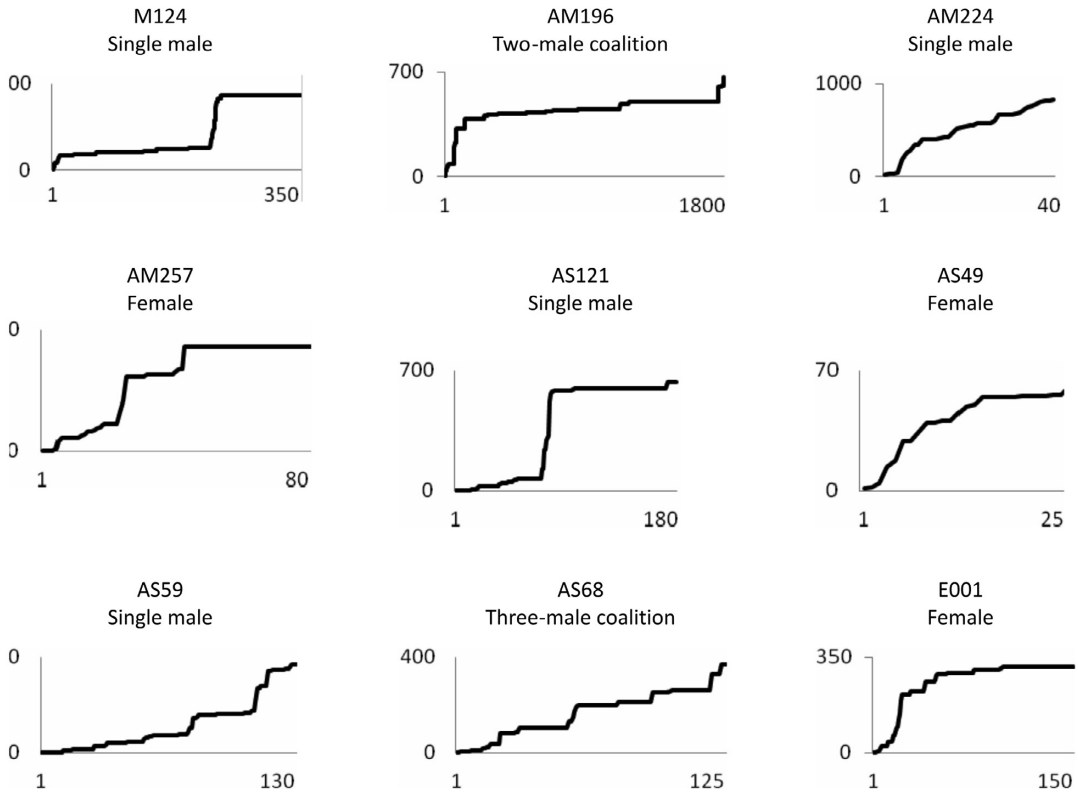

Fig. 2. Cheetah home range sizes measured over time. *Y*-axis denotes the size of the home range in km^2 and the *x*-axis denotes the number of GPS locations used in the analysis.

Park (Fig. 4). Home ranges were generally larger than the average ranch size of 18 km^2, with the average 95UD for all cheetahs covering approximately 18 properties. The average area of 12% of core utilization in relation to the 95UD in this study comprised similar percentages to those found in other studies in southern Africa: Namibia (average 13.9%; Marker, Dickman, Mills, Jeo & Macdonald, 2007), Botswana (males 11%, females 10%; Houser, Somers & Boast, 2009) and Kruger (average 13%; Broomhall, Mills & du Toit, 2003) (Fig. 4), despite the large variation in home range sizes recorded between the studies. The reason for this is unknown and warrants further investigation.

The average size of the 50UDs for all cheetahs in this study was 42 km^2 (Table 1) and is more than twice the size of the mean property size in the study area. The largest MCP was 2761.8 km^2 for a male cheetah, this cheetah also had the second largest 95UD of all cheetahs. This is probably because he was a young male and dispersing from his maternal range. He moved over a large area and was eventually shot *c.* 78 km from the capture site. The coalition of two males had a very small 50UD, this was centred on a property that had a large area of relatively open vegetation where plains game congregated at an artificial feeding site. The landowner of the property in which the 50UD was focussed was fortunately cheetah friendly (K.M., pers. obs) and some anti-predation measures were taken to prevent excessive damage to the prey population. Predator-proof camps were constructed for a breeding project for expensive antelope breeds; these camps would have been constructed regardless of the cheetahs' presence to eliminate predation by other carnivores. The camps did present a problem in the form of small artificial watering point outside one of the camps. Antelope would congregate around the water point and the cheetahs chased the herds into the fence on a few occasions. This resulted in several antelope being injured and the fence getting damaged. This was finally resolved by closing the small water point.

