The Spatial Ecology and Activity Patterns of Leopards (*Panthera pardus*) in the Baviaanskloof and Greater Addo Elephant National Park (GAENP), Eastern Cape Province, South Africa

A thesis submitted in fulfilment of the requirements
for the degree of

MASTERS IN SCIENCE
of
RHODES UNIVERSITY

by

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January 2009

ABSTRACT

The conservation of leopards in the Eastern Cape Province requires a holistic approach that considers both predator-human interactions as well as the biology of the carnivore. Numerous studies have been conducted on leopards within protected areas; however more information regarding the species is needed outside these areas to facilitate effective management of predators. The spatial ecology of the leopard (*Panthera pardus*) were studied in the Baviaanskloof and GAENP in the Eastern Cape.

The Baviaanskloof is an extensive area of mountainous terrain (approximately 2665km²) which has a mosaic of land uses, and leopards move from conservation areas to farmland where they come into contact and conflict with farmers. This study examined the spatial ecology of leopards living on farmlands adjacent to protected land. The space utilization and activity patterns of six leopards were analysed. These animals were caught and released on farmlands in the Baviaanskloof (n=4) or translocated (n=2) when not possible to release on site. The animals were caught by means of fall-door, walk-in traps and fitted with Vectronic GPS collars that facilitated the collection of high quality GPS fixes from each animal. Data was collected using VHF and UHF telemetry to download data. An understanding of spatial requirements in areas with different land use, and the extent of overlap of space use with other leopards allow, for the first time in the region, the calculation of possible maximum population size. Analysis of range size was carried out using two methods: minimum convex polygon, and Kernel Utilization Distribution.

Finally, a key predictor of space use is prey availability. I assessed the prey base using a grid of camera traps. The studied leopards revealed large range utilization with minimal overlap. The activity patterns suggest there is no preference between diurnal and nocturnal activity patterns and the population density was estimated between 0.3 – 1.3 leopards per 100km². Large home range sizes and low population densities suggest that leopards require large areas of suitable habitat, and that conservation efforts need to be extended beyond protected areas to ensure the long-term viability of leopard populations in such areas.

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ACKNOWLEDGEMENTS

A world of gratitude goes to the Landmark Foundation and the driving force behind it, Dr. Bool Smuts, for initiating and implementing a conservation project which facilitates the conservation of biodiversity within and outside of protected areas. He put blood sweat and tears into the project and gave me the opportunity to do something I love, thank you. Sincere thanks to Prof. Ric Bernard at Rhodes University for all of his time, guidance and effort during the preparation of this thesis. Important role players are the private landowners who thought we were nuts to release a leopard back on their land, but let us do it anyway. We have all learned a great deal from this well rounded and important project and have beaten the odds. Several landowners assisted in checking the traps on a daily basis and were always willing to assist with practical tasks and hosting me. This project was expensive to undertake and much gratitude goes to all sponsors these include Niels Wøldiche Pedersen and the Henry and Iris Englund Foundation, Polaris Capital, Deutche Bank, Vodacom Foundation, Woolworths Trust, Pick n Pay, Ackerman Family Foundation, Royal Canin, NSPCA, Ethics and Organics, Port Elizabeth Agricultural Society, NSPCA, Edge Financial Group and Travel Unite. A lot of time was spent in the air, thanks to Johan and Alma Swart for assisting me to download data from the air with their R44 Chopper, John Adendorf of SANParks assisted to download data by air using a Bantam aircraft and Brendan Tindall in his Jarabu fixed-wing aircraft. All ten of the vets who donated their time when needed even at 3 in the morning, especially: Brendan Tindall, Ross Kobus, Martin Botsma and Lucy Runnalls.

The section ranger of Darlington Dam of the GAENP, Riaan Nel and rangers Peit and Francois at Darlington Dam Section. Alan Southwood of Kazuko in the GAENP for his assistance and excitement for the project. Gerrie Ferrera and the rest of the team at the DEADA Office in Aston Bay have supported the project from its offset. Prof. J. du P. Bothma for his encouragement and constructive input into the research findings. I sincerely thank them all.

PREFACE

This thesis is structured as follows:

Chapter 1 is a general introduction that provides a broad understanding about the study. However, it does not serve to introduce the major research chapters. These chapters each have their own introduction and aims.

Chapter 2 provides a detailed description of the study site, and general methodology used throughout the study.

Chapters 3, 4 and 5 presents the major results of the study and each chapter has its own introduction, methods, results and discussion.

Chapter 3 examines the space use and habitat requirements of free ranging leopards in the Baviaanskloof mountains.

Chapter 4 addresses the possible population density of free ranging leopards in the region of focus.

Chapter 5 presents results of activity patterns of leopards, temporally and spatially.

Chapter 6 is management implications and general discussion as a result of the results derived from the research.

References are presented together and not for each chapter.

Appendix A: Morphological Data Capture Sheet.

Appendix B: Common and scientific names of mammalian species identified from camera traps and tracks and signs in the GAENP and Baviaanskloof.

Appendix C: A survey form to obtain economic feasibility of holistic husbandry practises.

The Spatial Ecology and Activity Patterns of Leopards (*Panthera pardus*) in the Baviaanskloof and Greater Addo Elephant National Park (GAENP), Eastern Cape Province, South Africa

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CHAPTER 1:

GENERAL INTRODUCTION

The leopard (*Panthera pardus* Linnaeus) like other felid species, is considered critically endangered in some parts of its range and, ironically, considered a pest in some others (Sunquist and Sunquist 2002). Leopards are the most widespread of the large felids (Myers 1986; Marker and Dickman 2005), with ranges in Africa and Asia and relict populations in the Middle East and south-eastern Europe (Hunter *et al.* 2003). The wide range is largely due to the leopards highly adaptable hunting behaviour and diet and ability to survive in different habitats (Mizutani & Jewell 1998; Bertram 1999; Sunquist and Sunquist 2002; Bothma and Bothma unpublished). Throughout much of its range, it is the last free-ranging large carnivore, occupying inhospitable regions with low human populations (Sunquist and Sunquist 2002). This is one reason why the leopard deserves management attention (Mills 1991). The leopard is not presently considered endangered in sub-Saharan Africa (Marker and Dickman 2005) but populations are threatened by persecution by local people, habitat destruction and fragmentation (Woodroofe and Ginsberg 1998). In South Africa, leopards are widely distributed, except for the greater Karoo basin (Friedman and Daly 2004). The Kruger National Park and surrounding private reserves appears to have the largest leopard population with numbers exceeding 1000 individuals (Bailey 1993). The Kgalagadi Transfrontier Park have an estimated population of 150 individuals (Daly *et al.* 2005), and within the private and public reserves in Kwa-

Zulu Natal (Daly *et al.* 2005) and Limpopo the species population is considered viable and widespread.

Leopard were present in the Cape Fold Mountains in the Western Cape when the European settlers arrived (Stuart *et al.* 1985), and population clusters have been detected in the mountain and forested areas of the Eastern Cape (Daly *et al.* 2005; Current study). This range of habitats illustrates that they can live under widely varying conditions and the species is considered to be the most adaptable large carnivore in the world (Easton 1978. Leopards have a well developed ability to cross fences and, their extensive ranges, often occupy a mosaic of habitats ranging from game reserves to farmlands (Mizutani and Jewel 1998). This diversity of habitat is matched by a diversity in the diet and leopards are considered to have the broadest diet of larger predators with 92 prey species recorded (Mills and Harvey 2001; Hayward *et al.* 2006). Although the secretive nature of the leopard makes studies of biology and behaviour difficult, a number of studies have reported on range size and habitat requirements. Range size and overlap varies in different habitats depending on a variety of factors including resource availability (Baily 1993; Mizutani and Jewell 1998; Marker and Dickman 2005; Bothma and Bothma unpublished). Investigating the underlying factors affecting spatial utilization is fundamental to understanding leopard ecology, and is required for the successful management and conservation of the species, and this is the focus of chapter three. Other aspects of their biology, ecology and behaviour are poorly known.

The low conservation status of the leopard in South Africa (Friedman and Daly 2004) does not reflect the true situation. Although protected areas play an important role in the conservation of leopards, only an estimated 8 % - 13 % of leopard habitat is in national protected areas, while the remaining 87 % - 92 % is privately owned (Martin and de Meulenaar 1988; Boitani *et al.* 1999). This problem is exaggerated (Mizutani and Jewell 1998) by the fact that leopards cross most fences and thus move between conservation areas where they are protected an adjacent public land in which the leopards may be considered a problem (Balme 2007).

Although leopards have displayed a resistance to human pressure, probably as a result of their adaptability, they are considered to be the most persecuted large felid species in the world (Hunter *et al.* 2003). They often survive in close proximity to humans, however reduced prey base, poisoned baits carnivore control, the fur trade and direct conflicts with people due to livestock predation have dramatically reduced leopard populations (Nowell and Jackson 1996; Sunquist and Sunquist 2002). In the early 1970's global concerns regarding the over-exploitation of spotted cats for fur products led to the leopard being added to the protected species list in South Africa (Ordinance No.19 of 1974) (Esterhuizen and Norton 1985). The persecution of leopards has led to listing the species on Appendix 1 of the Convention of International Trade of Endangered Species of Wild Fauna and Flora.

However, in South Africa, leopards continue to be killed and, according to the Department of Environmental Affairs and Tourism, between 2004 and present, 28 have been killed to date in a small part of the Eastern Cape of South Africa alone.

Conservationists recognise that protecting the land and ecosystems is the best way to conserve a species (Gavashelishvili and Lukarevskiy 2008). However, the protection of land often takes along time and depends largely on the political and social climate. Previous studies of the spatial ecology of leopards have been concentrated in protected areas (see Marker and Dickman 2005) when more than 80% of the potential range of the leopard is outside protected areas (Mackinnon and Mackinnon 1986; Martin and de Meulenaar 1988; Boitani *et al.* 1999). Thus, there is a need for further research on which the management of free-ranging leopards outside of protected areas can be based. This is the topic of the present research.

The Baviaanskloof study site is an extensive area of approximately 2665km² of mountainous terrain that is large enough to play an important role in the conservation of free-ranging leopards. It falls under a range of land uses including agriculture and conservation and holds an unknown number of leopards. Reports of leopards killing livestock on farms neighbouring the Baviaanskloof Conservation Area are numerous and a number of leopards have been trapped and removed from the area.

This study focused on aspects of the spatial ecology and conservation of leopards and had five specific aims:

1. to establish the home-ranges and core areas of leopards in the Baviaanskloof;
2. to explore factors affecting range size and space use including vegetation type, distance from rivers and roads, and prey abundance;

3. to establish the activity patterns and ranging patterns of leopards and
4. to establish the population density of leopards within the Baviaanskloof,
5. Finally, to explore alternatives to the lethal control of leopards.

CHAPTER 2:

STUDY AREA AND GENERAL METHODS

LOCATION

The research was undertaken in two areas in the Eastern Cape Province of South Africa: Baviaanskloof and the Greater Addo Elephant National Park (GAENP) (Figure 2.1). The Baviaanskloof is a long (85 km), relatively narrow conservation area that extends from (33°27') in the West, to (23°24') in the East. It stretches from Uniondale in the west to Patensie in the east (Figure 2.1). The area encompasses a wide diversity of landscapes and land uses, reflecting the regions high geological, topographic and climatic variability. It is characterised by rugged mountainous terrain, with high peaks interspersed with plateaux, steep valleys and few flat valley floors (Ott *et al.* 2007).

The GAENP extends from the coast south-east of Port Elizabeth northwards into the karroo (Figure 2.1). The park is approximately 3650km² (365 000ha) in size and is broken up into 8 different sections. The research was undertaken in the Darlington Dam and Kazuko contractual park sections of the GAENP (Figure 2.1). Formerly known as Lake Mentz, the Darlington Dam supplies irrigation water to the Sundays River Valley in the Eastern Cape Province. The eastern side of the Darlington Dam section of GAENP has expanded with a contractual agreement with the private Kazuko Game Reserve making up 280km². The GAENP was established in 1931 with an area of approximately 25km². The Darlington dam section was bought by South African National Parks between 2002 and 2005. It was previously farmland for small livestock, particularly goats.

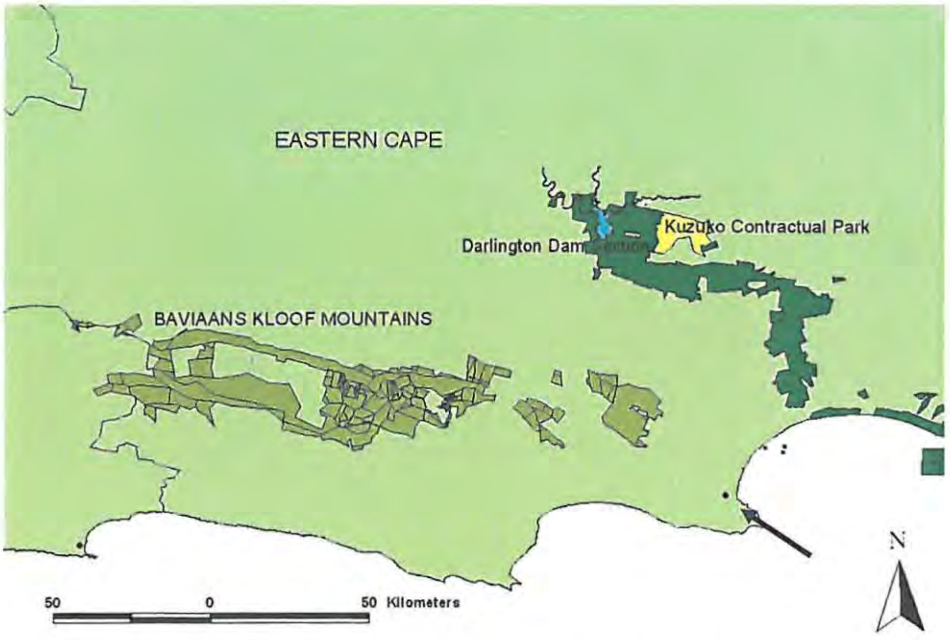


Figure 2.1. Map showing the location of the two study areas. Baviaanskloof (brown) and the GAENP (dark green). The Darlington Dam (blue) and Kazuko section of the GAENP (yellow). The arrow points to the city of Port Elizabeth.

GEOLOGY

The Baviaasnkloof forms part of the Cape Fold Belt Mountain range and most of the area lies at altitudes exceeding 900m above sea level, with the highest peaks reaching 1758m above sea level such as the Cockscomb, Smutsberg and Kougakop peaks (Rust 1998). The valley floors are below 500m altitude. The main components include quartzite, sandstones and shale of the Table Mountain and Bokkeveld Groups of the Cape Supergroup, and Enon conglomerate (Figure 2.2) are present in places (Rust 1998). The geology of the Darlington Dam section and Kazuko comprises glacial Dwyka Group tillites, with tillite deposits present along the northern edges of the Zuurberg mountain range and along the southern shores of Darlington Dam.

These deposits are referred to as the Dwyka Group rocks of the Karroo Supergroup. The Dwyka Group is overlain by the Ecca and Beaufort Group rocks, of the Karroo Supegroup. These are of fluvial origins and the only Koonap Formation of the Beaufort Group occurs within the northern fringes of Darlington Dam (Rust 1998).

Figure 2.2 An example of an Enon Conglomerate, created as a result of erosion of the mountains which produced thick sediments in the fault basins, and are represented in the Baviaanskloof area.

CLIMATE

The annual total precipitation for the Baviaanskloof varies from 300mm in the west to between 500–700mm in the east, with a higher proportion of summer rainfall (Teague *et al.* 1989). The maximum daily temperatures often exceed 35°C in the summer months (December, January and February) and minimum night-time temperatures below 5°C in the winter months (June, July and August) and frosts are rare (Figure 2.3). Rainfall is highly variable but peaks of rainfall occur from September to November and January to April (Figure 2.4).

The range in elevation of the Zuurberg Mountains on the southern boarder of Darlington Dam has a marked effect on rainfall patterns within the area. Lower elevation areas experience higher mean annual temperatures as well as lower mean annual rainfall, resulting in a hot semi-arid environment. Higher elevation areas have lower mean annual temperatures and higher mean annual rainfall figures, thus resulting in a cooler wetter environment. Aspect and slope causes further variations in the climate as southern slopes experience cooler more moist conditions, while north facing slopes are characteristically warmer and drier (Stone *et al.* 1998). Darlington has a warm temperate climate with maximum daily temperatures often exceeding 35°C in the summer months (December, January and February) and minimum night-time temperatures below 5°C in the winter months (June, July and August) (Figure 2.5). Rainfall is highly variable but peaks of rainfall occur from September to February (Figure 2.6).

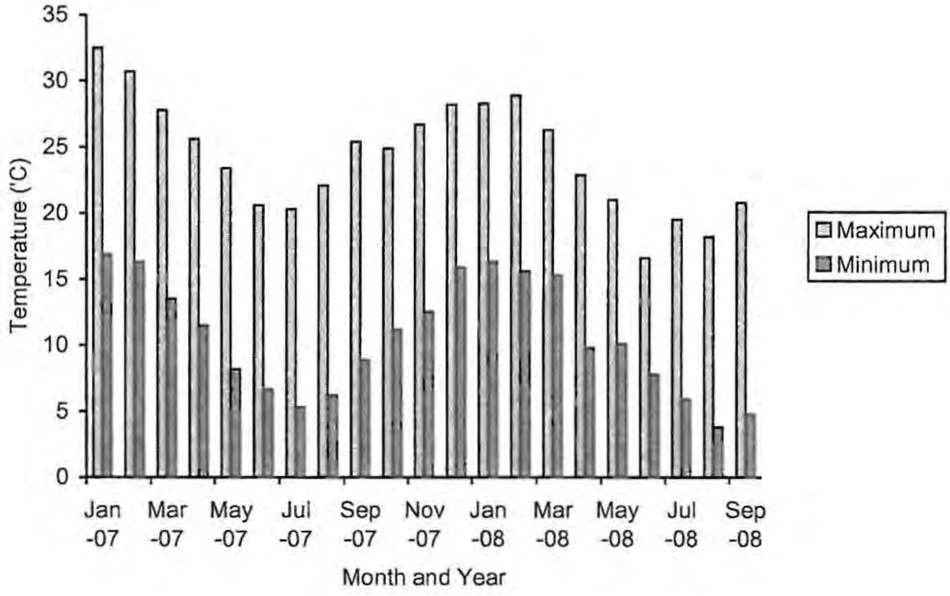


Figure 2.3 Monthly average minimum and maximum temperatures (°C) in the Baviaanskloof.

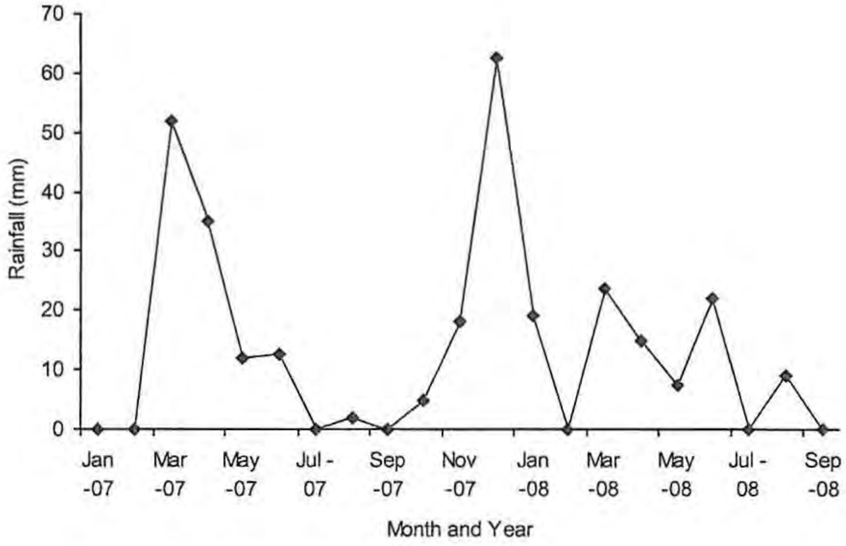


Figure 2.4 Total monthly rainfall for the Baviaanskloof.

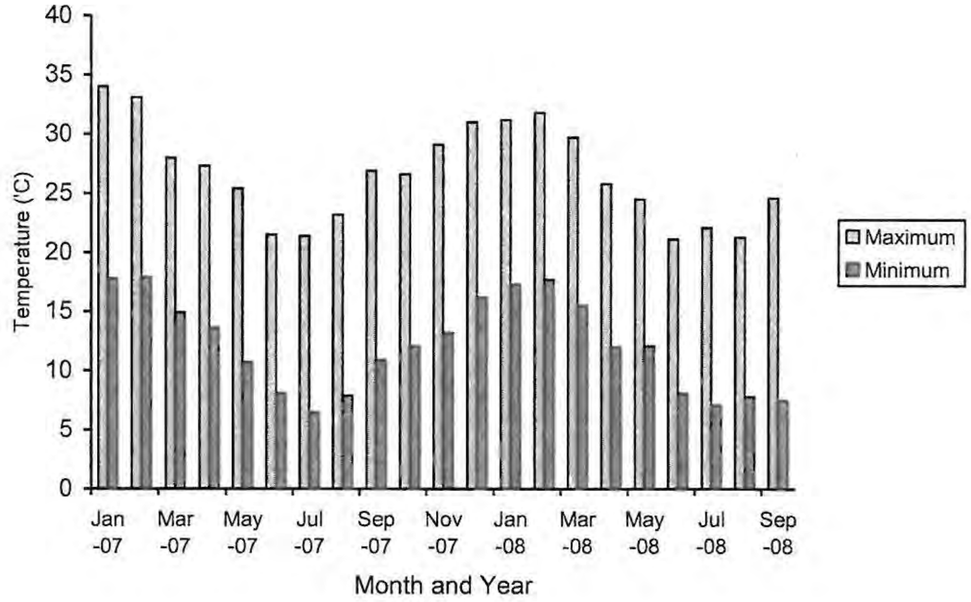


Figure 2.5 Minimum and maximum temperature (°C) for Darlington Dam Section of the GAENP.

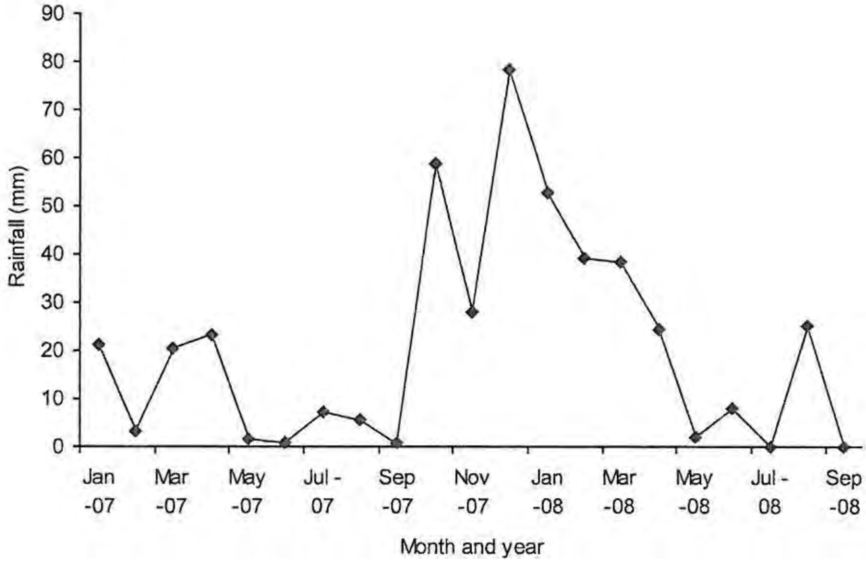


Figure 2.6 Total monthly rainfall for Darlington Dam Section of the GAENP.

VEGETATION

The Baviaanskloof is characterised by a mosaic of numerous vegetation types including (thicket types, fynbos, forest, and mosaics such as transitional thicket) (Figure 2.7). The area is dominated by fynbos on the plateaus, thicket types, and karoid vegetation types are found in the north and west of the Baviaanskloof Mountain Range (Boshoff *et al.* 2000). Plant communities are rich in species and do not show species dominance that is more typical of subtropical and tropical vegetation, except where vegetation is highly modified. The vegetation types found within the study area are based on the biome map of Low and Robelo (1996). All of the major biomes of South Africa except true desserts are found in the region of focus and will be described briefly below. The privately owned rangelands incorporate fruit orchards and irrigation-based crop production, and pastoralists focus on small stock (sheep and goats) with some cattle. Wild extralimital ungulates, which were introduced by game ranchers, are also present (Boshoff *et al.* 2000).

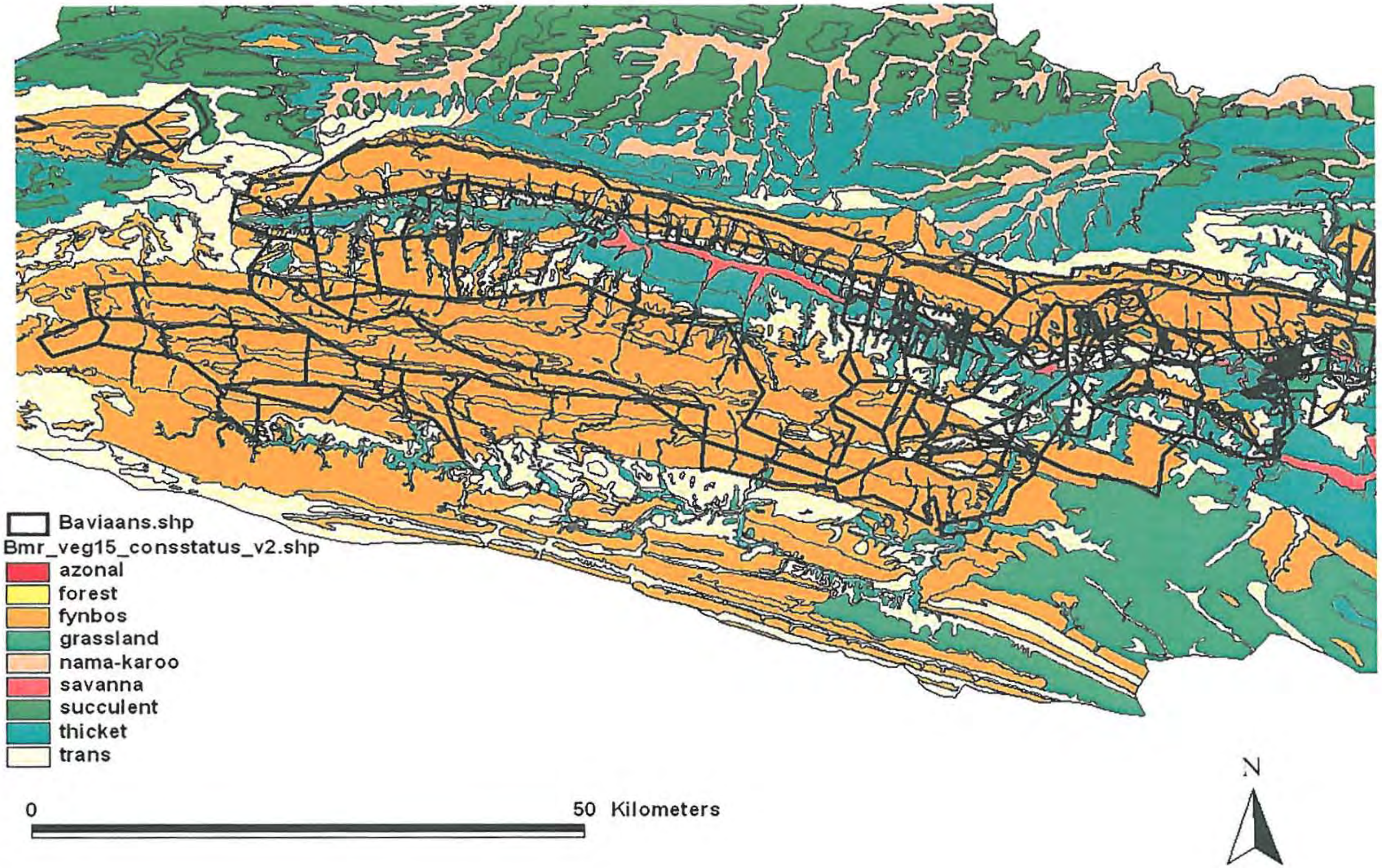


Figure 2.7 Vegetation Map of the Baviaanskloof Region (Black boarder indicates protected land).

The Darlington Dam section of GAENP is dominated by Nama Karroo on the northern plateaus offers little cover and is comprised of shrubs and grasses and Subtropical Thicket vegetation types are present on the southern mountainous areas offering cover and are dense in structure (Figure 2.8).

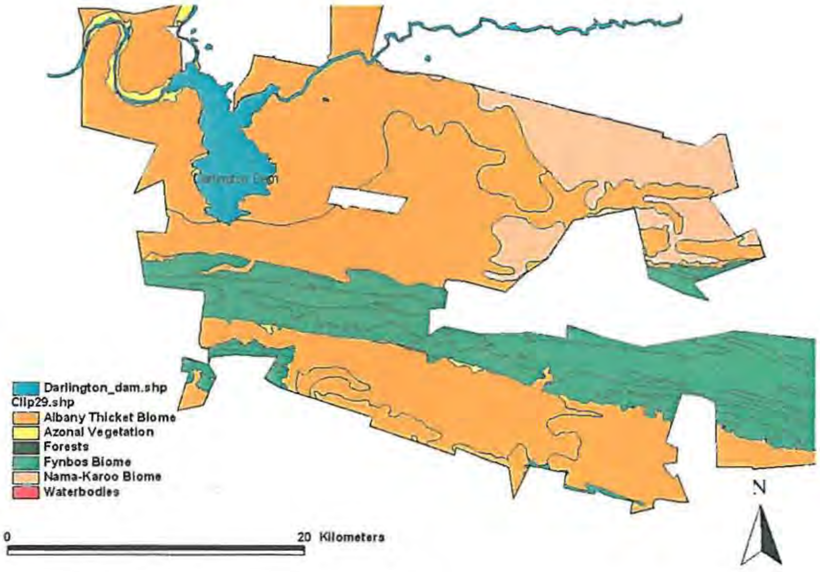


Figure 2.8 Vegetation map of the GAENP.

Subtropical Thicket / Albany Thicket

Thicket is a closed shrubland dominated by evergreen succulent trees, for example *Portulacaria afra* (Spekboom), shrubs and vines with the canopy rarely exceeding 3m in height (Manning 2001). However these thickets may reach forest proportions in sheltered areas or under optimal conditions. The vegetation type is dense and offers rich nutrient species for herbivores and sufficient cover (Figure 2.9).

Figure 2.9 Subtropical Thicket grown in a fertile, fire-protected valley near Cockscomb. *Portulacaria afra* shrub surrounded by *Aloe* spp. and some evergreen shrubs offers dense cover for mammals.

Fynbos

This is a shrubby complex of species such as proteaceous plants, ericas and restiods found on nutrient-poor soils. The fynbos component of the vegetation is characterized by the dominance of evergreen sclerophyllous shrubs (Teague *et al.* 1989). Grasses are largely absent, while restiod and ericiod elements are invariable and proteiod shrubs (e.g *Leucadendron salignum* and *Protea cynaroides*) are common (Figure 2.10). Fynbos shrubs are generally 1–2m tall and have drought resistant features (Lubke and van Wijk 1998).

Figure 2.10 Typical components of fynbos are proteas, ericas and restiods. This Protea sp. is growing between rocky, nutrient poor soils in the Baviaanskloof.

Forest

In the Baviaanskloof Mountains, on more moist sites, forest precursor elements occur (Teague *et al.* 1989). Forest occurs as patches and montane forests are found on protected south-facing mountain slopes and in the protected deep valleys in the Baviaanskloof Mountain range. Species can reach lengths of >20 meters (Figure 2.11) (e.g *Podocarpus latifolius, Celtis africana*) with shorter shrubs at the base (e.g *Carissa bispinosa*) and many grasses, herbs and ferns are present in the herbaceous layer (Manning 2001).

Figure 2.11 Forest in the Baviaanskloof with canopy exceeding 20 meters.

Tranistional Thicket

This is a low growing thicket type (1-2m tall). Characteristic species are *Grewia robusta* and *Brachylaena ilicifolia*. Renosterbos (*Elytropappus rhinocerotis*) is also present (Manning 2001). Transitional thicket shares similar floristic components with other phytogeographical regions and lie within almost all the formal biomes. This patch occurs on soils of intermediate quality between fynbos and denser subtropical thicket (Figure 2.12). Vegetation clumps may become evident with *Diospyros* and *Rhus* spp causing clumps (>1,5m tall), particularly around termite mounds where animals (mainly birds) disperse seeds (Manning 2001).

Figure 2.12 Transitional Thicket comprising herbs and renosterbos (*Elytropappus rhinocerotis)* which can be seen in the bottom-left corner of the picture.

Nama Karroo

The Nama Karroo is a dry vegetation type and comprises succulents, some grasses and many small bushes from 30-60cm tall (Lubke and van Wijk 1998). Species in the Nama Karroo biome include the sweet-thorn (*Acacia karroo*) along riverbeds, the stone plant (*Lithops ruschiorum*) and Noors (*Euphorbia coerulescens*) (Figure 2.13). There is little cover with grasses and small bushes.

Figure 2.13 Nama-karroo shrubs offer groundcover of up to 60cm. Grasses are evident and trees such as *Acacia karroo* occur along riparian areas.

Savanna

This area is dominated by *Acacia karroo* trees (up to 3m tall) with a relatively open basal cover (Manning 2001) (Figure 2.14). Savanna usually invades grasslands and in this case is found close to riverine areas. It is characterized by a grassy ground layer and a distinct upper layer of trees and shrubs.

Figure 2.14 The understory of Savanna system is relatively open with grasses present.

Grassland

Mixed grassland is present in the Baviaanskloof mountains. Some species become moribund during winter (e.g. *Merxmuellera disticha*, *Heteropogon contortus*) while others remain palatable throughout the year (e.g. *Themeda triandra* and *Erogostis* spp). Some shrubs and tree species may be present in protected valleys, while the grass height reaches approximately 60–90cm (Manning 2001).

GENERAL METHODOLOGY

The general methodology used throughout the study period is detailed in this section, and where more specific techniques are used, they have been described in detail in the relevant chapters. The field work for the study was done over 21 months, from December 2006 to September 2008.

Leopards and other mammals were captured and surveyed using two methods, walk-in traps and camera traps:

1) Walk-in, Fall-door traps

Walk-in, fall-door traps (2m long, 0.7m wide, 0.8m high) (Figure 2.15) designed by a governmental conservation department, Cape Nature, Western Cape, South Africa were used to catch leopards for this study. Placement of traps was based on presence of signs such as tracks and scrapes, which indicated regular leopard travel routes (Simcharoen *et al.* 2008). The traps were monitored every 12 or 24 hours. Captured leopards were sedated by a vet using Zolitol, and morphological data and DNA (tissue) samples were collected. Leopards were observed until they regained full consciousness and walked away. The morphological data included the animals shoulder height, neck and chest girth, dental information and photographs of each individual's markings were recorded by photographs at capture. Appendix A shows a data form used to record the individual leopards information.

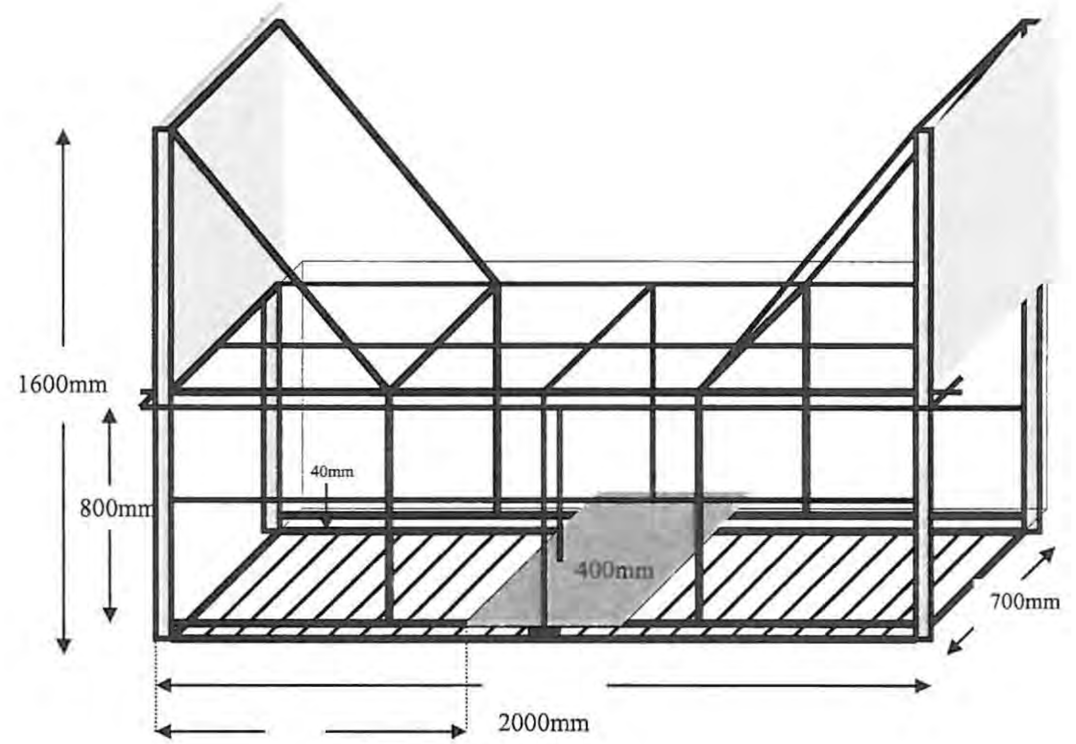


Figure 2.15 Design of the walk-in fall door traps used to capture leopards (Cape Nature, Western Cape, South Africa).

In addition, some farmers in the region used steel leg-hold traps (gin-traps) to catch a range of what they regard as 'problem predators'. These practices are potentially lethal to all animals caught and it is illegal to set traps to capture protected species such as leopards. However, by-catch is inevitable as these harmful methods are completely indiscriminate and in some cases leopards were caught. Farmers who were known to be using gin-traps were asked to contact me if a leopard was caught and in this way, I was able to both save leopards from unnecessary death and add to the sample size. Two of the studied cats (one male: one female) were caught in gin traps set by farmers.

Both of these animals were caught in the same general area north of Uitenhage. The female suffered injury and had to be kept at a rehabilitation facility overnight before being released. The male leopard also suffered injuries and lost control of his retractable claws in two of his toes due to the gin-trap. Fortunately this leopard was rescued early enough and was considered fit enough to be released immediately. The private land owners on whose land the animals where trapped insisted that the animals be removed and they were thus relocated. The relocated animals where moved some 75–80km (direct line) from site of capture or 135–145km via road to the Darlington Section of the GAENP. The remaining four leopards were captured in walk-in, fall-door traps and were released at the site of capture. Only the fully matured adult leopards captured were immobilized and fitted with collars. In one instance a juvenile was captured in a trap and released directly without immobilization or handling.

The two leopards moved for relocation, were done so by using transportation cages covered with canvas, or transport boxes with ventilation holes. Relocation sites were carefully selected based on proximity to site of capture, whether or not there was an existing leopard population, and the presence of suitable prey. The Darlington sector of GAENP was selected as there had been no reports of leopards for 19 years (Section Ranger Pers. Comm), the prey availability and diversity were considered adequate, the area was fully encompassed with a 2.5 meter, 6 electrical strand fence, and the distance from site of capture was about 80km.

Collars and Data collection

Five of the six leopards, (2996; 2997; 3704; 3710; 3809) numbered based on the frequency of the collars, were fitted with Vectronics GPS collars (Berlin, Germany). These collars allowed for VHF radio tracking and stored 6 GPS locations per day. Collars 2996, 2997, 3704 and 3710 were programmed to store GPS points at 02h00, 05h00, 12h00, 17h00, 20h00 and 23h00. Collar 3809 was programmed differently and only stored 5 GPS locations per day in order to increase battery life of the collar. These data were stored at 01h00, 05h00, 08h00, 16h00 and 20h00. Data were downloaded by air, vehicle or on foot and were retrievable as long as the collar had battery life (12 – 18 month longevity). Leopard 1038 was fitted with a cellular GSM GPS collar (Hotgroup, Johannesburg, South Africa) which worked only where cell-phone reception was available, therefore downloaded data records varied as the leopard moved in and out of reception. This collar did not perform as well as the Vectronics collars in the mountainous terrain. The quantity of data for each leopard varied as they were captured and fitted with collars at different times. Table 2.1 indicates monitoring periods and cumulative data collected for each leopard. All collared leopards, were monitored once a month, by means of vehicle, on foot or aircraft (Jabaru fixed-wing, Microlight or Helicopter). Although vehicle tracking was the most commonly used, it was problematic because there are few access roads and the animals covered massive distances making them difficult to locate.

However, over time, the animals were located and the data downloaded. The 4x4 vehicle was fitted with a whip antenna (African Wildlife Tracking, Johannesburg, RSA) which linked to the VHF and UHF telemetry inside the vehicle. A four element antenna was used when on foot, and it was attached to the various aircrafts when aerial tracking was undertaken. The collared animals were tracked with VHF in the 148–150mHz frequency range. Once close enough to the collared animal, the UHF telemetry communicated with the collar and the GPS fixes of the animal where downloaded onto a UHF handheld computer. These points where transferred and downloaded onto a PC using GPS Plus software (Berlin, Germany). Aerial location is the ideal method but a lack of funding prevented regular aerial monitoring.

Table 2.1. Duration of monitoring and number of GPS fixes fro the six leopards. The area each leopard is found in is A = GEANP or B = Baviaanskloof.

Leopard number	Area	Sex	Duration Monitored	Number of fixes
2996	A	M	December 2006 – December 2007	1897
2997	B	M	July 2007 – May 2008	1777
3809	B	M	January 2008 – June 2008	579
3710	B	F	August 2007 – December 2007	649
3704	B	F	September 2007 – July 2008	1315
1038	A	F	November 2007 – June 2008	148

2) Camera-trap systems

The camera traps were used for two functions, to determine population density of leopards in the region of focus and to determine potential prey availability. The capture-recapture sampling design used in this study was based on Karanth (1995); Karanth and Nichols (1998); and Soisalo and Cavalcanti (2006). A study by Silveria *et al.* (2003) concluded that camera trapping is the most appropriate method for mammal inventories in all environmental conditions, especially for population studies of cryptic animals and species where individuals can be individually recognised. 36 passive infrared camera traps (32 Stealth Cam, MC2-GV, Texas, USA; and 4 Deer Cam, Texas, USA) were used. One camera station consisted of two camera traps placed opposite one another to improve the chance of identifying individual leopards by their unique fur patterns (Soisalo and Cavalcanti 2006). The infrared beams of the camera traps were set at a height of about 40cm and the two cameras placed no further than 15m apart and often only 5m apart, facing the centre of the beam. The trap stations were located in areas where signs of felid species (based on photos from the pilot study, faeces and tracks). Each station was placed approximately at 3.5–5km intervals in valleys and dry riverbeds, where vegetation cover of >2m high was present and likelihood of detecting leopards was the greatest. One of the most important aspects of camera trapping is to capture and recapture as many different individuals as possible (Soisalo and Cavalcanti 2006) and it is critical to optimise trap placement to maximise the probability of capturing a leopard. Optimal sites for trap placement were selected based on the known locations of three (two female and one male) leopards (Chapter 3).

Areas with clusters of GPS locations, which indicated intensive use of a particular site, were selected to place a camera-trap station. In addition, camera traps were placed on the edge of the collared leopards ranges in an attempt to identify individuals that may be bordering, and have overlapping ranges. In total, 10 camera trap stations (two cameras per station) were set within and on the edges of the known ranges of three collared leopards in the Baviaanskloof. The number of camera traps used and their spacing was based on previously established home range size (Chapter 3) a minimum number of two to three camera traps within the female home range was suggested by Karanth and Nichols (2000). The cameras were checked every 21 days to change film and batteries and to ensure they were functioning correctly. The camera trap stations were rotated in 3 month trapping cycles. During each cycle the camera traps operated for 24hrs per day (= one trap night) (Martins and Martins 2006) and there were, 36 x 24hrs x 90= 77760 camera trap hours per trapping cycle. No bait or lure was used at any station to attract leopards. Every photo of a leopard in a sampling cycle is equivalent to one capture and photos of the same individual in successive sampling cycles are considered recaptures (Salom-Perez *et al.* 2007). Figure 2.16 shows camera trap stations layout in the Baviaanskloof and figure 2.17 shows camera stations 11 to 18 placed in the GAENP.

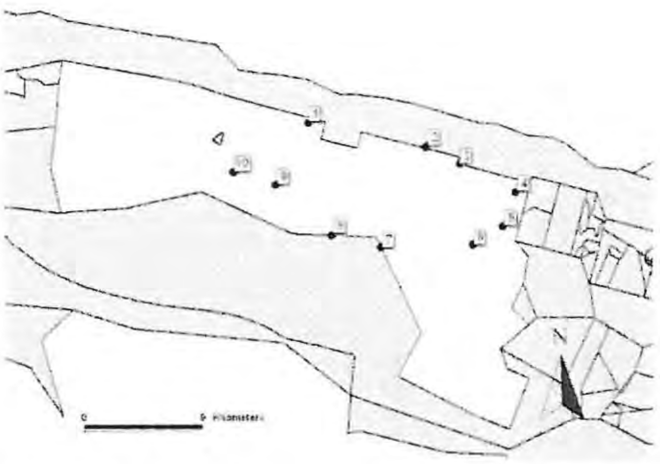


Figure 2.16 Camera trap layout in the Baviaanskloof study area

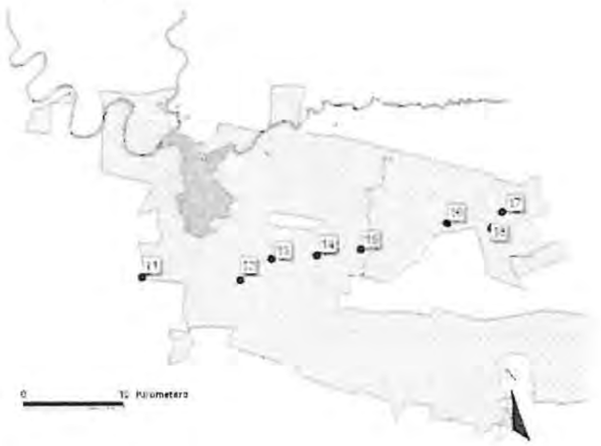


Figure 2.17 Camera Trap layout in the GAENP (Darlington and Kazuko Sections)

This camera trapping survey was carried out simultaneously with a GPS-telemetry method. The GPS fixes were exported into the GIS package, ArcView 3.3 (ESRI, Redlands, California) and placed on electronic aerial photographs and topographic maps of the study area.