The two-male coalition was the longest moni-

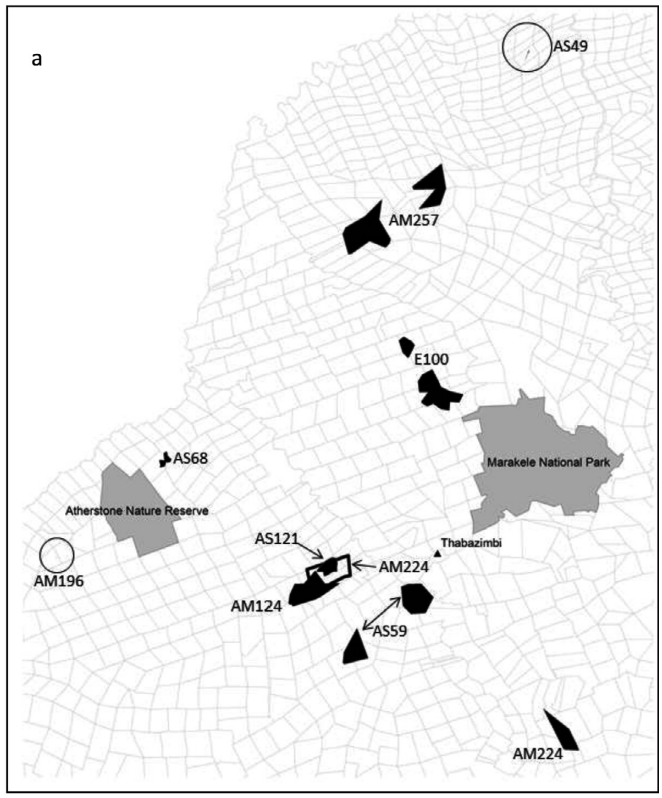

Fig. 3. **a & b**, Fifty utilization distributions and 95 utilization distributions for cheetahs on livestock and wildlife ranches in the Thabazimbi district, Limpopo province. (Continued on p. 230.)

tored in the study and while their home range appeared to reach an asymptote, the last few GPS fixes showed an increase in the range size. This could be explained by the death of the coalition partner which has been shown to result in an increase in range by the remaining cheetah (Caro, 1994; Marker *et al.,* 2007).

Cheetahs did not limit their movement to one individual property and moved over large areas as is generally typical for cheetahs in savanna habitats. This is despite the estimated high abundance of food and water, sedentary prey and the lack of intra-guild competition. The large home ranges of cheetahs in the Serengeti (>800 km^2 females and > 777 km^2 males; Caro, 1994) and the Kalahari (>320 km^2; Mills, 1998) could be due to prey mobility; while the smaller ranges in Matusadona (<100 km^2) could be due to prey congregating on the foreshore grassland (Purchase & du Toit, 2000). However, patchy distribution of suitable hunting habitat could drive large range use, and especially in felids, suitable hunting habitat may influence range size more than prey availability (Kruuk, 1986). Cheetah movements in woodland areas are influenced by the search for more open habitat suitable for hunting (Hunter, 1998). This could be the case in Thabazimbi as the bush is dense and open areas are scarce. The areas where the male coalitions centred their movement were previously ploughed, open grassland habitats in contrast to the hard boundaries of the surrounding densely wooded areas (pers. obs).

With the data available and no data on prey numbers and distribution, it is not known what drives the large range use of cheetahs in Thabazimbi. However, this study does provide useful information on the movement of cheetahs and shows that generally, cheetahs do not limit their movement to one property, thus causing excessive damage to the prey base on individual properties. However, there may be cases, like the two-male coalition, where cheetahs do have small areas of core utilization that could result in escalated conflict.

The patchy distribution of hunting habitat could also explain why cheetahs outside protected areas have larger ranges than cheetahs in Kruger.