Unfortunately the camera traps arrived late in the study to adjust the positioning to better suit prey availability and distribution. Therefore, prey availability was based on the same design as to determine leopard population density, as explained above and cameras were not repositioned. Therefore, prey availability within the 50% UD was not assessed, but at the 95% UD of leopards the prey availability were surveyed. The diverse types of prey taken by leopard suggests that they are largely unselective, however as they are solitary hunters and hunting strategy imposes limitations on the prey they can capture as well as the type of terrain they can successfully hunt in (Hayward *et al.* 2006). Therefore, the position of the camera traps were considered to be suitable to leopard habitat and the species captured were considered the likely prey these leopards could encounter.

Geographic Information System (GIS)

The Animal Movement Extension (Hooge and Eigenlaub 1997) was used in the GIS data base to analyse data. The projections settings used were Albers Equal-Area Conic and spheroid WGS 84. The central meridian was set to 24°, reference latitude 0, Standard parallel 1 was set at -18 and Standard parallel 2 at -32. The other settings were default. All of the data were analysed under this projection. Two methods to determine home range sizes were used: Minimum Convex Polygon (MCP) and the Kernel utilization distribution method. These methods will be discussed individually in Chapter three.

CHAPTER 3:

SPACE USE AND HABITAT SELECTION OF LEOPARDS IN THE BAVIAANSKOOF AND GAENP

INTRODUCTION

Spatial organization is considered by Mares and Lachner (1987) as the manner in which conspecifics within a population distribute themselves on a landscape, including the maintenance of core areas, home ranges and territories. Optimality models view territory size as the outcome of economic decisions based on cost and benefits of foraging and defence, while in more crowded populations territory size is the outcome of competition between neighbours or between established residents and potential settlers (Adams 2002). Territories are considered spatially stable and exclusive, with the presence of defence to keep out rivals (Mizutani and Jewell 1998). Home range is an area traversed by an individual in its normal survival activities such as gathering food, mating and caring for young (Burt 1943). It is not the entire area an animal traverses during its lifetime, but an area where an animal normally travels in pursuit of routine activities (Mizutani and Jewell 1998). Territoriality is considered to be one of the most important behavioural traits affecting the spatial organization of animal populations (Mizutani and Jewel 1998).

The range size in animals as diverse as ants (Adams 2002) and elephants (De Villiers and Kok 1997) is influenced by a number of interacting factors including availability of suitable space, food availability and distribution or patchiness, cover for hunting and concealment from threats, group size and social system, body mass, population density and relative competitive ability (Macdonald 1983; Laurenson 1995; Mizutani and Jewell 1998; Silva *et al.* 2001; Spong 2002; Jetz *et al.* 2004; Marker and Dickman 2005; Benson *et al.* 2006). Home range size generally increases with increasing body size because of the higher absolute energetic requirements of the larger species (McNab 1963; Gittleman and Harvey 1982; Jetz *et al.* 2004). However, with increased size comes increased mobility, which will allow the species to cover greater distances. Space use increases with increasing group size and this is probably also for energetic reasons. But, larger groups will also have increased competitive ability and larger prides of lions defend larger ranges with more resources than do smaller prides (Spong 2002). Home range size is often inversely correlated with environmental productivity and resource density (Herfindal *et al.* 2005; Marker and Dickman 2005) and may also be negatively correlated with the density of other predators. Finally, in many systems, human activities will influence space utilization, either through human-inflicted mortality or through habitat modification and the provision of additional prey (Grimbeek 1992). The way in which some of these factors interact can be seen in the effect of diet, prey abundance at a biomass level and carnivore body size on predator density and space use.

Energy requirements for the carnivore are set by body size, and variation in resource availability will determine the space required to meet those energetic needs (Carbone and Gittleman 2002). The final size of the area used will be further modified by the other factors mentioned earlier.

At least two contrasting approaches have been used to understand space use. The optimality approach is based on an analysis of the costs and benefits of defence and foraging (Adams 2002; Jetz *et al.* 2004). The space used is a balance between being large enough to meet all the energetic needs of an individual (Gittleman and Harvey 1982) and no larger so as to minimize the energetic costs of defending the territory or marking the boundaries of the space used. This approach typically does not consider inter and intra-specific interactions and is aligned with the concept of the Ideal Free Distribution (Fretwell and Lucas 1970). An alternative approach puts much more emphasis on interactions and sees space use as the outcome of interactions between an individual and members of the same or other species (Adams 2002; Carbone and Gittleman 2002; Berger and Gese 2007). The two approaches, while quite different, are not mutually exclusive (Adams 2002) and it is most likely that an animal's space use is the end product of an interplay between aspects of optimality and inter and intra-specific interactions. Because space use is the end result of complex interactions between various factors many of which change with time, space use is not fixed and will vary both temporally and spatially (Simcharoen *et al.* 2008).

One individual's utilization of space compared to that of a conspecific can provide insight in to the importance, distribution, availability and accessibility of a resource, such as food (Grimbeek 2005). Depending on the quality and distribution of resources, certain behavioural patterns such as the establishment of territories may develop (Grimbeek 2005). Kruuk (1972) for example showed that spotted hyena (*Crocutta crocutta*) were territorial in one population but not in another. This was also shown by Bothma and Bothma (unpublished) in a leopard population in the southern Kalahari where differences in resource availability resulted in different space use in both cases.

Carnivores typically maintain a home range that are large enough to provide necessary resources and a key determinant of home range size is food availability (Macdonald 1983; Spong 2002). In addition the presence of cover and water is important determinants of home range placement and size in large carnivores. The space use and home range size of male and female carnivores are determined by social systems such as reproductive systems. Male home range size is often driven by female distribution, with the males overlapping the ranges of several females (Mizutani and Jewell 1998; Sunquist and Sunquist 2002; Bothma and Bothma unpublished). While female habitat selection and range size is driven by resource availability, availability of suitable habitat for hunting and denning and proximity to water as female leopards parent offspring alone, is important to ensure reproductive success (Caro 1994; Mizutani and Jewell 1998).

Considerable variation has been reported in the space used by leopard in different parts of their geographical range and this has often been explained in terms of resource availability. A comparison of mean home ranges estimated by the minimum convex polygon method was used because most studies present only this value, unless otherwise stated: In India leopard home ranges using kernel estimation varied between 25.1km² to 31.3km² (Karanth and Sunquist 2000). In Kenya variation of size between males and females was 32.8km² and 14km² respectively (Mizutani and Jewell 1998). In Namibia mean ranges of 216km² and 127.8km² were used by male and female leopards (Mizutani and Jewell 1998). In South Africa, Kruger National Park variation between 5.6km² to 96.1km² occurred (Baily 1993). Previous studies in the Cape Province showed range use of 388 to 487km² (Norton and Lawson 1985). The Kalahari Desert showed the largest mean range size from all the compared studies of 1529 and 607km² used by male and female leopards respectively (Bothma and Bothma unpublished).

Social system and space use by leopards

Wild, solitary female cats with young have to ensure their own survival and it seems to be intuitively true that most felids tend to be solitary except when courting or when a female has young (Schaller 1972). The presence of cubs in prey poor environments such as the Kalahari does not cause the female to stay near their young for a long period after giving birth as they would not have enough hunting opportunities in limited ranges, however they did travel shorter distances than other female and male leopards (Bothma and Coertze 2004).

Home ranges of females with cubs less than six months were also smallest during a study on leopards in the Royal Bardia National Park, Nepal (Odden and Wegge 2005). Despite this, motherhood and the associated care of her cubs resulted in higher hunting success rate than females without cubs (Bothma and Coertze 2004).

Whether or not, and the extent to which home range overlap occurs, varies in different areas (Mizutani and Jewel 1998; Marker and Dickman for reviews). Although there is no clear relationship between extent of overlap and either range size or resource availability (see Table 3 in Marker and Dickman (2005)) overlap between males, and between males and females, is reported more often than overlap between females (Marker and Dickman 2005). As in many mammalian carnivores (Herfindal *et al.* 2005), male leopard home ranges are larger than those of the females (Jenny 1996; Mizutani and Jewell 1998; Sunquist and Sunquist 2002; Odden and Wegge 2005; Simcharoen *et al.* 2008).

Identifying important resources that relates to population persistence is a key to conservation planning (Simcharoen *et al.* 2008). An 'important' resource is considered to have a high contribution to an animals' survival or reproduction success. It may take a considerable amount of time and effort to establish habitat specific demographic parameters for long-lived animals with low reproduction rates such as leopard to determine these. Therefore it is necessary to identify key resources for short-term conservation planning in the process (Simcharoen *et al.* 2008).

Habitat selection refers to a behavioural response which results in the disproportionate use of habitat types that may affect the animals' fitness (Simcharoen *et al.* 2008). Leopards do not use the available habitat at random and various studies have shown selection for certain features. In Thailand, leopards selected two of three different forest types and low gradient slopes and areas with streams (Simcharoen *et al.* 2008). This corresponds with results from Ngoprasert *et al.* (2007) where leopard used habitat closer to streams and areas with low gradient to a greater degree. In general, leopards select vegetation which offers cover and tend to avoid areas which are more open as their hunting success is driven by stealth and the lack of detection (Hayward *et al.* 2006). As resources may change over time and space depending on the environmental and social interactions within a species at a given time, space use may vary (Odden and Wegge 2005; Simcharoen *et al.* 2008).

Management implications of understanding space use and habitat preference

A sound knowledge of the space needs, in terms of area, and habitat requirements in terms of vegetation, cover and slope is essential in management and conservation (Herfindal *et al.* 2005) and conservationists recognise that protecting the habitat of a threatened species is important in protecting that species (Ogada *et al.* 2003). Furthermore, once typical range size and habitat requirements are known, this information can be used to predict the population sizes of leopards in an area.

As persecution of predators by people is considered to have the highest influence of species loss (Woodroofe and Ginsberg 1998; Ogada *et al.* 2003) it is especially important that conservation efforts consider the context of local politics, economic stability and human needs in managing the species that these habitats support (Gaveshelishivili and Lukarevskiy 2008). This is further complicated in large free-ranging predators such as leopards which move in and out of protected areas where they may come into contact with people and their livestock (Woodroofe and Ginsberg 1998). Rates of livestock depredation by large carnivores can be influenced by local environmental conditions such as the abundance of natural prey, rainfall and socio-ecological factors including livestock husbandry practices (Kolowski and Holekamp 2005). Nevertheless, an understanding of the habitat requirements is a necessary first step and a primary aim of the present study is to establish the space and habitat requirements of leopards in the Baviaanskloof and GAENP in the Eastern Cape Province of South Africa. This study does not identify causal factors that drive spatial dynamics or density. Rather it focuses on providing baseline data and identifies important landscape features for leopards that can be used in conservation planning on a regional or national scale.

METHODS

Data collection and Analysis

Spatial data were collected from six leopards (3 males: 3 females) as described in Chapter two. Five of these animals were fitted with GPS collars and one leopard with a GSM cellular collar. The collection of data from the GPS collars was done by means of telemetry and the fixes from the GSM cellular collar were obtained directly from the internet. Space use was calculated in ArcView 3.3 with the Animal Movement Extension (Hooge and Eichenlaub 1997), using two methods: 1) Minimum Convex Polygon (MCP) method (White and Garrot 1990) and 2) Kernel Utilization Distribution (UD) method (Worton 1989; Powell 2000). These are discussed individually below:

The minimum convex polygon method

The minimum convex polygon method is the simplest of the polygon techniques, and one of the oldest techniques for range size calculation. It is the method that is most frequently mentioned in older literature, and is used in this study to allow comparison between studies (Harris *et al.* 1990). It involves joining all the peripheral fix points to create a convex polygon area that includes all the other fixes (Worton 1987). The range size obtained is strongly correlated to the number of fixes from the target animal, but is considered robust even when using a low number of fixes (Worton 1987). Although simple to use and highly comparable, this method has disadvantages. Firstly, the results may yield an overestimate of the actual range size of the animal, as the peripheral fixes heavily influence the shape and size of the boundary (Harris *et al.* 1990).

Some of the peripheral points may be exploratory movements that do not form part of the area in which the animal is normally active and large areas of the range estimate are never actually visited by the individual leopard. Secondly, animals will utilise some areas of their range more frequently than others, and identifying these core areas of use is of ecological importance (Dixon and Chapman 1980; Samuel *et al.* 1985). The minimum convex polygon method does not define the areas of high or low use intensity within the total range (Worton 1987; Harris *et al.* 1990). More recently, various studies have suggested that the MCP method is inefficient (Bothma *et al.* 1997) and subject to unpredictable biases (Börger *et al.* 2006). However, older literature utilized the MCP method and it is included in this study for comparative reasons. For the MCP method all points were used and the area generated (100% MCP) is a maximum size for the home range for the entire study period.

Kernel analysis

The second method used was the kernel Utilization Distribution (UD) method of analysis. This method has been used to calculate the range size of leopards in the southern Kalahari and Kenya (Bothma *et al.* 1997; Mizutani and Jewel 1998) and is being used increasingly in large carnivore studies (Bissett 2004). According to Seaman and Powell (1996), the kernel density estimate forms an efficient and effective basis for quantitative analysis of range size. The kernel UD method is a probability density estimation which calculates the home range of an animal based on the relative amount of time that it spends in different regions of its range.

A major advantage of kernel UDs is that fixes are not joined by straight lines but rather by contours which closely match the distribution of fixes (Worton 1989). As a result, kernel UDs include far less unused space than do MCPs and are more appropriate for studies of habitat selection (Harris *et al.* 1990; White and Garrott 1990; Börger *et al.* 2006). In addition, unlike the MCP which generates a single polygon, the UD method will generate more than one polygon where appropriate. For these reasons, the UD method is seen as a meaningful way to calculate home range size (Worton 1995; Seaman and Powell 1996; Bothma *et al.*1997; Nilsen *et al.* 2005) and is the preferred method for making comparisons at an intra-specific level (Nilsen *et al.* 2005).

The minimum number of fixes required and whether or not it is necessary to avoid autocorrelation of fixes has been debated in the literature. Seaman and Powell (1996) suggest that to maximize the effectiveness of the kernel UD method, at least 100 fixes should be obtained, if at all possible. By contrast, Börger *et al.* (2006) recommended a minimum of 10 fixes per month. While most of the early literature stressed the importance of avoiding autocorrelation of fixes, more recently it has been argued that in using only one fix per day, a great deal of biologically valuable information is lost (Börger *et al.* 2006). Thus, in this study, all GPS fixes were used. For the Kernel UD, it was possible to include various proportions of the fixes and 50%, 90% and 95% were selected. These are comparable to more recent studies and are generally considered the most robust estimators of an animal's core area (50% UD), home range (90% UD) and total range size (95% UD) (Mizutani and Jewell 1998).

In calculating the Kernel UD, the smoothing factor H is the key variable. Variations around 1000 were tested (Bissett 2004) and a value of 1000 was selected as it resulted in the least overlap of ranges with reserve boundaries. As with the MCP analyses, data were pooled for each leopard and there was no seasonal analysis of space use. The effect of sex, study site and UD (50%, 90% and 95%) on range size has been compared using ANOVA in Statistica (Stasoft, version 7).

Habitat selection

Habitat selection was examined by assessing preferences for different vegetation types, prey availability and proximity to rivers and roads. Each of these variables are discussed individually.

Vegetation

A vegetation map of South Africa (Low and Rebelo 1996) was used to determine habitat preference within the Baviaasnkloof and GAENP. The availability of different vegetation types was calculated using ArcView 3.3 by overlaying the range (50% and 95% UD) for each leopard and the vegetation map and using the clip function. The availability of each vegetation type is defined as the proportion of each vegetation type within the leopard's range (Creel and Creel 2002). The observed habitat use was calculated by overlaying the leopard fixes on to the clip shape and counting the number of points in each vegetation type. Habitat use was defined as the proportion of GPS fixes for each leopard which fell into the individual vegetation types.

To test if leopards showed a significant preference for certain vegetation types, observed use was compared to expected use using chi-squared tests in Statistica. The expected habitat use was calculated by multiplying the total number of fixes by the percentage of each vegetation type occurring in the 50% and 95% UD for each individual leopard. This analysis was done for each leopard separately, using the full data set.

Distance from Rivers and Roads

For each leopard, the distances of each GPS fix in the 95% UD, from river lines and roads were calculated in ArcView 3.3. These values were used to calculate a mean distance for each leopard from these features using the full data set. Values were compared using ANOVA and t-tests or the non-parametric equivalent as necessary.

Prey availability

A measure of the abundance of mammals and birds in the home range and core areas of individual leopards was determined using a combination of camera traps and random 50m belt transects in the Baviaanskloof and GAENP. As leopards appear to be non-selective predators (Sunquist and Sunquist 2002; Hayward *et al.* 2006; Bothma and Bothma unpublished) this study defines potential prey species as all of the mammals and birds captured on camera-traps in the study areas (Ngoprasert *et al.* 2007) as well as the mammals recorded at the random 50m belt transects.

Prey abundance at each of the study sites was recorded as species richness (number of different species), the number of each species (total number of pictures per species), species diversity (Shannon Index H) and species evenness (Equitability E_H). The Shannon Index (H) was calculated as follows:

$$H = -\sum P_i.\ln P_i$$

Where P_i is the proportion of the ith species

Equitability (E_H) was calculated as follows:

$$E_H = H/\ln S$$

Where lnS is the natural log of species richness.

The total number of each species is probably inflated by multiple pictures of the same animal since it was rarely possible to identify individuals of prey species.

Camera trapping protocol

The camera trapping protocol is fully described in Chapter 2. However, the camera trapping protocol was designed to maximise the likelihood of photographing leopards rather than measuring prey abundance and the data from the camera traps should be seen as a first estimate of possible prey diversity.

Belt transect protocol

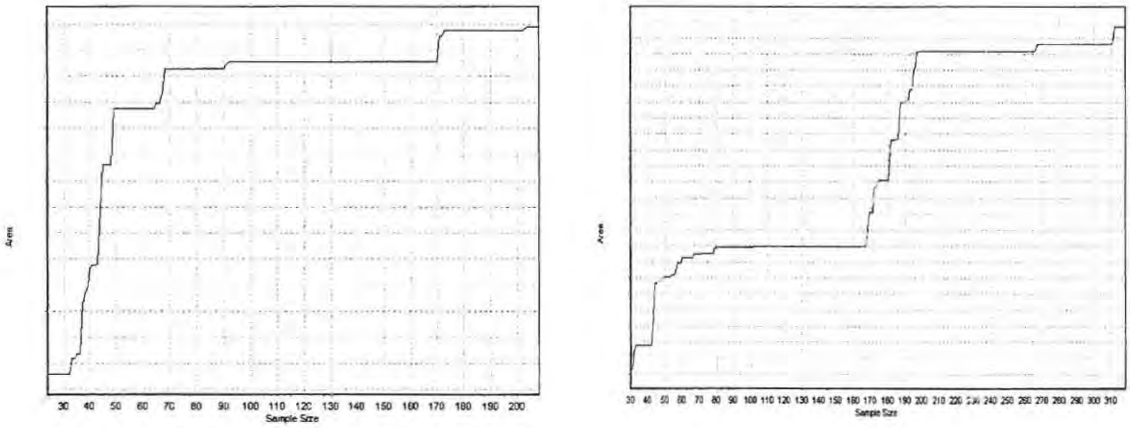
A total of 30 belt transects of 50m x 2m were used randomly in each of the respective study areas. The transects were located in various vegetation types and altitude and slope in the study area to include various prey species. The transects were walked along the length once to avoid recounting signs.

In each transect, tracks and faeces were recorded and identified by using a field guide "Smithers' mammals of southern Africa" (Apps 1996). If the track of a specific animal was found to walk through the length of the 50m transect it was recorded as one count.

RESULTS

Space utilization

Since the estimate of space used is affected by the number of fixes, it is necessary to establish if an asymptote has been reached by plotting estimated space use against the number of accumulated fixes. This was done using the software Biotas™ 1.0.3 (Ecological Software Solutions; Florida; USA). An asymptote for the individual leopards varied between 60 - 210 fixes (Figure 3.1 A and B for two examples) and sufficient GPS fixes were obtained to calculate the home range for all the leopards.



A B

Figure 3.1 Area curves for male leopard 2996 (A) and female leopard 3704 (B) showing that the asymptote is reached at between 70 and 80 fixes for A, and 190 and 200 fixes for B.

Size of home ranges and core areas

The MCPs were significantly larger than the 95% UD (t-test for dependent samples; $t = 2.96$; $df = 5$; $P<0.05$; Table 3.1; Figures 3.2 & 3.3). The extent of the difference varied greatly between the MCP and 95% UD, from 133km^2 (leopard 3809) to 43km^2 (leopard 3704) and for only one leopard (female 3710) (Table 3.1). The mean size of the 50% UD of males (20.3±11.4km^2) was very similar to that for females (24.1±2.9 km^2) while at the 90%UD and 95%UD levels the males used more space than females (90%UD; male, 157±119.2km^2; female 88.4±7.1km^2; 95%UD; male 244.3±221.8km^2; female, 115.6±12.9km^2; Figure 3.4). However, in an ANOVA with sex, kernel UD (50%, 90% and 95%UD) and reserve (GAENP or Baviaanskloof) as categorical variables and area as the dependent variable, neither sex ($F_{1,6} = 0.57$; $P>0.05$), UD ($F_{2,6} = 2.1$; $P= 0>0.05$) or reserve ($F_{1,6} = 1.45$; $P>0.05$) had a significant effect on space used. The likely reason for this lack of significance is the extensive variation in space used particularly by the male leopards (Table 3.1; Figure 3.2).

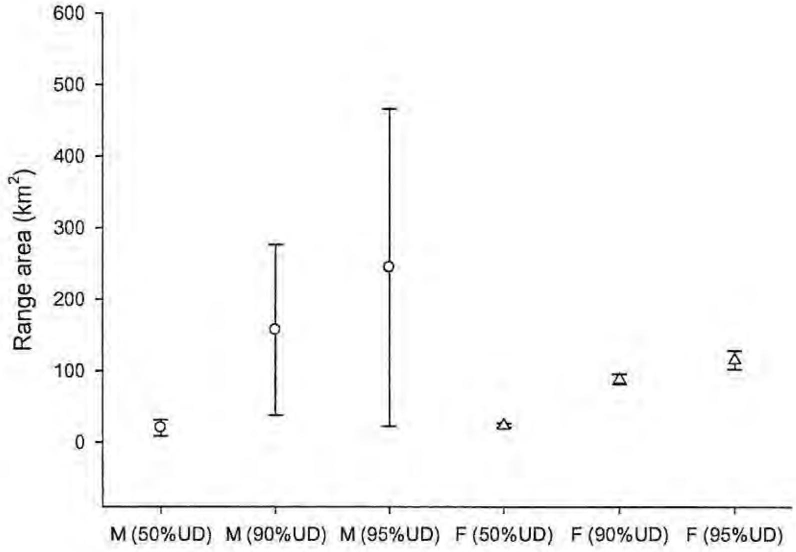


Figure 3.2 Mean size of 50%, 90% and 95% UDs' of male (M) and female (F) leopards. Data are mean ± 1sd.

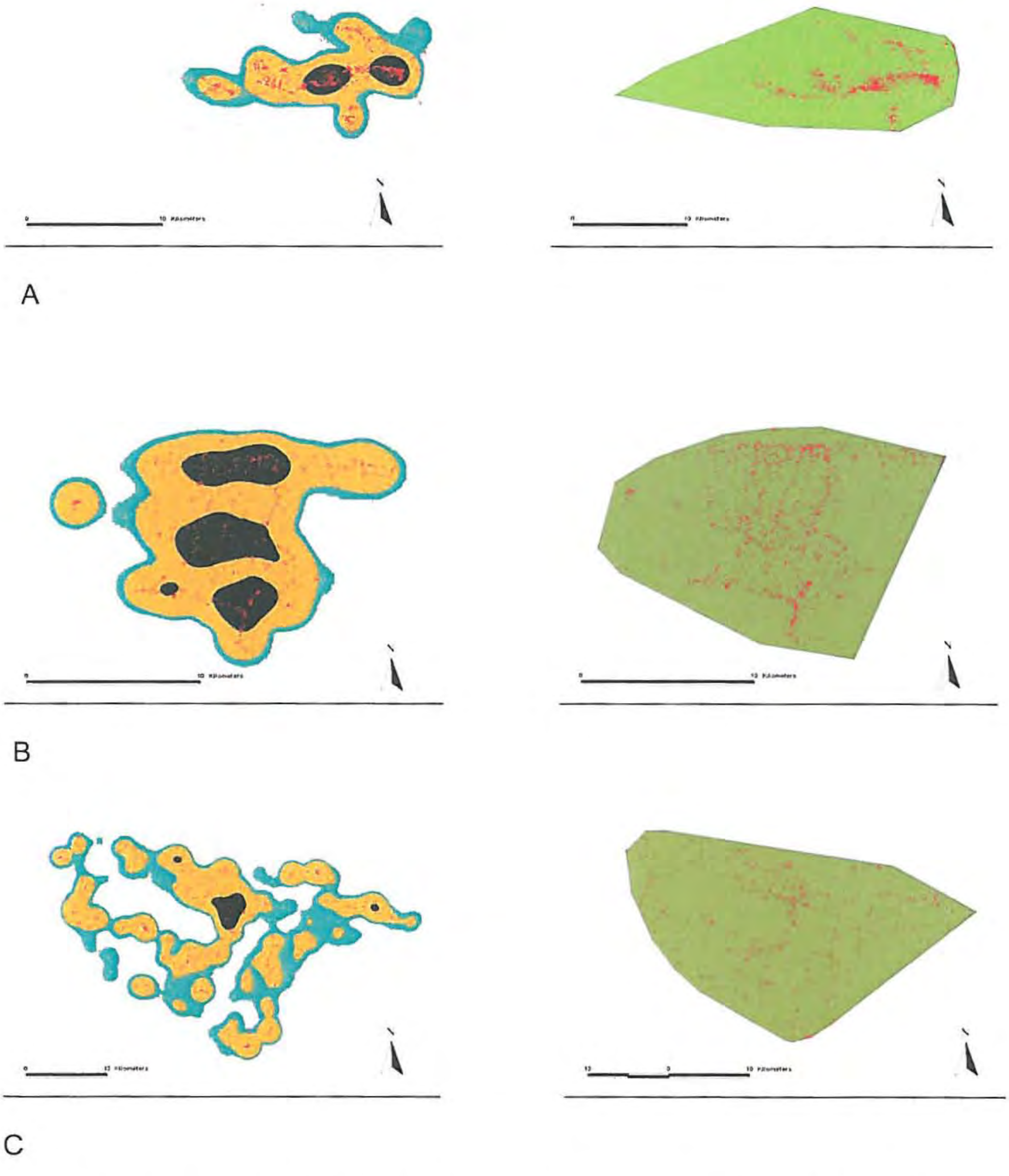


Figure 3.3 Kernel UDs (50% black, 90% orange, 95% blue) in the left hand column and 100% MCP on the right for the male leopards. Orange dots are individual GPS fixes. A = 2996; B = 2997; C = 3809.

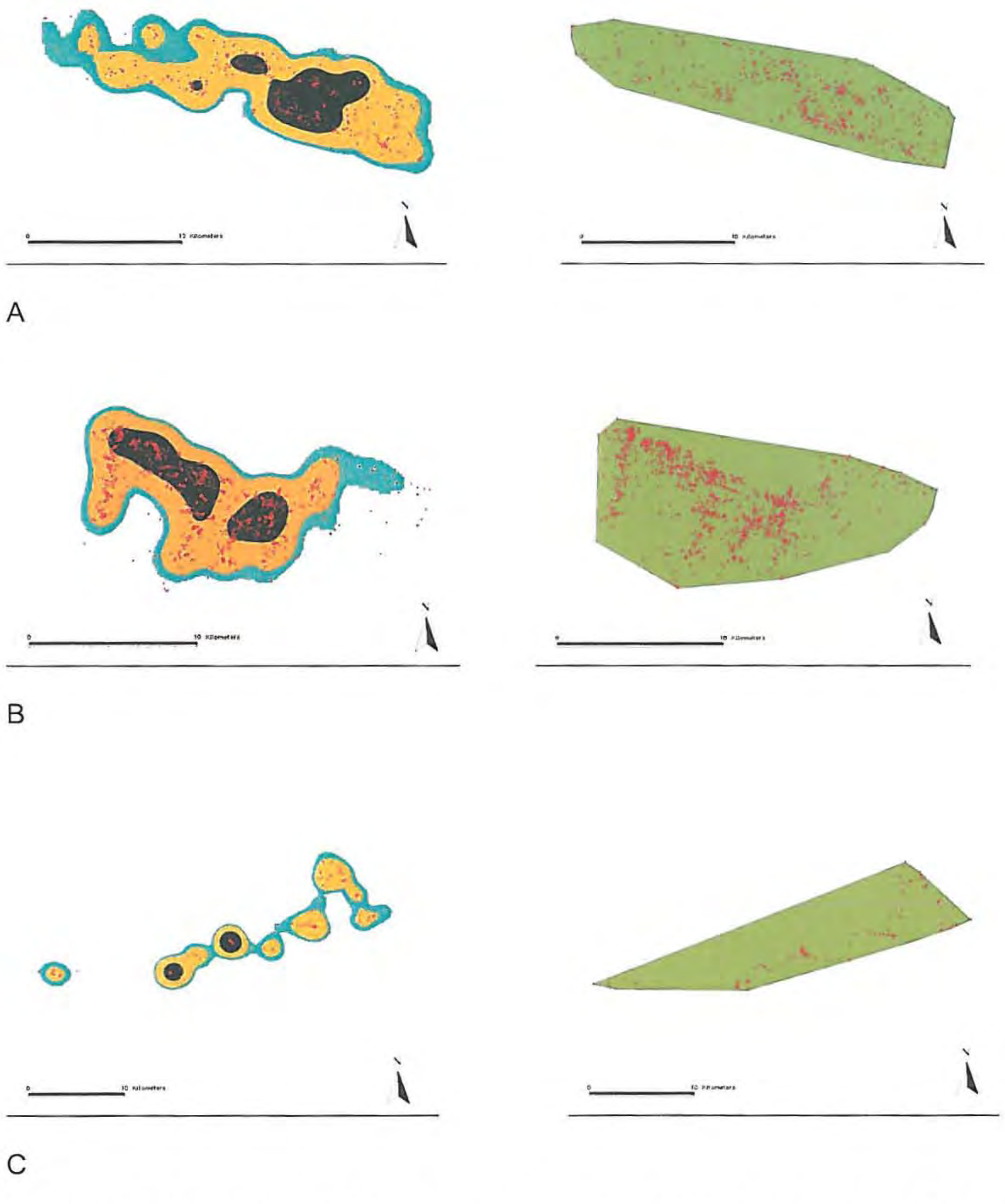


Figure 3.4 Kernel UDs (50% black, 90% orange, 95% blue) in the left hand column and 100% MCP on the right for the female leopards. Orange dots are individual GPS fixes. A = 3710; B = 3704; C = 1038.

Table 3.1 Range size (km^2) of tracked leopards in the Baviaanskloof and GAENP. Reserve, A = GAENP, B = Baviaanskloof.

Collar number	Period tracked	Reserve	Sex	Data points	Range size (km^2)			
					MCP	Kernel UD Probability		
						50 Percent	90 Percent	95 Percent
2996	Dec. 2006 - Dec. 2007	A	M	1897.00	213.45	10.70	56.66	85.90
2997	Jun. 2007 - May 2008	B	M	1777.00	183.36	32.91	126.14	149.14
3809	Jan. 2008 -April 2008	B	M	338.00	631.75	17.34	289.02	497.84
3710	Aug. 2007 - Dec. 2007	B	F	649.00	123.40	21.90	94.90	130.30
3704	Sep. 2007 - July 2008	B	F	1315.00	148.57	22.87	80.89	105.86
1038[1]	Nov. 2007 - Feb. 2008	A	F	148.00	180.80	27.44	89.37	110.60
Mean			M		342.85	20.32	157.27	244.29
Stdev			M		250.60	11.40	119.27	221.84
Mean			F		150.92	24.07	88.39	115.59
Stdev			F		28.77	2.96	7.06	12.96

Habitat Selection

Because the available habitat varied for each leopard, habitat use is described separately for each animal after which general trends are identified.

Vegetation

Leopard 2996

There were only two vegetation types present in the home and core ranges of male 2996 (Figure 3. 5; Table 3.2). This male leopard did not use the available habitat at random (95%UD; χ^2= 966.7, df=1, $p<0.05$; 50% UD; χ^2=376.9, df=1, p<0,05) and was observed much more often in the Albany Thicket than expected and much less often in the Nama-Karroo (Table 3.2).

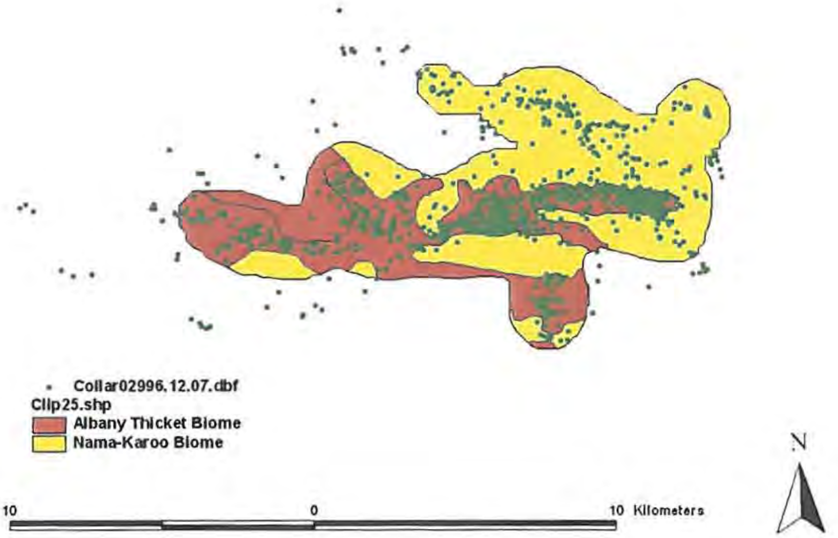


Figure 3.5 95%UD for leopard 2996 overlaid on the vegetation map of GAENP showing the presence of two vegetation types. Leopard GPS fixes are in green.

Table 3.2 Analysis of vegetation use by leopard 2996.

Vegetation type	Size (km²)	% Vegetation	Observed points	Expected points
95%UD				
Nama-Karroo	49.93	58.30	397	1046.52
Albany Thicket	35.71	41.70	1398	748.48
Total	85.64		1795	
50%UD				
Nama-Karroo	4.2	38.85	75	364.44
Albany Thicket	6.6	61.05	863	572.69
Total	10.8		938	

Leopard 2997

All seven vegetation types were present within the 50% and 95% UDs of male 2997 (Figure 3.6; Table 3.3). In the 95% UD, this male did not use the habitat at random (χ^2=1059.7, df=6, $p<0.05$) and was recorded more often than expected in Forest, Savanna and Albany Thicket and avoided Fynbos, Grassland and Nama-Karroo (Table 3.3). The habitat utilization within the 50% UD was also not random (χ^2=228.3, df=6, $p<0.05$) and the leopard used Forest and Albany Thicket more than expected, and Fynbos, Grassland, Nama-Karroo and Savanna, less than expected (Table 3.3; Figure 3.6).

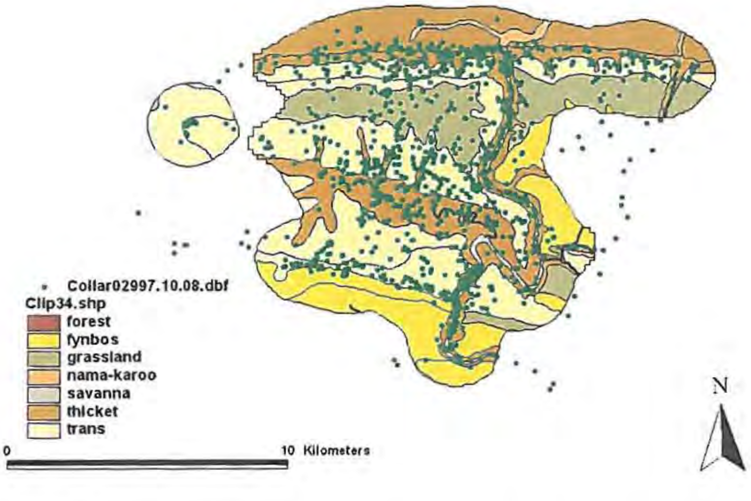


Figure 3.6 95%UD for leopard 2997 overlaid on the vegetation map of the Baviaanskloof showing the presence of seven vegetation types. Leopard GPS fixes are in green.

Table 3.3 Analysis of vegetation use by leopard 2997.

Vegetation type	Size (Km^2)	% Vegetation	Observed points	Expected points
95%UD				
Forest	0.59	0.40	14	6.95
Fynbos	20.73	13.95	47	242.31
Grassland	22.37	15.05	106	261.42
Transitional Thicket	54.65	36.78	692	638.87
Savanna	2.25	1.51	165	26.23
Nama-Karroo	1.44	0.97	2	16.85
Albany Thicket	46.56	31.33	711	544.2
Total	148.59	100.00	1737	1736.83
50%UD				
Fynbos	1.23	2.92	4	26.32
Grassland	1.55	3.68	12	33.16
Transitional Thicket	15.82	37.52	365	338.46
Forest	0.05	0.12	4	1.07
Savanna	7.8	18.50	74	166.88
Nama-Karroo	2.36	5.60	1	50.49
Albany Thicket	13.35	31.67	442	285.62
Total	42.16		902	

Leopard 3809

Six vegetation types were present within the 50% and 95% UD ranges (Figure 3.7; Table 3.4). The vegetation types were not used at random, (χ^2= 616.8, df=5, $p<0.05$) within the 95% UD and Forest and Fynbos were used more than expected, while Nama-karroo, Transitional Thicket and Albany Thicket were avoided (Table 3.4). Within the 50% UD, vegetation types were not used at random (χ^2= 12.3, df=5, $p<0.05$) and Forest, Savanna and Transitional Thicket were utilized more than expected while Nama-Karroo and Fynbos were avoided (Table 3.4).

Figure 3.7 95% UD for leopard 3809 overlaid on the vegetation map of the Baviaanskloof showing the presence of seven vegetation types. Leopard GPS fixes are in green.

Table 3.4 Analysis of vegetation use by leopard 3809.

Vegetation type	Size (km^2)	% Vegetation	Observed points	Expected points
95%UD				
Albany Thicket	95.28	40.83	170	230.71
Fynbos	25.11	10.76	228	60.80
Transitional Thicket	95.26	40.82	101	230.66
Forest	4.83	2.07	39	11.70
Savanna	11.03	4.73	27	26.71
Nama-Karroo	1.83	0.78	0	4.43
Total	233.34		565	
50%UD				
Transitional Thicket	3.05	22.90	29	22.21
Albany Thicket	4.75	35.66	32	34.59
Forest	0.25	1.88	4	1.82
Fynbos	2.56	19.22	11	18.64
Savanna	2.29	17.19	21	16.68
Nama-Karroo	0.42	3.15	0	3.06
Total	13.32		97	

Leopard 3710

Five vegetation types were present within the 50% and 95% UDs of female 3710 (Figure 3.8; Table 3.5). Within the 95%UD, vegetation types were not used at random (χ^2=118.3;df=5;P<0.001) and Transitional Thicket, Albany Thicket and Forest were used more than expected and Fynbos and Savanna, less than expected (Table 3.5). The vegetation types within the 50% UD were also not used at random (χ^2= 30.66; df = 4; P<0.001) and there was a greater use of Albany Thicket and Forest than expected while Savanna and Fynbos were used less than expected.

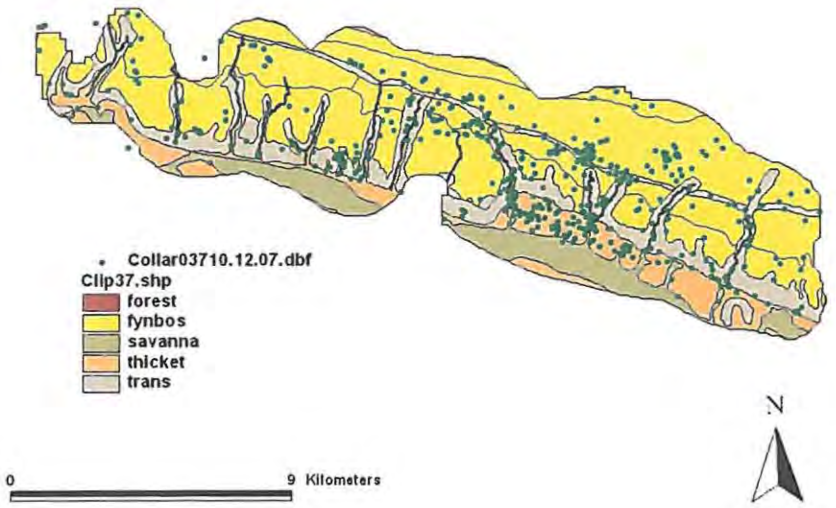


Figure 3.8 95% UD for leopard 3710 overlaid on the vegetation map of the Baviaanskloof showing the presence of five vegetation types. Leopard GPS fixes are in green.

Table 3.5 Analysis of vegetation use by leopard 3710.

Vegetation type	Size (km^2)	% Vegetation	Observed	Expected
95%UD				
Transitional Thicket	25.61	19.75	167	116.95
Albany Thicket	15.95	12.30	118	72.84
Fynbos	73.95	57.04	278	337.69
Forest	2.05	1.58	21	9.36
Savanna	12.08	9.32	8	55.16
Total	129.64	100.00	592	592
50% UD				
Albany Thicket	4	18.08	92	60.04
Transitional Thicket	4.86	21.97	67	72.94
Fynbos	12.01	54.29	162	180.26
Forest	0.378	1.71	9	5.67
Savanna	0.87	3.93	2	13.06
Total	22.118		332	

Leopard 3704

Five vegetation types were present in the home range and core area of this female leopard (Figure 3.9; Table 3.6). Within the 95% UD the leopard used the vegetation significantly differently than expected (χ^2=896; df=4; p<0.05) and Albany Thicket and Forest were used more than expected and Fynbos and Savanna less than expected (Table 3.6). Similarly, within the 50% UD the habitat was not used at random (χ^2=204; df=4; p<0.05) and Forest and Albany Thicket were used more than expected and Fynbos, Savanna and Transitional Thicket, less than expected (Table 3.6).

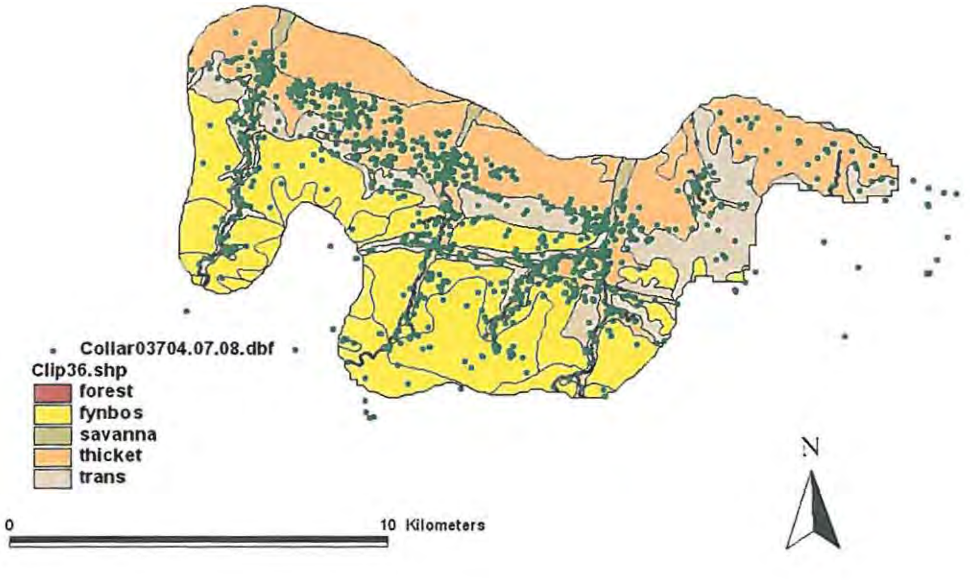


Figure 3.9 95% UD for leopard 3704 overlaid on the vegetation map showing of the Baviaanskloof the presence of five vegetation types. Leopard GPS fixes are in green.

Table 3.6 Analysis of vegetation use by leopard 3704.

Vegetation type	Size (km^2)	% vegetation	Observed points	Expected points
95%UD				
Albany Thicket	42.35	36.10	850	518.00
Transitional Thicket	19.29	16.44	234	235.95
Forest	1.68	1.43	110	20.55
Fynbos	41.14	35.07	241	503.20
Savanna	12.86	10.96	0	157.30
Total	117.32		1435	
50%UD				
Forest	0.59	2.57	73	23.31
Transitional Thicket	4.98	21.72	106	196.77
Albany Thicket	13.99	61.01	661	552.77
Fynbos	3.24	14.13	66	128.02
Savanna	0.13	0.57	0	5.14
Total	22.93		906	

Leopard 1038

Three vegetation types were present in the 95% UD and their use was significantly different from random ($\chi^2=8.8$; df=2; $P<0.05$; Figure 3.10; Table 3.7). Fynbos was used more than expected and Nama-Karroo was avoided (Table 3.7). Within the 50% UD, only two vegetation types were present and these were used at random ($\chi^2=3.4$; df=1; $p>0.05$; Table 3.7).