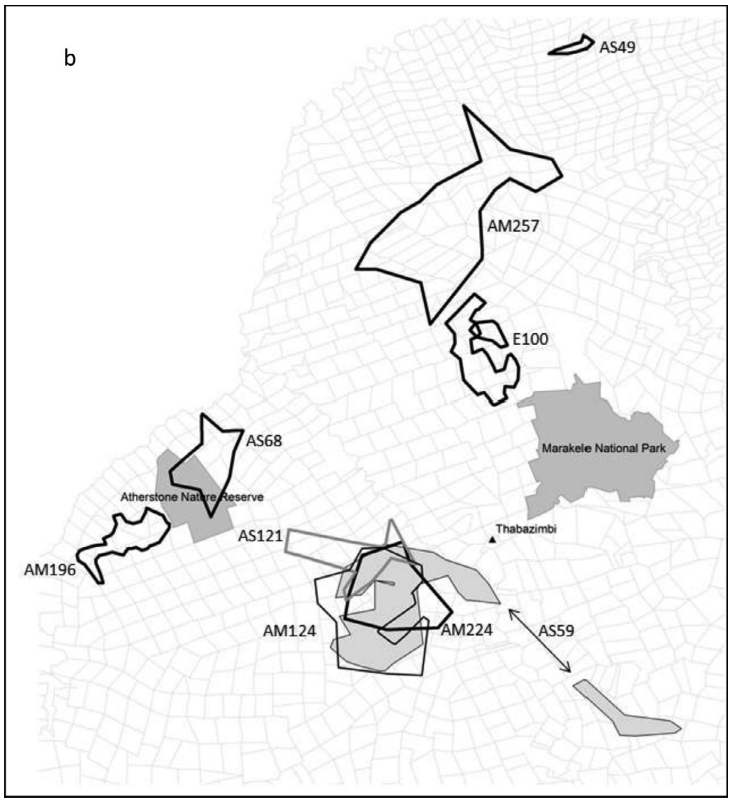

Fig. 3 (continued).

Ranching areas are prone to being over-utilized for long periods of time and, as a result, the vegetation becomes encroached. This makes more open areas sought after as hunting habitat for cheetahs. Additionally, cheetahs outside protected areas are affected by human disturbance that could require them to move larger distances to avoid conflict (Houser *et al.,* 2009). It is likely that the large ranges of cheetahs outside protected areas are driven by the search for suitable habitat in an

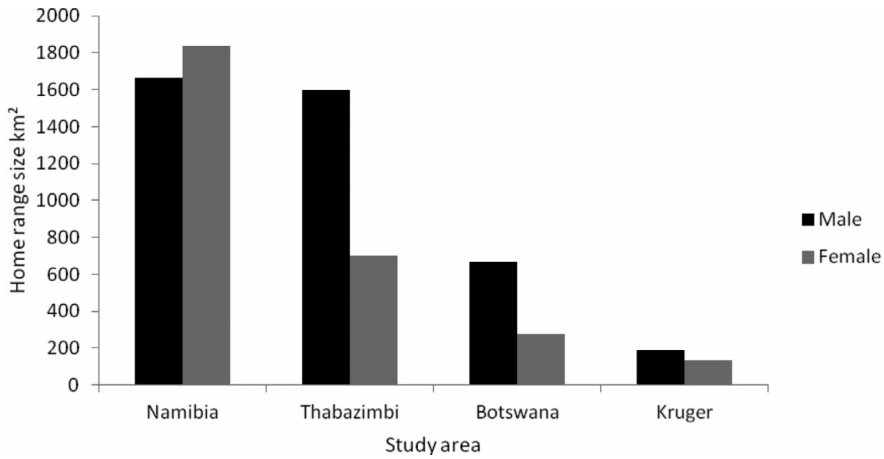

Fig. 4. Comparison of mean male and female cheetah home ranges sizes across study areas in southern Africa. Namibia (Marker *et al.,* 2007), Botswana (Houser *et al.,* 2009) and Kruger (Broomhall *et al.,* 2003) using 95MCPs and Thabazimbi using MCPs.

encroached environment and by human avoidance where cheetahs in Kruger have other range use drivers.

In this study, 44% of the collared cheetahs were shot by landowners while in Botswana 55% of collared cheetahs were shot (Houser *et al.,* 2009). These high levels of persecution highlight the need for effective conflict mitigation projects outside protected areas as high levels of human-induced mortality could outweigh the advantages of a lack of intra-guild completion and a plentiful food and water resource. Most of southern Africa's cheetah population and distribution range occurs outside protected areas with approximately 22% (25 8264 km^2 of 1 170 479 km^2) of cheetah range being protected and 23% (1460 of 6260) of cheetahs occurring inside protected areas (IUCN/SSC, 2007), conflict can pose a significant challenge to the survival of the species.

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