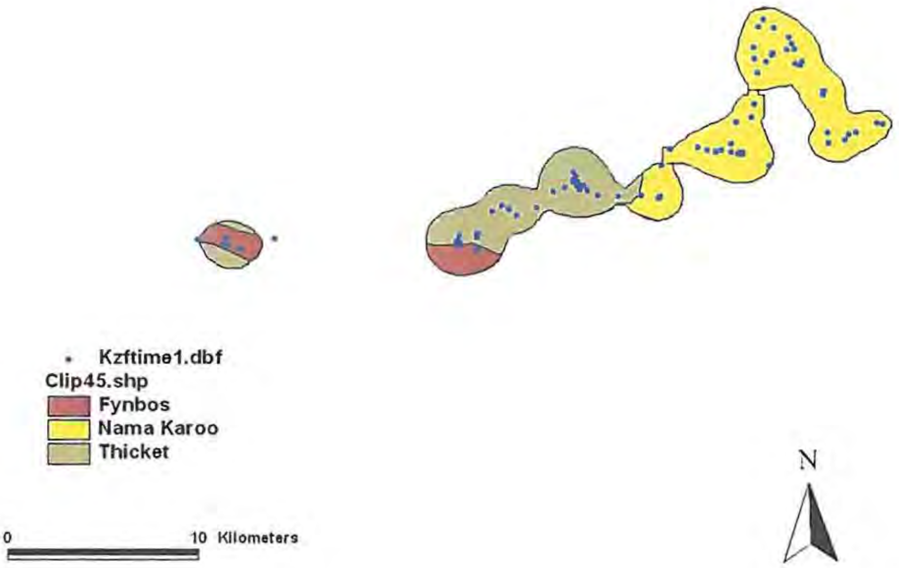


Figure 3.10 95% UD for leopard 1038 overlaid on the vegetation map showing of the GAENP the presence of three vegetation types. Leopard GPS fixes are in blue.

Table 3.7 Analysis of vegetation used by leopard 1038.

Vegetation type	Size (km^2)	% Vegetation	Observed points	Expected points
95%UD				
Fynbos	14.98	17.07	34	23.90
Nama-Karroo	25.74	29.33	29	41.10
Albany Thicket	47.05	53.61	77	75.04
Total	87.77		140	
50%UD				
Fynbos	23.5	36.28	29	22.13
Albany Thicket	41.27	63.72	32	38.86
Total	64.77		61	

Although both the presence and use of the vegetation differed within the home ranges of the leopards, some trends were apparent. Grassland occurred in only one of the leopards' ranges (Table 3.7) where it was used less than expected. The thicket vegetations, including forest, occurred commonly and were mostly used more than expected. Savanna was mostly avoided and Fynbos and Nama-Karroo were strongly avoided (Table 3.8).

Table 3.8 Summary of the use of vegetation within the 95% and 50% UDs of the six leopards. Number is the number of ranges in which the vegetation type occurred. +ve, -ve and neutral indicate if the vegetation was used more, less or as expected. If the observed was within 10% of expected it was recorded as neutral.

Vegetation type	95%UD				50%UD			
	Number	+ve	neutral	-ve	Number	+ve	neutral	-ve
Albany Thicket	6	4	1	1	6	4	0	2
Forest	4	4	0	0	4	4	0	0
Transitional Thicket	4	2	2	0	4	1	2	1
Savanna	4	2	0	2	4	0	1	3
Fynbos	5	1	0	4	5	0	0	5
Grassland	1	0	0	1	1	0	0	1
Nama-Karroo	4	0	0	4	3	0	0	3

In terms of basic structural characteristics of these vegetation types (see chapter 2), the leopards selected habitats with dense or relatively dense cover and avoided the more open vegetation types.

Distance from Rivers and Roads

The mean distance of male leopards from rivers was 1.05 ± 0.10km while for female leopards, it was 1.14 ± 0.17km; Table 3.8). In an ANOVA, with sex and reserve as categorical variables, there was no significant effect of sex or reserve on distance to rivers and no significant interaction between sex and reserve. The mean distance from roads for male leopards was 14.58 ± 7.52km and 10.3 ± 0.85km for female leopards (Table 3.9). In an ANOVA with sex and reserve as categorical variables, there was no significant effect of sex or reserve on distance to roads and no significant interaction between sex and reserve. However, leopards were significantly closer to rivers (1.1 ± 0.12km) than to roads (12.7 ± 5.2km; $t = -5.46$; $df = 10$; $P<0.001$).

Table 3.9 Distance from rivers and roads of 6 leopards. Reserve, A= GAENP, B = Baviaanskloof.

Collar number	Reserve	Sex	Data points	Average distance (km)	
				Rivers	Roads
2996	A	M	1897	1.05	15.50
2997	B	M	1777	0.91	6.65
3809	B	M	579	1.20	21.60
3710	B	F	649	1.30	11.80
3704	B	F	1315	1.16	10.20
1038	A	F	142	0.97	10.50
mean		M		1.05	14.58
Stdev		M		0.10	7.52
mean		F		1.14	10.83
Stdev		F		0.17	0.85

Prey availability

Within the Baviaanskloof, 14 mammalian species and two avian species were captured on the camera traps and 14 mammalian species and two avian species were recorded from the line counts (Table 3.10). The camera traps recorded bushbuck, caracal, honey badger and a bat there were not detected on the transects, while the transects detected bateared fox, scrub hare, cattle and sheep (Table 3.11). Three species (baboon, porcupine and large spotted genet) made up 45% of all photographs but only 10% of all spoor on the line transects. Spoor of sheep, kudu and bushbuck comprised 34% of all sign on the line transects (Table 3.11).

In the GAENP 11 mammalian species were captured on camera and 16 mammalian species were recorded from the line transects (Table 3.10). The camera traps recorded eland and a horseshoe bat that were not detected on the transects while the transects detected aardvark, bateared fox, blesbuck, grey duiker, small grey mongoose, ground squirrel, large spotted genet and red hartebeest (Table 3.11). Four species (kudu, baboon, eland and red hartebeest) made up 64% of all photographs while porcupine, which was common in the Baviaanskloof was rarely photographed (5% of all photographs) in the GAENP (Table 3.11). The line transects in the GAENP revealed that three species (springbuck, kudu and red hartebeest) made up 47% of all spoor (Table 3.11).

Although overall mammalian species richness (all species detected by both methods) was slightly higher in the Baviaanskloof (18) than the GAENP (17), the species diversity (Shannon Index H) was very similar as was the equitability (E_H) (Table 3.10). The rock hyrax, baboon, vervet monkey and bushpig were recorded at both sites.

As might be expected since the GAENP is a National Park, more species of antelope were recorded in the GAENP than in the Baviaanskloof (Table 3.11). The Baviaanskloof includes conservation and Cattle and sheep were recorded in the Baviaanskloof and not the GAENP. Interestingly, more species of medium sized and small carnivores were recorded in the Baviaanskloof than the GAENP (Table 3.11).

Table 3.10 Summary of the results from the camera trap survey and line transects for the two study sites.

		Baviaanskloof	GAENP	Total
Camera traps		22	16	38
Trap nights		765	720	1485
Total number of pictures		201	265	466
Pictures/ trap night		0.26	0.37	0.63
Species	Mammals	14	11	25
	birds	2	0	2
Species diversity (H)		2.4	2.1	
Equitability E_H		0.88	0.93	
Line Transects		30	30	60
Total number of spoor		220	198	418
Spoor / transect		7.3	7.0	
Species	Mammals	14	16	
	Birds	2	0	
Total number of mammal species		18	17	

Table 3.11 Complete list of all species detected by camera trap or line transect in the two study sites. Numbers are either the number of photographs or spoor detected.

Species	Baviaanskloof		GAENP	
	Camera traps	Line transects	Camera traps	Line transects
Baboon	39	18	45	14
Vervet monkey	2	7	12	12
Bushpig	14	19	15	6
Bushbuck	17	22	21	7
Cape grysbok	10	10	0	0
Grey duiker	0	0	12	12
Eland	0	0	36	0
Red hartebeest	0	0	24	23
Blesbuck	0	0	0	17
Klipspringer	13	3	0	0
Kudu	14	24	64	42
Springbuck	0	0	0	29
Cattle	0	20	0	0
Sheep	0	29	0	0
Rock hyrax	19	5	21	12
Scrub hare	0	4	0	0
Porcupine	34	0	15	7
Ground squirrel	0	0	0	6
Grey mongoose	11	17	0	4
Large spotted genet	18	4	0	3
Honey badger	2	0	0	0
Caracal	1	0	0	0
Bat eared fox	0	4	0	3
Aardvark	0	0	0	1
Francolin	3	15	0	0
Night jar	4	0	0	0
Heron	0	19	0	0
Totals	201	220	265	198

Habitat avoidance

While the previous section has explored some aspects of habitat selection, the data available allows a comment on habitat avoidance. The possible avoidance by leopards of farmed land can be seen from the space use by three leopards in the Baviaanskloof (Figure 3.11). These three leopards avoided an area of approximately 150km^2 that was used for agricultural purposes, in spite of the fact that valleys and streamlines were present.

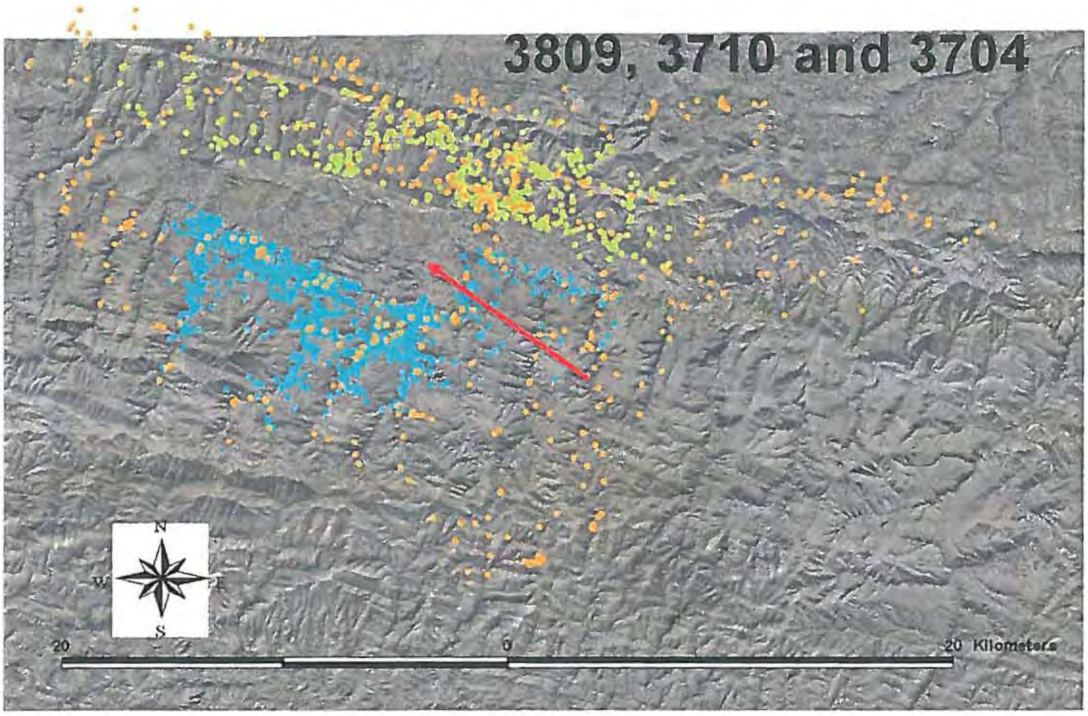


Figure 3.11 The locations for three leopards, one male (orange) and two females (blue and yellow)showing the apparent avoidance of an area adjacent to higher human activity and modified vegetation due to husbandry practices (indicated with arrow).

DISCUSSION

Range size and utilization

In the present study, ranges estimated using the MCP method were mostly larger than those estimated using the kernel UD method. While this is often the case, it may vary with the degree of territoriality and movement patterns of the species or sex (Bissett 2004). In female cheetahs, with relatively small ranges, MCPs were smaller than equivalent UDs, while in a coalition of three male cheetahs that ranged more widely, MCPs were twice equivalent UDs (Bissett 2004). The results in this study are similar to those reported for cheetahs in that for the male leopards, MCPs were substantially larger than the equivalent UDs, while for female leopards the difference between MCP and UD was not as great, and in one female, the MCP was smaller than the UD. Mizutani and Jewel (1998) compared range size of leopards using different methods and their data showed that for both male and female leopards, the MCP method generated smaller maximum range sizes than did the harmonic mean method (similar to the UD method). However, for two male leopards, when outliers were excluded, the peeled MCP was larger than the equivalent Harmonic mean (see table 6 in Mizutani and Jewel (1998)). Bothma *et al.* (1997) has also reported kernel UDs of leopards as being larger than equivalent MCPs.

The range size of leopards is highly variable (Myers 1986; Mizutani and Jewel 1998; Marker and Dickman 2005) ranging from a minimum of about 10km^2 to a maximum of 800km^2 and the mean home-range from 11 studies is 179±327km^2 (Nilsen *et al.* 2005).

However the value of such a mean should be questioned since it conceals the enormous variation that is known to occur and this variation has a biological basis and biological significance. Home-ranges of leopards in South Africa range from less than 10km^2 in the Kruger National Park, to 33km^2 in Londolozi Game reserve, 53 – 127km^2 in the Cape Province and as much as 3559km^2 in the Kalahari Desert (see Mizutani and Jewel 1998; Marker and Dickman 2005; Bothma and Bothma unpublished). A more recent study in the Western Cape Province has revealed that ranges are also large 235–800km^2 (Martins & Martins 2006). The results from the present study (mean male 90%UD 157km^2; mean female 90%UD 88km^2) are similar to those previously reported for the Cape Province (Norton and Henley 1987) and the mean of Nilsen *et al.* (2005), and larger than those reported for Londolozi and the Kruger National Park. Macdonald (1983) suggested that carnivores maintain a home range that is large enough to provide necessary resources and this is the most likely single explanation for the variation in space use by leopards across Africa. Comparable data on food availability are summarised by Marker and Dickman (2005) who show that food availability varies extensively from a low of 35kg/km^2 in Namibia or 0.6 animals per km^2 in the Kalahari, to about 4500kg/km^2 in the Kruger National Park and 24 animals per km^2 in Londolozi. The Kalahari has the largest home ranges (2182km^2 for males and 489km^2 for females) while in Londolozi and the Kruger National Park home ranges are small (Marker and Dickman 2005). While food availability is likely to be the most important determinant of range size, many of the other factors mentioned in the introduction such as availability of water and cover for hunting, will further modify space use.

In spite of the apparent relationship between range size and resource abundance, Marker and Dickman (2005) argue that in Namibia resource availability alone does not explain the low density of leopards and that the long history of leopard persecution by humans has played an important role. Based on relationships between home range size and prey abundance (Marker and Dickman 2005) it is likely that the density of prey in the Baviaanskloof and GAENP is between 500 and 700kg/km^2. The accuracy of this prediction should be tested in future research.

In the present study, male leopards had larger home ranges but similar sized core areas to female leopards, and this pattern has been reported previously both for leopards and carnivores in general (Sandell 1989; Mizutani and Jewel 1998; Sunquist and Sunquist 2002; Bothma and Bothma unpublished). By contrast, in Namibia, although males had larger home ranges than female leopards, the difference was not statistically significant (Marker and Dickman 2005). As female leopards rear young by themselves, their reproductive success is closely correlated with the amount of energy they can allocate to reproduction and this is dictated by the food resources available during the rearing period. Therefore, food is the most important resource for females, and females will use space so as to maximize their chances of securing food resources (Sandell 1989). By contrast, the space used by male leopards overlaps that of several females so as to maximize mating opportunities and as such will be larger than the space used by females. Since the space used by females has been selected based at least in part on food availability, the same space will also hold sufficient food for the male leopards.

Habitat selection

Leopards occupy habitats which range from tropical rainforest to arid savanna, and from alpine mountains to the urban edges, and reach their highest densities in riparian areas (Bailey 1993; Ngoprasert *et al.* 2007; Simcharoen *et al.* 2008). Such habitats may offer increased prey density and, or increased cover for hunting resulting in increased hunting success (Sunquist and Sunquist 2002; Hayward *et al.* 2006). Establishing the resource requirements of leopards by identifying what habitat types are selected, presumes that animals select areas and features which will increase survival and the potential for reproduction (Simcharoen *et al.* 2008).

Therefore, investigating how a species selects different features of its environment is an essential first step towards assigning importance to those variables. The variables studied here included vegetation, distance from rivers and roads and prey availability.

Vegetation

For successful hunting, leopards requires dense cover, as their camouflage allows them to stalk exceedingly close to their prey before initiating a short sprint (mean of 10.3±1.3m in Namibia) (Hayward *et al.* 2006) of up to 120m, at up to 60km/h (Bertram 1999). In the present study, the presence and level of utilization of the vegetation differed within the home and core ranges of leopards and all of the leopards selectively utilized specific components of the available vegetation types. The dense Albany Thicket and Forest occurred commonly in leopard ranges, and were mostly used more than expected.

By contrast, vegetation types with little cover such as Grassland, Fynbos and Nama-Karroo were avoided. Thus, the results for the Baviaanskloof and GAENP support the previously reported tendency for leopards to select habitats with cover. Fynbos makes up a large part of the Baviaanskloof and the fact that it is avoided by leopards will affect the number of leopards that the area can support. However, although leopards were recorded in the vegetation less often than expected, the vegetation types were utilized to some degree in the ranges of most animals. Fynbos occurs largely on plateaus, mountain tops and northern facing slopes. The structure of the vegetation differs at different ages and as it matures it becomes dense and offers more cover. However, very few grazers utilize the Fynbos once grasses have phased out (approximately 4 years after burning) as it offers little nutritious food (van Rooyen 2002).

Thus, there may be several reasons why leopards do not selectively use Fynbos; it occurs in areas that are not preferred by leopards (plateaus and mountain tops), it may offer little cover, and it supports a low resource density.

Distance from rivers and roads

Male and Female leopards were located on average about 1km from rivers, indicating a strong utilization of the riparian areas. There may be several reasons for this. Firstly, the Baviaanskloof is very mountainous and it is likely that leopards utilize the streamlines as pathways which would save them energy while moving through the area.

It is also likely that the vegetation in the streamlines would offer greater cover and that the riparian region would offer a greater density of resources (both food and water). Similar habitat selection has been reported in two studies in Thailand (Ngoprasert *et al.* 2007; Simcharoen *et al.* 2008), where it was found that streams and low gradient slopes were important habitat features in the home ranges of leopards. It is important to note that streams and slope are probably correlated and these factors are not independent.

The mean distances from roads for male and female leopards were 14km and 10km respectively, suggesting that leopards in the area do not use roads as pathways. Many of the large mammalian carnivores use roads both as pathways and as marking sites but the results from the present study suggest that this is not the case. This may be to avoid human activity but it is also possible that the roads, which were located in mostly mountainous and hilly terrain, were simply not situated in areas that leopards prefer to use.

Habitat avoidance

Habitat avoidance as described in this study may represent an avoidance of human activity but may also be due to a lack of suitable habitat. It is common for farmers to modify the vegetation by bush clearing and this would result in a reduction in cover. So, while small stock farming may result in an increase in the density of potential prey (small livestock) and thus attract leopards, it may also result in small scale habitat modification and an increase in the human activity which could deter leopards.

Prey availability

It is widely accepted that resource availability is a key determinant of territory size, particularly for females (Macdonald 1983) and it is therefore surprising that while many authors report the size of the space used, fewer have attempted to establish the density of suitable prey (Marker and Dickman 2005). Without this complementary information, it is impossible to comment on the possible role of prey density in territory size and it is difficult to interpret differences in space used. In an attempt to overcome this problem habitat productivity, established from satellite images, has been used as a surrogate for prey density and is negatively correlated with home range size of Eurasian lynx (Herfindal *et al.* 2005). Future studies of space use of leopards should place as much emphasis on establishing the density of prey as on establishing the size of the space used and the possibility of using satellite imagery should be explored. Hayward *et al.* (2006) considered the preferred weight range of the prey of leopards to extend from 10–40kg, with an optimal weight of 23kg and with the overall ratio of leopard body mass to optimal prey body mass of 1:0.75. The mean prey mass fails to take into account variation in the body size of leopards through Africa.

Male and female leopards in the Western and Eastern Cape average 31kg and 21kg respectively, and 36kg and 21kg respectively which is nearly half the size of leopards further north in Southern Africa (Mills and Harvey 2001). This suggests that leopards in the Eastern Cape Province will prey on smaller species and individuals than elsewhere in Africa.

This is supported by the observation that in the Kalahari, female leopards, which are smaller than males, had a higher success rate when killing small prey compared to males (Bothma and Coertze 2004). Furthermore, prey selection varies with resource abundance. In prey rich environments, leopards select their prey in terms of those species, age, and sex classes that are most abundant or easiest to hunt and which allow them to be energy 'maximizers' (Bothma and Coertze 2004). By contrast, leopards in prey poor environments such as the Kalahari, hunt a wider variety of prey, ranging from a black lizard (*Mabuya variegata*) to an adult male gemsbok (*Oryx gazelle*) (Bothma and Coertze 2004) and thus the kill list is more diverse than in prey rich areas (Bailey 1993; Bothma and Coertze 2004).

The present study reports the presence of a wide range of small to medium sized mammals where either the species or young of the species would be potential prey for a leopard. However, the methods used did not produce robust estimates of prey abundance and future studies should concentrate on this aspect and develop standard methods that can be used across multiple sites. Ott *et al.* (2007) found that medium sized ungulates and small mammals made up the largest part of the leopards' diet on rangelands in the Baviaanskloof. Faecal analysis is a valuable method for ascertaining predator diets, although if used alone, it may overemphasize the importance of small prey items (Hayward *et al.* 2006). Although the samples in Ott *et al.* (2007) did not reach an asymptote, it indicated that bushbuck, rock hyrax and cape grysbok, constituted 15%, 12.5% and 12.5 % frequency of occurrence respectively in the observed scats.

Significantly, these same species comprised 23% of all photographs from the camera traps in the Baviaanskloof (present study).

CONCLUSION

These results are the first of their kind for the Eastern Cape Province and extend our understanding of space use and habitat selection by leopards. The data have important management implications for the species and will allow managers to assess population status and model responses to different possible threats. Information regarding the leopards' spatial requirements can be used with existing satellite coverage's to guide the management of the species on a landscape-level, as has been done for tigers (*Panthera tigris*) (Simcharoen *et al.* 2008).

CHAPTER 4:

POPULATION DENSITY

INTRODUCTION

In a solitary species such as the leopard, the density of animals is inversely related to the space use (territory size) and the factors that affect space use will also affect density (Silva *et al.* 2001; Marker and Dickman 2005). Thus, much of the introduction to Chapter 3 is relevant here. Crude density is the number of animals per unit area while the more meaningful ecological density is the number of animals per unit of the animal's habitat (Elton 1933). The calculation of the latter requires an understanding of the habitat requirements of the species and is thus more difficult to calculate than is crude density. Ecological density is particularly important for endangered species and those that come into conflict with humans as various anthropogenic activities may reduce the amount of suitable habitat. For example, a change in land use to small livestock farming may result in increased hunting of large carnivores and their natural prey, and bring about a reduction in predator density.

Like space use, animal density scales with body size but the relationship is an inverse one and density decreases with increasing body size (Silva *et al.* 2001; Carbone and Gittleman 2002). Importantly, these relationships are modulated by variations in resource abundance and distribution (Bradbury and Vehrencamp 1976; Carbone and Gittleman 2002) and social structure or group size (Macdonald 1983; Mills and Gorman 1997).

Density estimation has been described as a key goal in ecology (Peters 1991) and a variety of methods have been used for large mammalian carnivores. There are a number of indirect methods in which predator density is assessed from questionnaires, modelled from home range and demographic data, or from resource availability or environmental productivity (Gros *et al.* 1996; Jenny 1996; Herfindal *et al.* 2005). Relative abundance can also be assessed from counts of spoor and scats along trails and roads (Stander 1998; Ramakrishna *et al.* 1999). These methods all have their strengths and weaknesses and work best under certain conditions (Gros *et al.* 1996; Stander 1998; Gusset and Burgener 2006). As long as these methods are applied consistently, they will generate data that can be compared from different areas within a large site, but all share the common problem of needing to be calibrated against a known predator density. Robust population density estimates rely on the identification of individual animals (Henschel and Ray 2003). This can be done through unique spoor, DNA (from scats or hair traps) or unique coat patterns from photographs. The use of camera-traps in studies of large carnivores has become increasingly popular and it is now a method of choice in studies of elusive species such as leopards (Carbone *et al.* 2001; Karanth and Nichols 2002; Silveira *et al.* 2003; Soisalo and Cavalcanti 2006). Camera traps are set so as to maximise the chances of capturing leopards and then capture-recapture statistics are used to generate a population size (Henschel and Ray 2003). Alternatively, it is possible to use capture rates to estimate predator density (Carbone *et al.* 2001).

There have been a number of attempts to estimate the status (not true density) of leopards in Africa. Several of these relied on questionnaires and interviews (Myers 1986), and another used interviews supplemented with field work in Kenya (Hamilton 1981). Another was based on a rainfall model (Martin and de Meulenaar 1988) which estimated that the total leopard population of Africa exceeds 714 000. This figure has been considered to be an overestimate (Norton 1990; Nowell and Jackson 1996) because the method failed to incorporate persecution and areas where lower prey densities were present. Studies of space use have been used to estimate leopard density in the Tai National Park (Ivory Coast) where home ranges overlap, and the density of leopards was estimated at one leopard per 9-14km^2 (Jenny 1996). Although no other study has reported density in the region the variation in home range size from less than 10km^2-800km^2 (Mizutani and Jewell 1998; Marker and Dickman 2005) and the inverse relationship between home range size and density suggests that density will vary similarly.

In this study, I use two methods to estimate leopard density in the Baviaanskloof and GAENP of the Eastern Cape Province as an essential step in the process of establishing the significance of the region for leopard conservation. The objectives of this study are:

1. to estimate the abundance of leopards at the study sites using capture-recapture techniques with the use of camera-traps
2. to estimate the effectively sampled area and use this information to calculate the leopard density within it

3. to compare the estimates of effectively sampled areas based on camera-traps compared to animal movement obtained from GPS collar data, and use this comparison to provide information for future calibration of the mean maximum distance moved (MMDM) method for large cats, and
4. to provide baseline data for long-term population monitoring programmes.

METHODS

To gain a better understanding of the density of leopards in the Baviaanskloof, two standard approaches were used: a camera trap survey (see Soisalo and Cavalcanti 2006), and an estimation based on range size, range overlap, habitat selection and available suitable space. Although camera traps were set in the GAENP, no leopards were photographed and data from the Baviaanskloof only are presented here.

Camera trap survey

The camera trap sampling design used in this study was based on studies of tigers in India (Karanth 1995; Karanth and Nichols 1998) and of jaguars in Brazil (Soisalo and Cavalcanti 2006). One of the most important aspects of camera trapping is to capture and recapture as many different individuals as possible (Soisalo and Cavalcanti 2006) and it is critical to optimise trap placement to maximise the probability of capturing a leopard. Optimal sites for trap placement were selected based on the known locations of three (two female and one male) leopards (Chapter 3). Areas with clusters of locations, which indicated intensive use of a particular site, were selected to place a camera-trap station. In addition, camera traps were placed on the edge of the collared leopards ranges in an attempt to identify individuals that may be bordering, and have overlapping ranges. In total, 10 camera trap stations (two cameras per station) were set within and on the edges of the known ranges of three collared leopards. The number of camera traps used and their spacing was based on previously established home range size (Chapter 3) and a suggested minimum number of two to three camera traps within the female home range (Karanth and Nichols 2000).

Camera traps were left in the field for three months, generating 1800 trap nights (trap days of Carbone *et al.* 2001). Carbone *et al.* (2001) have suggested that 1000 or more camera days may be successful in estimating presence or absence of tigers at very low densities and it was assumed that it would be sufficient a period for leopards in the Baviaanskloof.

Analysis of camera trap photographs

Each photograph of a new individual represented one capture, and a second capture of the same individual was a recapture. Although most studies have analysed photographs using capture- recapture methods (e.g. Karanth *et al.* 2004) this is not necessary if all the leopards in the area have been identified. Carbone *et al.* (2001) estimated tiger density from the number of individual tigers photographed divided by the sampling area. In this study I have used a plot of the number of unique leopards photographed against cumulative trapping hours to show that an asymptote was reached and then calculated density as above (Carbone *et al.* 2001). To allow comparison with data from Carbone *et al.* (2001), trap success rate is expressed as number of trap days per leopard photograph.

The size of the sampled area is an essential piece of information and it has been calculated in various ways. The size of the sampled area was estimated using the 10 trap stations and adding a buffer strip to allow for the daily movement patterns of the leopards (Salom-Perez *et al.* 2007). The addition of the buffer avoids underestimating the sampled area and overestimating the predator density (Soisalo and Cavalcanti 2006).

The width of the buffer strip can be estimated in a number of ways (Karanth and Nichols 200; Silver *et al.* 2004; Soisalo and Cavalcanti 2006). In studies where home range information is not available the width of the buffer strip can be determined using the *estimated* mean maximum distance moved (MMDM) of an animal that has been recaptured (Soisalo and Cavalcanti 2006). For each recaptured individual, the mean maximum linear distance between the camera traps at which it was captured and then recaptured is calculated and the mean is used for the buffer strip width. In many studies, this distance is also halved to provide an estimate of the average radius of a mean home range and this serves as the width of the buffer strip (Soisalo and Cavalcanti 2006). Alternatively, if the *real* mean maximum distance moved is known, as in the present study (Chapter 5), it can be used as the buffer width. In the present study, the buffer width has been calculated using four methods:

1. Half of the estimated MMDM between trap stations.
2. The full estimated MMDM between trap stations.
3. The real MMDM calculated from the collared female leopards (n=3) derived from the GPS collars (Soisalo and Cavalcanti 2006).
4. The real MMDM calculated from both male and female leopards (n=6) derived from the GPS collars.

Estimation of density based on home range size, range overlap, habitat selection and available suitable space

The estimation of home range size and habitat selection is fully described in Chapter 3 and is not further described here. Home-range overlap was calculated using ArcView 3.3 by overlaying the ranges of the studied individuals and measuring the size of the region of overlap. The overlap area was then expressed as a percentage of the total range size. The estimation of density in the Baviaanskloof was achieved by simply dividing the home range size into the total available area, having taken into account habitat suitability and range overlap.

RESULTS

Camera Trap Survey: number of leopards recorded

A sampling effort of 1800 trap nights (43200 trap hours) in the Baviaanskloof resulted in a total of 226 photographs. Of these, 25 were of leopards, showing four unique leopards (3 adults: 1 sub adult) and 22 recaptures. One of these individuals was a sub adult male (<18 months) still walking with his mother (Figure 4.1). The trap success rate was 72 trap nights per leopard picture.

Figure 4.1 Photograph of a sub-adult (left) and adult female leopard captured at a camera trap station.

The three adult leopards were the collared animals that were known to be resident in the area and only the sub adult was not collared. All of the leopards were recaptured on several occasions, but only two were recaptured at two different stations.

A graph of the number of unique leopards photographed against cumulative trapping hours shows that an asymptote was reached at four unique leopards after about 417 trap nights (Figure 4.2) after which no further new leopards were photographed. Since all photographs after day 21 were recaptures, there was no need to use capture- recapture methods to calculate population size.

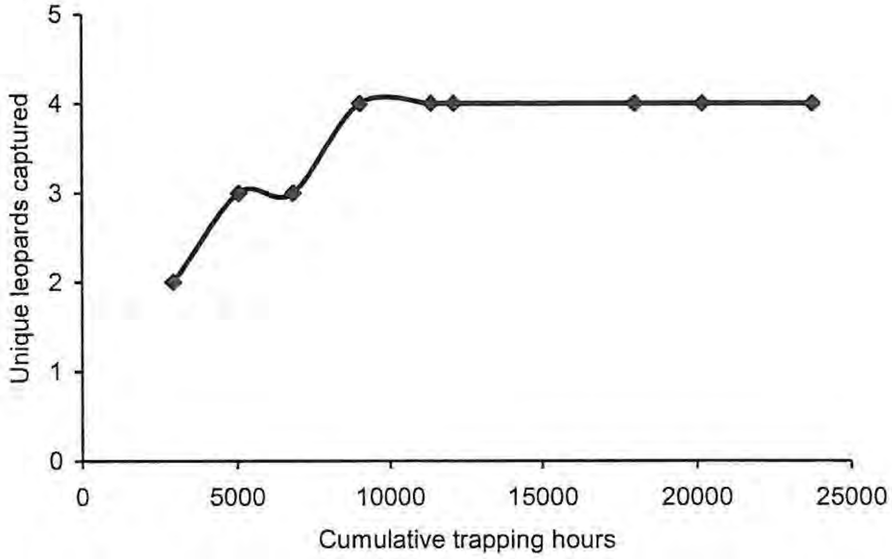


Figure 4.2 Cumulative number of unique leopards captured in the Baviaanskloof.

Camera Trap Survey: estimation of area surveyed and leopard density

The large amount of GPS locations (n=6217; Chapter 3) allowed for a calculation of *real* mean maximum distance moved (Chapter 5) that is likely to be more accurate than the estimate based on the limited recapture of individuals at more than one trap station (n=2) . The GPS collars produced considerably larger daily movements (8-10km/day; Table 4.1) and thus larger effectively sampled areas than those produced using the camera traps (3.5km/day; Figure 4.3; Table 4.1).

Consequently, the GPS data resulted in lower density estimates than the camera trap methods (Table 4.1). The area encompassed by the outer traps was 123.9km² and the buffer width calculated by the four different methods varied from 1.75km to 10.6km (Table 4.1). Because of the large variation in the estimated size of the area effectively sampled, the density varied by an order of magnitude from 3 leopards per 100km² to 0.3 leopards per 100 km² (Table 4.1).

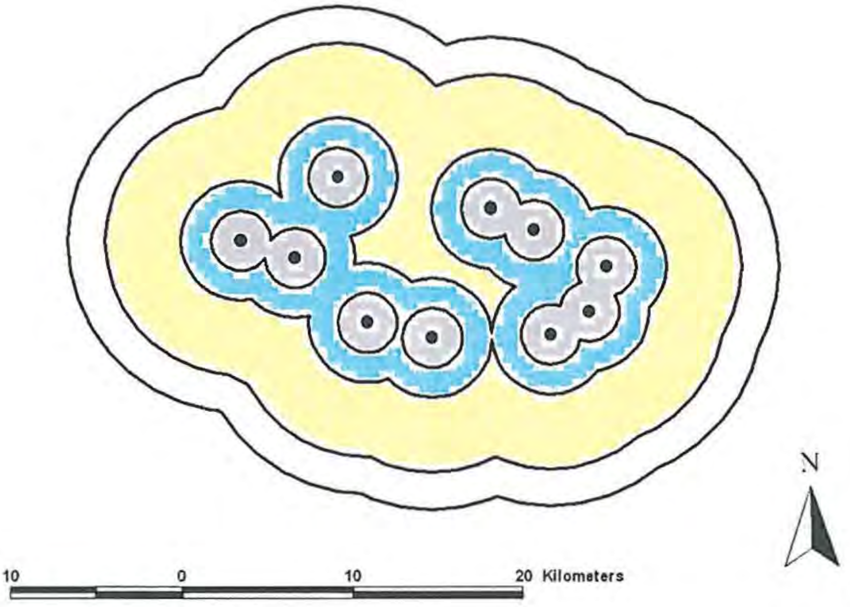


Figure 4.3 Survey area in the Baviaanskloof indicating the 10 camera-trap locations and the effectively sampled area sizes using four methods to calculate buffer width. Camera trap stations (•), Half MMDM (grey) 92.4km², Full MMDM (blue) 278.24km², Female MMDM (yellow) 693.7km², and Combined MMDM (white) 922.6km².

Table 4.1 Sampled area size calculated from camera-trap and GPS collar data. Density has been estimated based on the three adult leopards and assumes that the sub-adult will disperse from the area.

Method used for buffer width calculation	Buffer width (km)	Effective sampled area(km^2)	Density estimate (leopard/100km^2)
Outer trap polygon	(no buffer)	123.9	
Camera Traps			
Half MMDM	1.75	92.4	3.25
Full MMDM	3.5	278.2	1.08
GPS Collars			
Female MMDM	7.9	693.7	0.43
Combined MMDM	10.6	922.6	0.33

Estimation of density from GPS collars: Overlap of ranges

Amongst males

As a consequence of leopards being captured at random, no collared males held neighbouring territories and the closest two collared males (2997 and 3809) were 15km apart. Therefore it was not possible to establish if the home range of male leopards overlapped. However, the results from the camera traps showed no unknown males in 90 days of sampling, suggesting that overlap is unlikely.

Amongst females

Two female leopards (3710 and 3704) were neighbours (Figure 4.4). There was no overlap of space used at the 50% and 90% UDs and at the 95% UD probability the ranges just overlapped at a single point (Figure 4.4 red arrow). The camera trap survey did not identify additional female leopards other than those collared within the respective ranges.

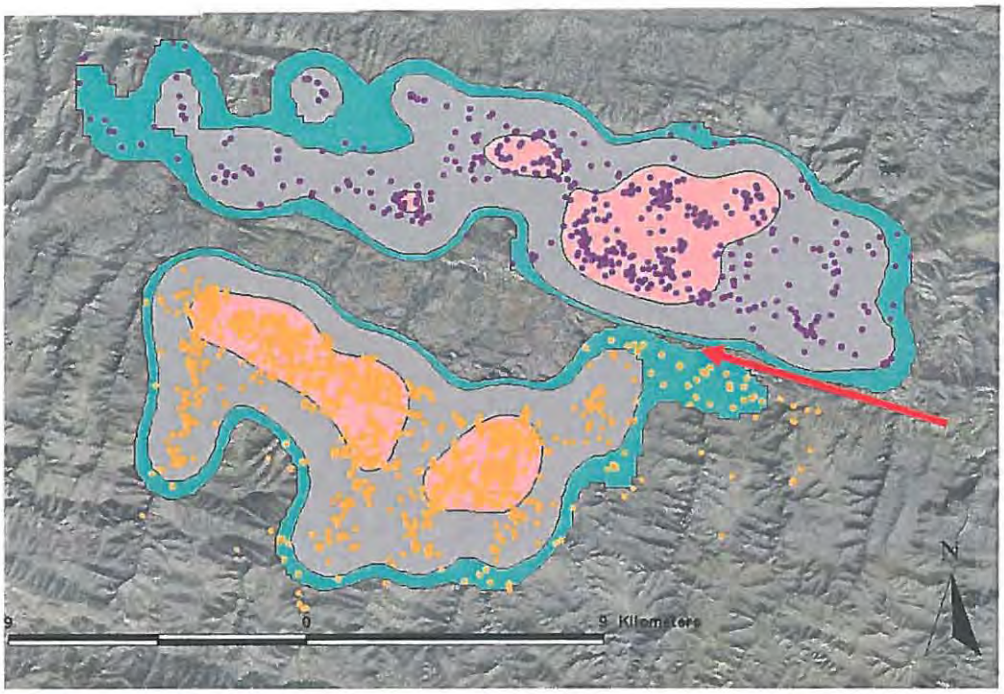


Figure 4.4 Female leopards 3710 (north; purple points) and 3704 (south; mustard points) showing the minimal overlap of home ranges (red arrow). Kernel UDs shown are 50% (pink), 90% (grey) and 95% (green).

Between sexes

The data set in this study provided the opportunity to determine the extent of range overlap between leopards 3809 (male), and 3710 and 3704 (females). Within the 95 percent utilization distribution of female 3710, 93.57km² (72% of total 95% UD of female) was covered by male 3809 (Figure 4.5). Similarly, 72% (76.4km^2) of the 95% UD of female 3704 was covered by the same adult male leopard (Figure 4.5). At the core area level (50% UD), the male overlapped the core area of female 3710 by 8.3km² (37.8% of female core area) but did not overlap the core area of the other female (Figure 4.5).

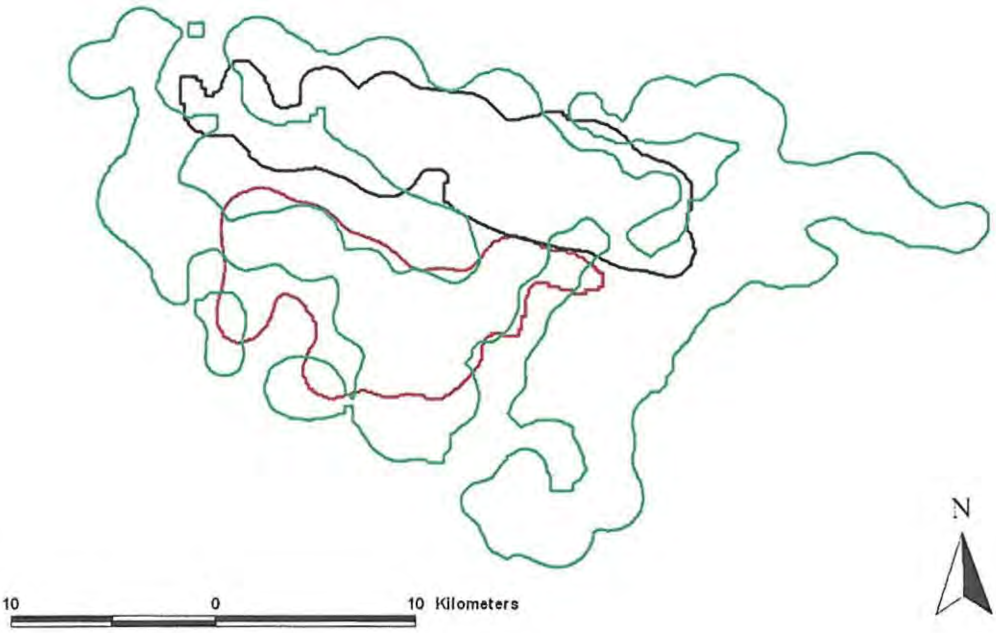


Figure 4.5 The overlap of home ranges (95% UD) between male 3809 (green) and females 3704 (red), and 3710 (black).

Estimating Population Density using home range size

The mean 95% UDs for male and female leopards were 244.3km² and 115.6km² respectively (Chapter 3; Figure 4.5). Since it appears that the home ranges of female leopards do not overlap, the density of adult females will be about 0.9 /100km^2. Assuming that male home ranges are also exclusive while overlapping extensively with those of females, the density of adult male leopards will be approximately 0.4/100km^2. The overall density (adult males and females) will be about 1.3 leopards/100km^2.

All of the vegetation types within the Baviaanskloof were used by leopards, although some were used less than expected, and for this reason I have used the entire 2665km^2 of the Baviaanskloof to calculate maximum possible density in the area. The 2665`km^2 of the Baviaanskloof should hold 23.17 adult female leopards and 10.9 adult male leopards with a total adult population of 34.07 leopards. Based on the MCP method, which generated larger home range sizes (Figure 4.6 and Chapter 3), the Baviaanskloof could support 17.6 females and 7.8 males with a total of 25.4 leopards (0.95 animals/100km^2).

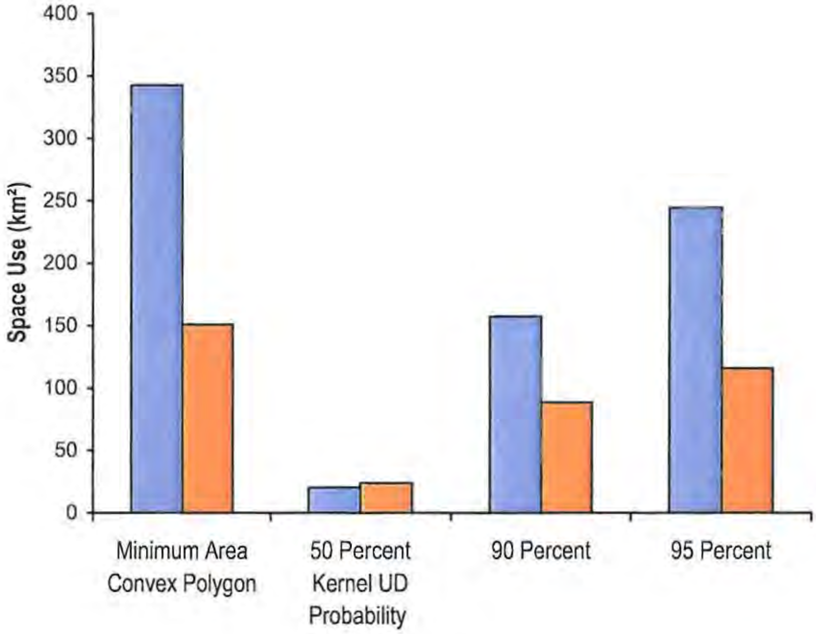


Figure 4.6 Indicates the average range use by male (blue) and female (orange) leopards at 50%, 90% and 95% UD as well as the MCP estimate (Data from Chapter 3).

These estimates of leopard density based on home range size and zero overlap within sexes, fall within the range of estimates based on the camera trapping survey (Table 4.3).

Table 4.2 A comparison of estimates of leopard population density in the Baviaanskloof. The first four estimates are based on camera trap results using different methods to calculate the area sampled (data from Table 4.1). The final two estimates are based on estimates of home range size and zero overlap.

Method		Density estimate (leopards/100 km^2)
Camera Traps	Buffer calculation	
	Recaptures	
	Half MMDM	3.2
	Full MMDM	1.1
	GPS Collars	
	Female MMDM	0.9
	Combined MMDM	0.4
GPS Data (home range size)		
95%UD		1.3
MCP		0.95

DISCUSSION

Estimation of leopard density in the Baviaanskloof

In this study a number of different approaches have been used to establish the density of leopards in the Baviaanskloof. Each has its advantages and disadvantages and it is hoped that the use of multiple methods may result in a more robust understanding of leopard density.

Data from the camera trap survey have been used in various ways to contribute to the estimation of density. Trap success which is the number of camera trap nights per picture, correlates with tiger density across a wide range of studies (Carbone *et al.* 2001). Using the data from Carbone *et al.* (2001), Wallace *et al.* (2003) have shown a close fit between estimated densities of jaguars based on camera trap success and based on capture-recapture methods. Assuming that the relationship established for tigers can be applied to leopards in the Baviaanskloof, a capture rate of 72 trap nights per leopard picture would generate a density of about two leopards per 100km^2. However, it is important to not that camera traps were placed so as to maximise the likelihood of photographing leopards so that the capture rate in the Baviaanskloof will be inflated as will the estimated density. Using the camera traps, the number of unique leopards photographed reached an asymptote of four after 417 trap nights and no further leopards were photographed in the following 1383 trap nights. Thus it is reasonable to assume that the population in the area sampled was three adults and one sub-adult.

This excludes the possibility of transient adults and dispersing sub-adults that can be expected to move through the area (Mizutani and Jewel 1998) but the fact that these were not detected in a three month survey suggests that these encounters did not occur within the survey period in the sampled area. To estimate leopard density, the area sampled must be known and this has been calculated in the present, and other studies, in a number of ways (Soisalo and Cavalcanti 2006).

An accurate estimation of sampled area is crucial as underestimates will inflate the estimated population density and may result in poor management decisions (Soisalo and Cavalcanti 2006). Soisalo and Cavalcanti (2006) compared several methods of calculating the size of the area sampled and concluded that the widely used estimated MMDM method (based on distance between locations at which the animal was caught and re-caught) underestimated distance travelled and inflated estimates of density. They conclude that the buffer width should be calculated either from known home range size or (preferably) from known daily distance travelled. The same trends were seen in the present study where the traditional estimated MMDM method gave the shortest distance travelled, the smallest area sampled and greatest density (3 leopards/100km^2). When the buffer width was based on known daily distance travelled (from GPS collars), the distance travelled was greater, the sampled area was greater and the estimated density ranged from 0.3 leopards/100km^2 to 0.4 leopards/100km^2. The variation in estimated density is simply due to fact that the average distance travelled per day was slightly smaller for females than for males and females together.

For comparative purposes, the density of leopards was also estimated using known home range size and overlap of space use. The data from the present study indicated little or no overlap of space used within a sex, but extensive overlap of space used between the sexes. The home range of adult female leopards was about 115km^2 and males, 244km^2 giving maximum possible densities, in the absence of overlap, of 0.9 female leopards per 100km^2 and 0.4 male leopards per 100km^2. The total of 1.3 leopards (both male and female) per 100km^2 is about 4 times the estimated density generated from the camera trap survey when the buffer width was calculated using known daily distance travelled. The maximum density of leopards in the present study was 3.2 per 100km^2 where the buffer was calculated as half the estimated mean maximum daily distance travelled. Although this value has been used in some earlier studies, it is criticised by Soisalo and Cavalcanti (2006) and there is no justification for halving the distance and it should be considered as an underestimate of the sampled area and discarded. The minimum estimates of 0.3 and 0.4 leopards per 100km^2 were generated when the buffer width was based on real MMDM. In this case, the sampled area was the maximum possible and therefore densities should be regarded as the minimum possible. Three methods yielded estimated densities between 0.4 and 1.1 leopards per 100km^2 and it is probably wise to suggest that the density of leopards in the Baviaanskloof ranges from a minimum of 0.3/100km^2 to a maximum of 1.3/100km^2. Few studies have reported densities of leopards, but based on reported home range sizes and some reports of density, the density in the Baviaanskloof is low.

On a ranch in Kenya where home ranges are small, the density of leopards is about 12 leopards/100km^2 (Mizutani and Jewel 1998) and in the Tai National Park, home ranges are 85km^2 (male) and 24km^2 (female) and the density of leopards is about 10 animals per 100km^2 (Jenny 1996). By contrast, in the Kalahari, home ranges exceed 2000km^2 and despite considerable range overlap (Marker and Dickman 2005), density is less than 1 leopard per 200km^2. The variation in density is explained primarily by the variation in home range size which is affected primarily by variation in the abundance and distribution of resources (see discussion from Chapter 3). Population density is not fixed and social organisation should adapt, either by increasing range overlap or reducing range sizes when a change in prey availability occurs (Benson *et al* 2006). Density may also be affected by various anthropogenic activities such as problem animal control operations (Tuyettens *et al.* 2000; Lynch 2008). The removal of specimens results in an increase in range size of those remaining and an initial reduction in density (Lynch 2008). This may be followed either by the arrival of a conspecific to fill the vacated space (personal observations), or by increased reproductive output (Harrison-White 2008).

Overlap of home ranges

The results from the present study indicate very little or no overlap of home ranges within the sexes and a large overlap between the sexes. However, this is not the case in all regions and a number of studies have reported differently levels of range overlap both within and between sexes (Mizutani and Jewel 1998; Marker and Dickman for reviews).

Although there is no clear relationship between the extent of overlap and either range size or resource availability (see Table 3 in Marker and Dickman (2005)) overlap between males, and between males and females, is reported more often than overlap between females (Marker and Dickman 2005). Theoretically, the likelihood of overlap should increase with increasing range size as large ranges are more difficult and more expensive to patrol (Mizutani and Jewell 1998).

This is illustrated in Namibia and the Kalahari where male home ranges are very large and overlap between males, and between females is between 20 and 40% (Marker and Dickman 2005; Bothma and Bothma unpublished). However, high levels of overlap have also been reported in areas such as the Kruger National Park, where resources are abundant and home ranges small (Marker and Dickman 2005). In the latter case, it has been suggested that surplus food allows several leopards to use the same area (Bailey 1993; Mizutani and Jewel 1998). The extensive overlap at the home range level between males and females is not surprising and allows the resident male to assess the reproductive status of several females. At the core area level, there is no overlap of space used within a sex (Baily 1993; Marker and Dickman 2005; Bothma and Bothma unpublished; present study) suggesting that while leopards may tolerate other leopards of the same sex within their home range, they maintain exclusive core areas.

It should be noted that while overlapping home ranges may suggest that space is shared; leopards may be separated in other ways such as by using the common space at different times.

CONCLUSION

The combination of techniques used in this study provided a basis for analysing how sample area size calculations can affect population density estimates. A major factor influencing density calculations is affected largely by sample area size. The buffer calculation used to produce the effectively sampled area is a crucial factor during camera-trapping capture-recapture surveys, as it ultimately affects population density estimates (Soisalo and Cavalcanti 2006). Overestimations using MMDM methods can produce concerning overestimation in calculating population densities as this affects management decisions. Camera-trapping can deliver a biased representation of the movement of the animals, while the information from GPS data collars is a more accurate representation of their movements and, consequently of the effectively sampled area size which is crucial in calculating final density populations (Soisalo and Calvalcanti 2006).

The results of camera trapping to determine population density was between 0.4 to 2 leopards per 100km² equating to 10.6 to 53.3 leopards in the Baviaanskloof assuming the entire area can support a similar density. The use of real distance travelled data from GPS collars resulted with 0.4 to 1.3 leopards per 100km². Therefore, assuming that all the area can support a similar density, the Baviaanskloof hosts between 10.66 and 34.6 adult leopards. Great care should be heeded when using only camera traps where real movement data is not available. I suggest that MCPs' and the 95% UDs' are best when calculating population density.

Therefore, where possible, when determining the size of effectively sampled areas, existing studies of the same species and their known home ranges in the relevant regions are useful to add when deciding the size of the buffer width, rather than using MMDM from camera trapping alone (Soisalo and Cavalcanti 2006).

CHAPTER 5

ACTIVITY PATTERNS

INTRODUCTION

In predators, activity is principally associated with the acquisition of food and to a lesser extent, territorial maintenance and reproduction. It is not surprising therefore that a key factor determining the time of activity is hunting success (Van Orsdol 2008). However, activity patterns are flexible and vary in time and space, and important factors such as the presence of a superior predator or human activity may result in an adjustment to activity patterns. For example, it is suggested that cheetahs (*Acinonyx jubatus)* may hunt during the day (morning and evening) to avoid nocturnally active sympatric lions (Durant 1998; Sunquist and Sunquist 2002). In Israel, Blanford's fox (*Vulpes cana*) is strictly nocturnal and it is suggested that this is to avoid diurnally active birds of prey (Geffen and Macdonald 1993). Many studies indicate that different species including black bears (*Ursus americanus*), bobcats (*Felis rufus*), coyotes (*Canis latrans*) and leopard (*Panthera pardus*) have modified activity patterns in areas of increased human activity (Beckman and Berger 2003; Tigas *et al.* 2002; Ngoprasert *et al.* 2007) and many canids become more nocturnal in areas with high human persecution (Sillero-Zubiri *et al.* 2004). Leopards tend to have different calling patterns in areas with high levels of human activity (Eisenberg and Lochart 1972; in Eisenberg 1981).

Leopards are generally thought to be nocturnal, hunting alone at night and to be mostly inactive during the day, resting in areas that provide cover (Bothma and Le Riche 1994; Jenny and Zuberbuhler 2005). However, most available evidence for this comes from savannah and arid habitats and little is known about leopards in mountainous, more mesic areas such as the Eastern Cape Province. One of the aims of this chapter is to establish patterns of activity in this region and to assess if and how patterns of activity differ from those reported elsewhere.

Patterns of leopard movement have been reported in a number of studies and in general, adult male leopards move greater distances than adult females (Mizutani and Jewell 1998; Marker and Dickman 2005, for review). The aims of this chapter is to use data from GPS collars to report on distance travelled by adult male and female leopards in the Baviaanskloof and to test the assumption that males will move further than females, and to identify and assess changes in monthly activity patterns.

METHODS

The GPS collars were programmed to collect GPS locations assuming that the leopards would be inactive during the day. Thus, the GPS collars were programmed to record locations at 02:00, 05:00, 17:00, 20:00 and 23:00. One of the collars was programmed to collect GPS locations at 05:00, 08:00, 16:00 and 20:00 to encourage longevity of the collars battery life. To accommodate the different numbers of hours between data collection by the different collars, movement has been standardized per hour. The distances moved between GPS points were estimated using the Home Range Tool for ArcView GIS 3.3 (Hooge and Eigenlaub 1997). This measures the straight line distance between consecutive points and is thus a minimum for distance moved by a leopard.

Data have been analysed at three different time scales; within a single day, across multiple days, and over multiple months. Within a single day, data from the GPS collars only were used as they were programmed to collect locations at the same times (n = 4; one male and two female in the Baviaanskloof, and one male in the GAENP). It was however possible to include data from the additional GPS collar, on a male in the Baviaanskloof, when comparing distance moved in the day (05:00 to 20:00) and at night (20:00 to 05:00) as both sets of collars included these times for data collection.

Across multiple days, I calculated and compared the mean daily movement for 50 consecutive days per leopard using data from all five leopards. Over multiple months, I calculated and compared the total distance covered per month for all five leopards.

For this analysis, the total number of fixes per animal varied and the dates monitored varied as each individual was captured at different times (Chapter 2, Table 2.1).

Unfortunately the cellular GSM collar fitted to female 1038 did not record daily positioning points constantly enough to analyse distances or activity patterns and data were available for 2 males and 2 female leopards in the Baviaanskloof and one male in GAENP. Distances travelled per unit time were compared using ANOVAs, t-tests and appropriate post hoc tests (or their non parametric equivalent) as applicable in Statistica (Statsoft, version 7.0)

RESULTS

24 Hour movement patterns

Distance moved varied between about 0.1 and 0.4km/hour through a day, with a trough (0.09±0.05km/hour) between 05:00 and 12:00 (Figure 5.1). However, in an ANOVA with sex and time of day as categorical variables, there was no significant effect of sex ($F_{1,12} = 1.0$; $P>0.05$) or time of day ($F_{5,12} = 2.1$; $P>0.05$). When the daily data were pooled to allow comparison of distance moved per hour at night (17h00 to 05h00) and during the day (05h00 to 17h00) the results were similar and there was no statistically significant effect of sex ($F_{1,20} = 0.7$; $P>0.05$) or time of day ($F_{1,20} = 0.02$; $P>0.05$) on distance travelled per hour (Figure 5.2).

Total distance moved per day

Within the Baviaanskloof, mean daily movement of males (6.8±5.2km/day) was significantly greater than that travelled by the two female leopards (3.2±1.9km/day; Mann-Whitney Rank Sum test; $t = 1127$; n (small) = 99; n (big) = 198; $P<0.001$). The male leopard in the GAENP travelled 4.6±3.6km/day which was significantly less than that of the Baviaanskloof males (Dunn's Method post hoc test; $P<0.05$) and not different from the Baviaanskloof females (Dunn's Method post hoc test; $P>0.05$; Figure 5.3).

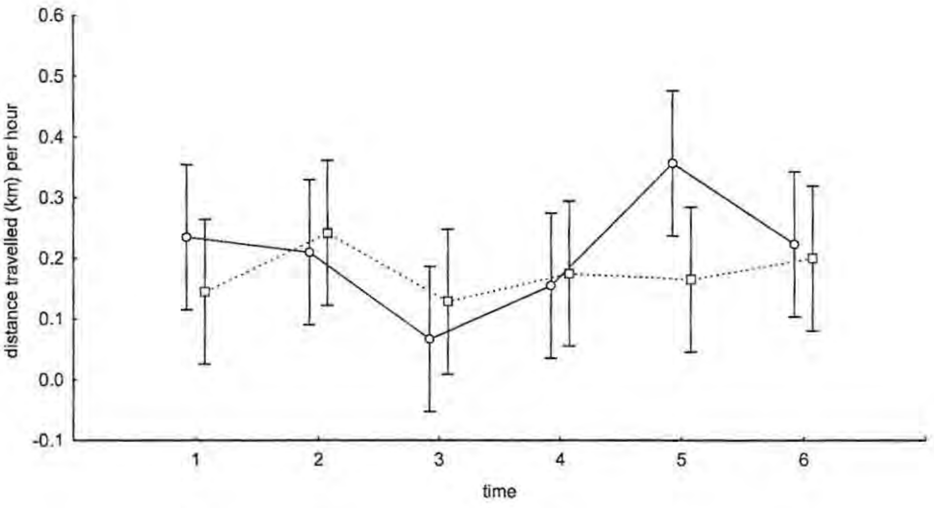


Figure 5.1 Distance travelled per hour by male (dashed line and circular symbol) and female leopards in the Baviaanskloof. Data are means ±0.95% confidence intervals. On the x axis, 1 = 23h00-02h00; 2=02h00-05h00; 3=05h00-12h00; 4=12h00-17h00; 5=17h00-20h00; 6=20h00-23h00.

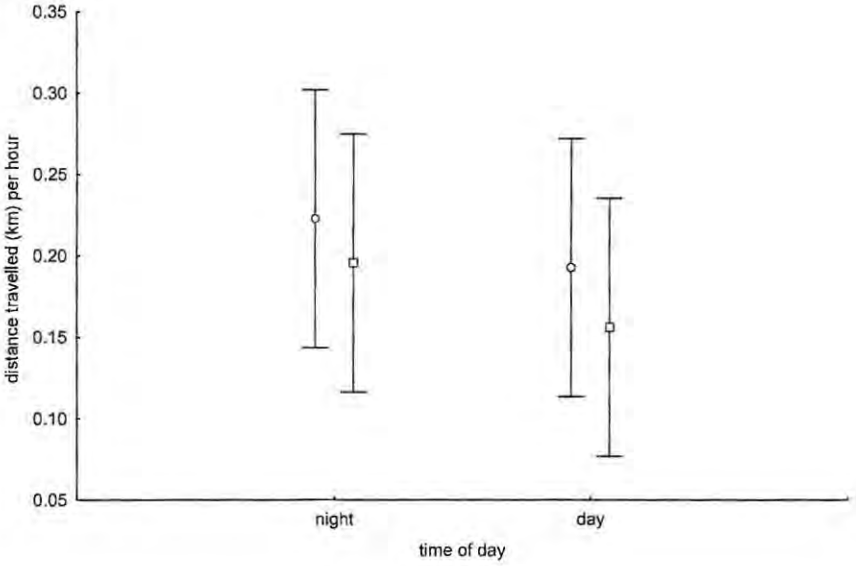


Figure 5.2 Distance travelled per hour at night and during the day by male (round symbols) and female leopards. Data are means ± 95% confidence intervals.

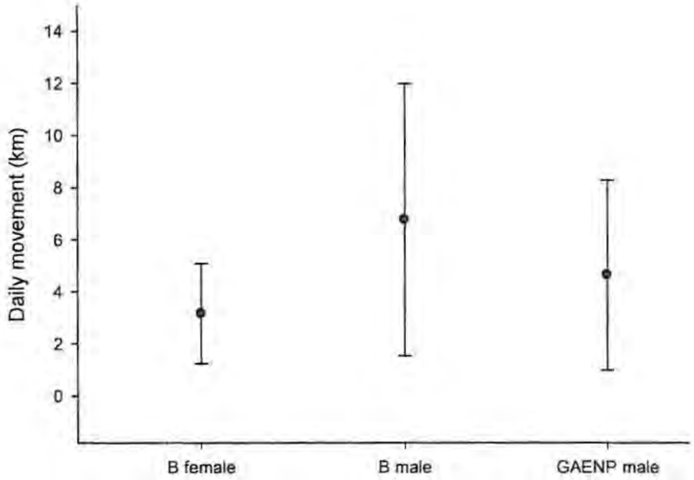


Figure 5.3 Movement of male and female leopards in the Baviaanskloof (B) and GAENP. Data are means ± 1sd daily movement (km).

50 Day activity patterns

Comparable data were available for five leopards and because pooling of data would conceal asynchronous patterns of activity, data are presented separately for each leopard.

Leopard 2996; male, GAENP

The 50 day daily distance survey revealed an average distance of 4.6±1.7km/day with a maximum of 11.9km and minimum distance of 0.06km/day (Figure 5.4; Table 5.1). The average distance travelled in one week was 32.3±12.4km with a peak of 52.9km and a minimum distance of 16.4km (Figure 5.9; Table 5.1).

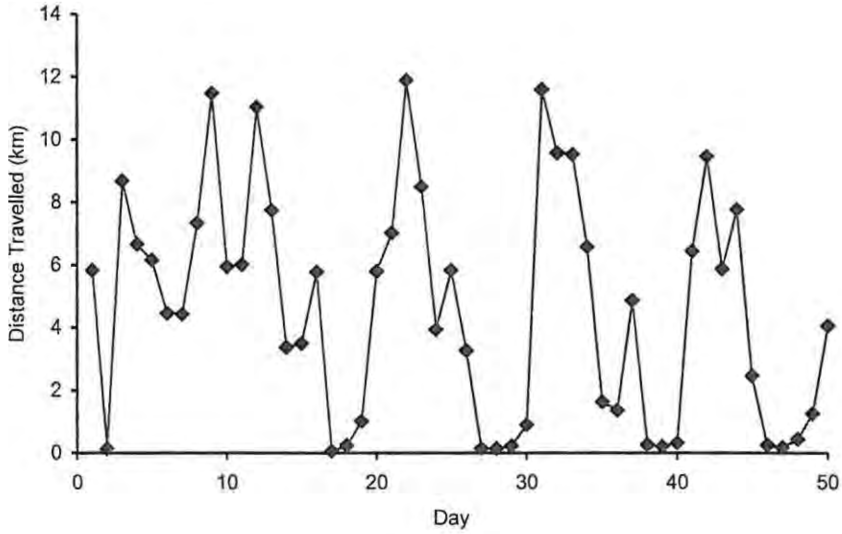


Figure 5.4 Daily distances travelled (km) by leopard 2996 within a 50 day survey period.

Leopard 2997; male, Baviaanskloof

Within the 50 day daily activity survey period, the average distance travelled was 3.2±0.8km/day, with a maximum of 7.3km and minimum distance of 0.01km (Figure 5.5). On average this male leopard covered 21.3±6.6km/week with a maximum of 27.8km and minimum of 9.8km (Figure 5.9; Table 5.1).

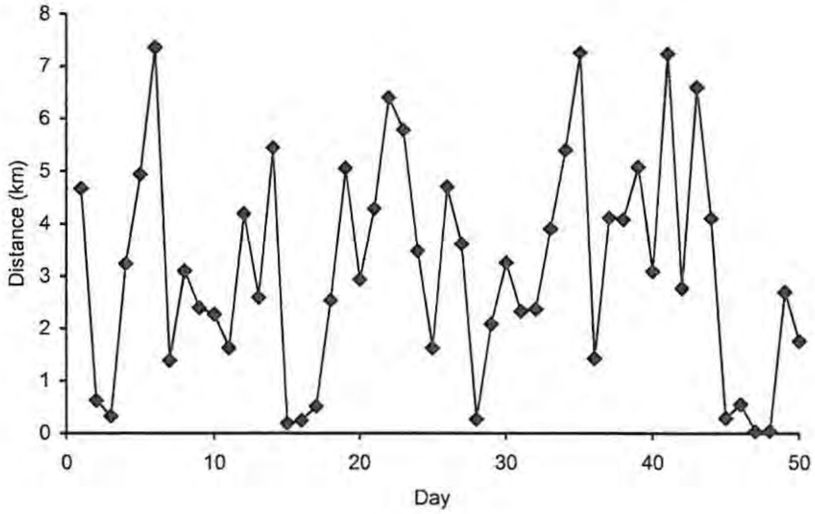


Figure 5.5 The daily distance travelled (km) by leopard 2997 during a 50 day survey period.

Leopard 3809; male, Baviaanskloof

During the daily survey period, the average distance travelled was 8.1±1.8km/day with a peak of 17km and a minimum distance of 0.2km/day (Figure 5.6). The mean distance the male covered during one week was 57.1±12.4km with a peak of 58km and minimum distance of 44km (Figure 5.9).

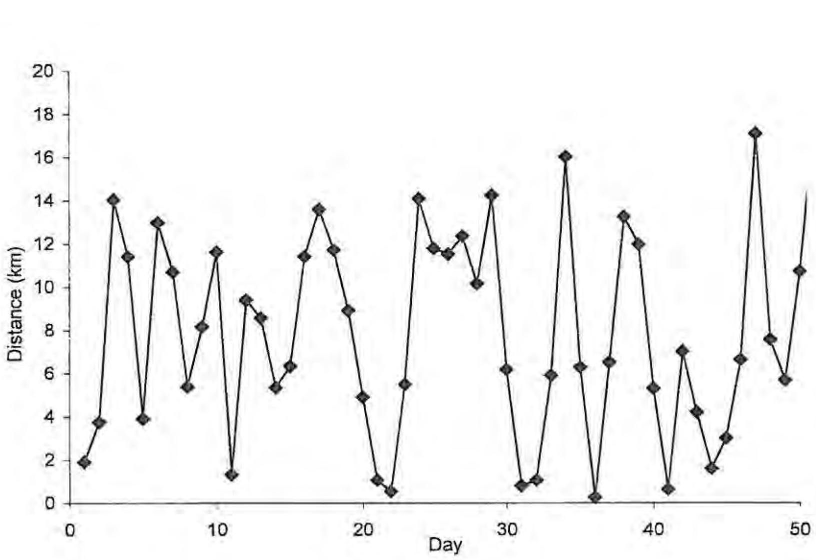


Figure 5.6 The daily distance travelled (km) by leopard 3809 within a fifty day survey period.

Leopard 3710; female, Baviaanskloof

The average distance travelled per day over 50 consecutive days was 21.7±0.8km with a maximum daily distance of 6.9km and a minimum of 0.07km. The average distance travelled per week was 19.6±4.7km with a maximum of 29.1km and a minimum of 14.0km (Figure 5.9).

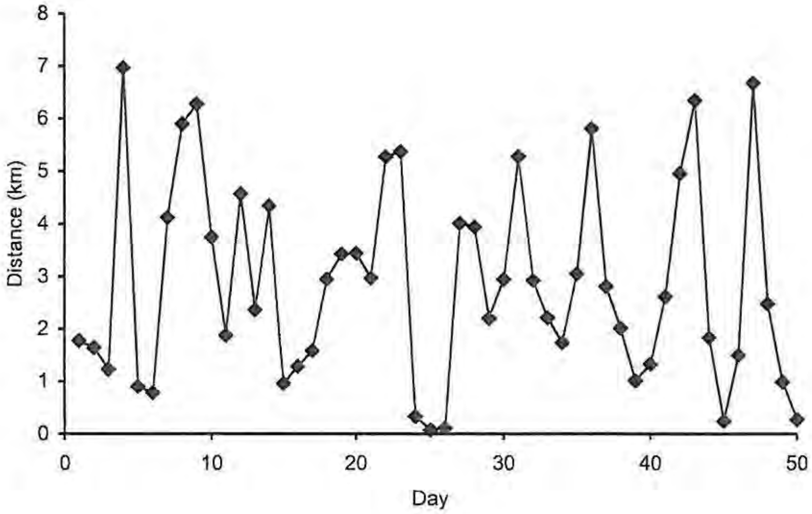


Figure 5.7 The daily distance travelled (km) by leopard 3710 during a 50 day survey period.

Leopard 3704; female, Bavianskloof

The average distance travelled per day over 50 days was 3.5±1.0 km with a maximum of 8.9km and a minimum of 0.2km (Figure 5.8). On average this female moved 25.1±7.1km with per week, with a peak of 32.7km and a minimum distance of 14.6km (Figure 5.9).

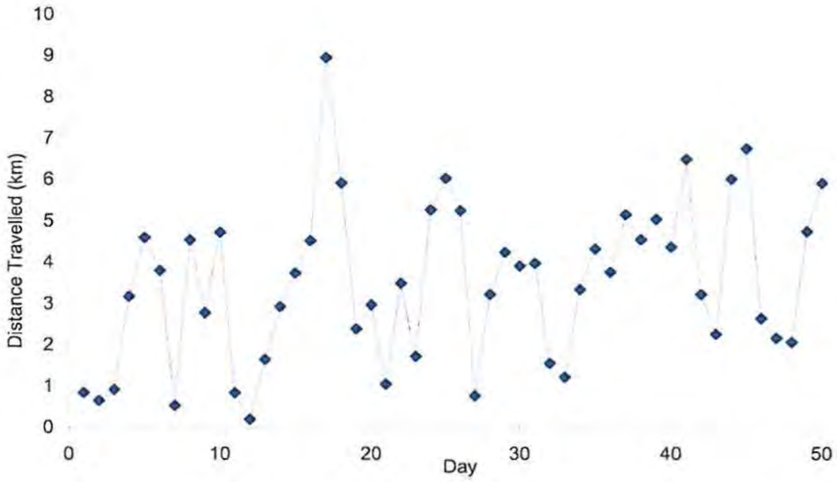


Figure 5.8 The daily distance travelled (km) by leopard 3704 during a 50 day survey period.

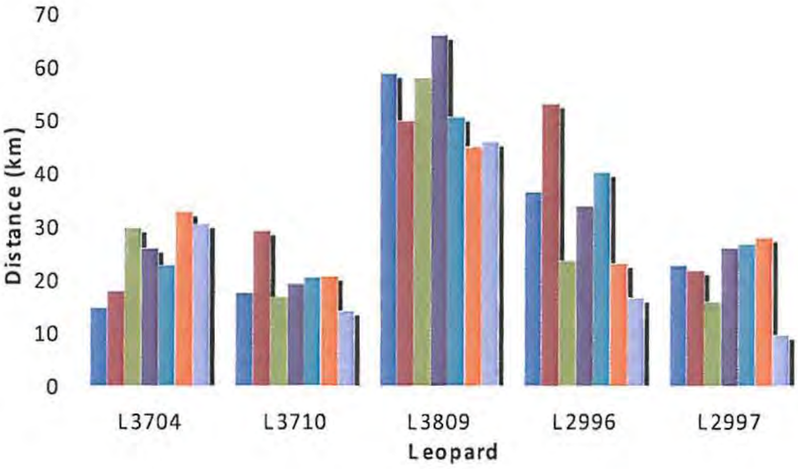


Figure 5.9 The total distance travelled by each leopard for seven consecutive weeks.

To summarise, all the leopards showed a similar pattern of movement with periods of high daily distance travelled separated by periods of much reduced movement. During the periods of increased activity, the distance covered per day varied between the leopards, with one male (3809) covering almost twice the distance of the others (Table 5.1). During the periods of reduced activity, the leopards all moved between 1 and 2km/day. There was a positive correlation between home range size (95%UD) and mean monthly distance travelled ($r^2 = 0.89$; $P<0.05$). However, this was driven strongly by male 3809 which had a very large home range and travelled the furthest.

Monthly activity patterns

As indicated previously, the availability of data was determined by when leopards were caught and collared rather than by experimental design. Although the latter would have been preferable, it was not possible to guarantee when an animal would be captured. Consequently, data for the different leopards covered different time periods and were not directly comparable. In an attempt to establish if there was any seasonal change in distance moved per month, the available data were plotted on a single graph (Figure 5.10). Although the actual distance travelled per month varied between the leopards, there is some evidence of a repeated pattern with reduced distances (<100km/month) travelled in February and March 2007 and 2008 (Figure 5.10). There was no significant effect of month on mean daily distance travelled for male leopard 2996 (ANOVA, $F_{12,1883} = 0.34$; $P>0.05$) but for male leopard 2997 daily distance travelled did vary significantly between months ($F_{11,1776} = 5.07$; $P<0.001$) with a significant peak in daily distance travelled in April (Figure 5.10). Mean daily distance travelled by female leopard 3704 also varied significantly between months ($F_{10,1473} = 5.01$; $P<0.001$) with an increase in daily distance travelled from April onwards (Figure 5.10).

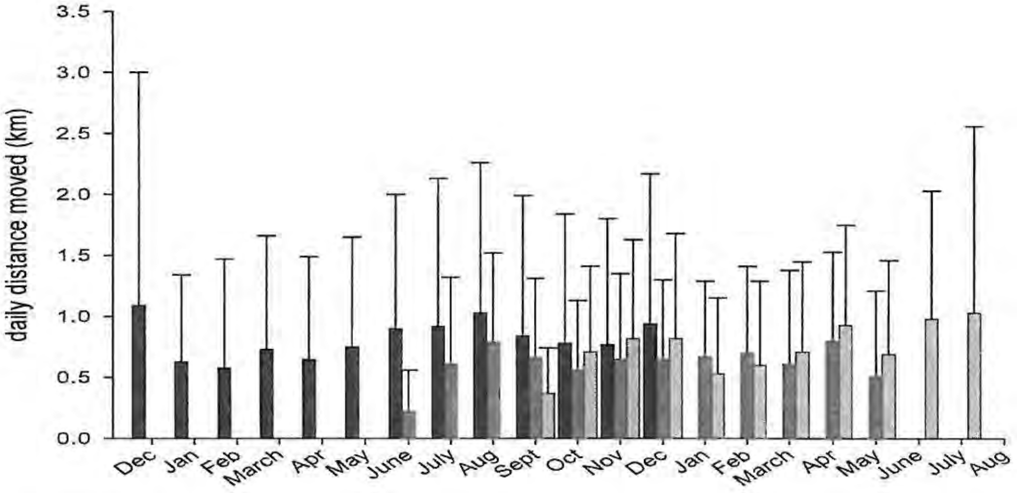


Figure 5.10 Mean daily distance travelled each month by male leopard 2996 (black bars), male leopard 2997 (red bars) and female leopard 3704 (green bars). Data means ±1sd. X axis is months from December 2006 to August 2008.

Table 5.1 Summary of the average distances travelled by male and female leopards (GAENP = A and Baviaanskloof = B) per day, week and month.

Male Leopards Collar Number	Study Site	Average Distance Travelled (km)			Female Leopards Collar Number	Study Site	Average Distance Travelled (km)		
		Per Day	Per Week	Per Month			Per Day	Per Week	Per Month
2996	A	4.6±1.8	32.3±12.4	119.8±22.9	3704	B	3.5±1.0	25.1±7.1	105.9±41.9
2997	B	3.2±0.8	21.3±6.64	101.4±17.02	3710	B	2.7±0.8	19.6±4.7	75.3±17.5
3809	B	8.1±1.8	57.2±12.4	254.1±18.4					
Average		5.3	36.9	158.3			3.1	22.4	90.6
Stdev		2.52	18.39	83.35			0.56	3.89	21.63

DISCUSSION

The results from the present study show no significant diel pattern of activity for leopards in the Baviaanskloof. Previous studies have reported leopards to be strongly nocturnal (Sunquist and Sunquist 2002; Skinner and Chimimba 2005) although a study of forest leopards in Tai National Park, reported that leopards show strong diurnal and crepuscular activity (Jenny and Zuberbuhler 2005). The results for the Baviaanskloof are more similar to those from the Tai National Park than to those from more open and arid systems. Although the Baviaanskloof includes pockets of agricultural land where levels of human activity are elevated, and it is a region in which leopards have been persecuted, it is very remote and mountainous and the likelihood of human interference is otherwise low. In addition, the vegetation in the stream beds, which are selectively used by the leopards (Chapter 3), will offer high levels of cover. It is possible that this reduced human interference and the dense cover, as in the Tai Forest, explains the change in activity.

In the Baviaanskloof, male leopards covered a significantly greater total distance per day than female leopards and this has been reported in previous studies. In all of seven studies (see Table 3 in Marker and Dickman 2005) for which data were available, male leopards moved a greater distance per day than the females. This is simply explained by the fact that in most cases home ranges of males are larger than those of females and males will thus have to travel further.

However, male leopards are larger than females and sexes may differ in their hunting tactics (Bothma *et al.* 1997) and it is possible that the associated increased absolute energetic requirements may partly explain the greater distance travelled per day by male leopards.

The total distance travelled per day in the present study (male, 6.7km; female 3.2km) is greater than previously reported for all studies except two; one in the Kalahari where the home ranges were very large (Bothma *et al.* 1997) and the other in Bushmanland, Namibia, where home ranges were approximately double those of the present study (Stander *et al.* 1998). It is likely that differences in resource abundance and distribution affect range size, which in turn is strongly correlated with distance travelled per day.

Through a 50 day period, the leopards of the Baviaanskloof showed repeated periods of movement followed by periods with much reduced movement. As leopard activity is motivated by hunger, it is most likely that this pattern reflects the hunting activity of the leopards with periods of reduced movement occurring after a successful hunt. This supports Bothma and Le Riche (1997) who report that leopards in the Kalahari move increasingly longer distances per day as the number of days since the last successful hunt increased. The apparent seasonal pattern of movement, with increased distance travelled in April and from April onwards for one female is hard to explain and further, long term data are required. However, leopards do not reproduce seasonally (Le Roux and Skinner 1989) so it is unlikely to be associated with a reproductive event. It may be associated with a change in activity or abundance of an important prey item and this could be the target of future research.

CONCLUSION

The results from the Baviaanskloof support those from a previous study in a forest region (Tai National Park) and suggest that under certain conditions, leopards are far more active during the day than often reported. Distances moved per day are strongly affected by range size which is probably affected by resource abundance and distribution.

CHAPTER 6

TOWARDS THE MANAGEMENT OF LEOPARDS IN THE BAVIAANSKLOOF AND OTHER OPEN SYSTEMS

INTRODUCTION

Worldwide, carnivore populations are exposed to strong external pressures as their requirements often conflict with those of local people (Woodroofe and Ginsberg 1998; Frank *et al.* 2003; Ogada *et al.* 2003). Where carnivore populations cross the boarders of protected areas or reside in private rangelands, intentional or accidental killing by humans frequently limits their numbers (Frank *et al.* 2003). Even in protected areas, conflict with humans is usually the single most important cause of adult mortality such that it causes declines comparable with harvested populations of the same species (Mills 1991; Woodroofe and Ginsberg 1998; Hoogesteijn 2002; Frank *et al.* 2003; Ogada *et al.* 2003).

An estimated 8-13 % of the potential range of leopards is within national protective areas (Boitani *et al.* 1999; Marker and Dickman 2005), highlighting the importance of private land in the future conservation of leopards (Marker and Dickman 2005). In South Africa, Daly *et al.* (2005) suggest that only Kruger National Park and Kgalagadi Transfrontier Park are large enough to maintain genetically viable leopard populations. Although the recent increase in private game reserves in South Africa may be seen to relieve the persecution of predators (Kharika 2005), these reserves are mostly small ($300km^2$) and in many cases used for hunting. Populations in small reserves will not be genetically viable, and large mammalian predators tend not to be tolerated on game reserves that are used for hunting as they compete with the hunters for valuable prey species (Hunter and Balme 2004).

Even if the game reserve is not used for hunting, leopards are rarely constrained by fences and will move into adjacent areas where they may come into contact with farmers or hunters. In this respect, the edge effect is relevant. Woodroofe and Ginsberg (1998) have suggested that the species most likely to disappear from small reserves are those that range widely (such as the leopard), and are therefore exposed to threats on reserve boarders. Proximity to a reserve border affects both habitat use and activity patterns in leopards and tigers (Ngoprasert *et al.* 2007). It has been suggested that both stochastic processes and strong edge effects will contribute to the extinction of isolated populations of large carnivores (Woodroofe and Ginsberg 1998). This further suggests that human-induced mortality contributes more to the extinction of populations of large carnivores isolated in small reserves than do stochastic processes, and conservation practices must seek to not only maximise reserve size (Woodroofe and Ginsberg 1998), but to mitigate carnivore persecution on privately owned land and reserve borders. Much of this is clearly pertinent to the conservation of leopards which range widely covering both conserved and farmed land (Mizutani and Jewel 1998), and the management of leopards outside conservation areas may be central to the conservation of the species (Marker and Dickman 2005). Indeed, the importance of game ranches and privately owned land in South Africa and Namibia is becoming recognised in the conservation of free roaming cheetahs, leopards and wild dogs (Marker *et al.* 2003; Lindsey *et al.* 2005; Marker & Dickman 2005).

The conservation of leopards in the Baviaanskloof requires a holistic approach, which will address a diverse range of questions. Aspects of the spatial ecology of leopards in the area need to be considered carefully in management planning [including density, space use, habitat selection and movement patterns and how these differ in areas under different land use (conservation or agriculture)]. Persecution of predators on privately owned land can not continue, especially when there are as few as 1.3 leopards/100km² (Chapter 4) and alternative, more effective management tools available.

The Baviaanskloof is a large, remote, mountainous region that is both suitable habitat for leopards and also used extensively for small livestock (sheep and goat) farming. Results from the preceding chapters indicate that, in comparison with other studies from other parts of their range, leopards in the Baviaanskloof, occupy relatively large home ranges, travel long distances per day and occur at a low density. That they come into conflict with farmers in the region is well known and both stock losses and the persecution of leopards is documented (Esterhuizen and Norton 1985; Stuart *et al.* 1985). Conflict between predators and livestock farmers in the mountain areas of the Eastern Cape Province dates back to the settlers (1600's) and bounty systems were put in place to eradicate these animals (Esterhuizen and Norton 1985). Between 1977 and 1980, more than 110 leopards were killed legally within the then Cape Province alone (Stuart *et al.* 1985) and the number killed illegally may well be much higher. According to the Eastern Cape Department of Environmental Affairs and Tourism, 28 individuals are known to have been killed in the Baviaanskloof region since 2004 and again these numbers are considered to be conservative.

The justification for this persecution of leopards is that the farmers need to protect their livestock and their livelihoods. Between 1977 and 1982, an average of 690 leopard-related stock deaths were reported per year in the former Cape Province alone (Esterhuizen and Norton 1985). Although seemingly insignificant on a large scale, such losses can be magnified at the level of the individual farmer who may lose a significant percentage of his or her stock.

Although lethal control through hunting and gin-traps has been used widely to control problem predators, there is evidence that it does not result in a reduction in predation on livestock. Berger (2005) found that government-subsidized predation control on coyotes (*Canis latrans*) in U.S.A. was ineffective at preventing sheep losses and that simply killing carnivores was not improving the sheep industry. In South Africa, lethal control has been used to limit livestock losses due to predation by black-backed jackal (*Canis mesomelas*). The eradication of individual jackals is indiscriminate and ineffective and in many areas where intense hunting takes place, the problem of depredation remains (Harrison-White 2008.). What is often overlooked is the fact that livestock lost to natural mortality is often greater than to predation (Butler 2000). In Zimbabwe African wild dogs (*Lycaon pictus*), spotted hyaenas (*Crocuta crocuta*) and leopards (*Panthera pardus*) killed cattle amounting to 0.4% of all stock on ranches, while disease accounted for 2.2% of the stock (Butler 2000). On a ranch in Kenya wild carnivores killed 2% and 0.8% of sheep and cattle, while disease killed 7.8% and 2.2%. Therefore, although depredation is considered a problem, natural mortalities often cause greater financial losses (Butler 2000). Non-the-less, historically prevailing attitudes and practices have been that leopard conservation and stock farming are incompatible (Stuart *et al.* 1985).

There is a perception that the mere presence of predators brings with it the consequence of depredation of livestock, resulting in their extermination, even in the absence of loss of livestock (Hoogestiejn 2002).

Mills (1991) has suggested that there is a need to change the approach to predator control and that the main aim of predator control should be to reduce the damage caused by predator's at the most economic price. This would entail the management of livestock rather than killing the predators (Mills 1991). This proposal has been supported by the development of robust scientific arguments against lethal 'predator control' and the development of nonlethal approaches to carnivore management. Together, these have created the opportunity to move away from lethal control of predators towards a more holistic approach that permits carnivore populations to remain in tact, and improve, despite human population growth (Treves and Karanth 2003). However, the attitudes of many private land owners towards carnivores are difficult to change (Eaton 1978; pers obs.), while others are open to change that can lead to an increased tolerance towards carnivores. The latter is usually achieved when economic benefits are readily available (Hunter and Balme 2004; Lindsey *et al.* 2007; pers obs.).

Compensation systems have been widely dismissed as being impractical, expensive and vulnerable to exploitation (Stuart *et al.* 1985). However it has never been accepted by agriculturalists to suffer financial losses due to depredation caused by predators.

There are a number of ways in which compensation can be provided including through increased tourism, the provision of support of 'green' products linked directly to husbandry practices and direct financial compensation for loss. In 2004 the Landmark Foundation initiated a limited compensation scheme in the Baviaanskloof whereby they set up walk-in, fall door traps (See chapter 2) to capture perceived damage causing leopards. Once captured the animal was fitted with a GPS collar and, with the farmer's agreement, released on site. The landowner had to agree to forgo the use of lethal means of control and was advised on methods of improved animal husbandry that would reduce livestock depredation. If the landowner suffered livestock losses that could be attributed to the collared leopard, the Foundation reimbursed the farmer.

In this chapter, I present two case studies associated with the Landmark Foundation compensation scheme and discuss possible ways in which leopards and livestock can be managed to ensure the coexistence of predators and farmers and the conservation of leopards in large, open systems.

METHODS

Eight farmers in the Baviaanskloof were interviewed to gain information on predator control methods used in their areas. Seven farmers were interviewed in September 2007 using a simple questionnaire (Appendix 2) while the eighth farmer was interviewed verbally, but based on the questionnaire. All eight farmers had practised lethal control means (hunting and gin-trapping) to control predators and subsequently, under encouragement from the Landmark Foundation, initiated holistic, "predator friendly" control measures. The questionnaire and interview collected details of livestock losses and management costs during both phases, and this information has been used to establish and compare the costs and benefits of the holistic husbandry practises and the conventional lethal means of control.

RESULTS

The results are presented in the form of two case studies.

Case study 1:

Between 1984 and 2004, a farmer in the Jansenville district of the Eastern Cape Province, near the Darlington Dam section of GAENP, controlled problem predators such as jackal and caracal (*Caracal caracal*) by lethal means including hunting and the use of gin-traps. Hunting was carried out four times per year with two jackals or caracals killed per hunt at a cost of R8400 per year. Labour costs to monitor gin-traps were R15600 per year and the total cost of predator control efforts was R24000 per year. During the same period, the average loss of livestock to predators was 130 head of livestock per year. The typical value for a sheep or goat is R600 per animal and the loss of 130 animals per year has a total value of approximately R78000 per year.

In 2005, the farmer introduced two Anatolian dogs to protect 4500 head of small livestock on 120km^2. The year preceding the introduction of the dogs, 200 livestock had been lost to predators. With the introduction of the dogs, the loss to predators was reduced and, between 2005 and 2008, the average loss was 35 livestock per year. The Anatolian dogs cost R18000 per year to buy, feed and manage the dogs, as well as increase working dogs by one each year. The loss of the 35 livestock killed per year has a value of R21000. When the two methods are compared (Table 6.1) It is clear that the introduction of Anatolian dogs has resulted in the loss of fewer livestock, a reduction in costs and a total saving of about R63000 per year.

Table 6.1 Comparison of the costs of lethal control of predators and the use of Anatolian dogs.

		Lethal Control	Anatolian Dogs	Difference
Costs (Rand/year)		R24000	R18000	R6000
Losses	number	130 animals	35	95 animals
	value	R78000	R21000	R57000
Total cost		R102000	R39000	R63000

Case study 2:

The Landmark Foundation equipped several farmers in the Baviaanskloof with over 12500 'Dead Stop' protective collars for livestock (Mr. Klaas Louw, Cape Town, South Africa). Once the collars were fitted to the livestock I monitored the losses of seven of these farmers with a total of 7000 livestock over an 11 month period (October 2007 – September 2008). The collars cost R20 each, are reusable and are made of broad metal mesh which is epoxy-coated (Figure 6.1). Four different sizes are available for lambs or kids to adult sheep and goats.

Figure 6.1 Reusable 'Dead Stop' protective livestock collars provided to farmers to reduce livestock losses caused by leopard and other predators.

Reported losses from the seven farmers before the collars were fitted were 792 per year (11.3% of the 7000 stock) with a value of R 615200. The labour costs associated with monitoring the gin-traps was not estimated. During the 11 month trial period using protective collars, only three of the seven farmers reported stock losses. The total stock loss was 12 animals (0.17% of the 7000 stock) with a value of R7200.

When the two methods are compared (Table 6.2) the financial benefits of the use of protective collars is clear. Since the collars are reusable, their cost is not a recurring one and the financial benefit will increase with time.

Table 6.2 A comparison of the costs of lethal control of predators and the use of protective collars.

		Lethal Control	Protective collars	Difference
Costs (Rand/year)		Not estimated	R140000	
Losses	numbers	792	12	780
	cost	R615200	R7200	R608000
Total cost		R615200	R147200	R468000

The two case studies illustrate a number of points which are summarised and discussed here. Firstly, the case studies are based on qualitative data from questionnaires and interviews and it was possible to confirm the reported losses. However, the magnitude of the differences in stock losses reported before and after the initiation of "holistic" forms of predator control are so great any error in the estimation of stock losses is unlikely to make a difference to the interpretation of the results. Secondly, this analysis has looked at financial aspects only.

Gin-traps are indiscriminate killers and their removal will have resulted in reduced loss of a wide range of “non-target” mammal species. This is illustrated by the fact that in 2005 and 2006, while gin-traps were still being used in the second case study, at least three leopards were killed.

DISCUSSION AND RECOMMENDATIONS

The conservation of large, wide ranging mammalian predators such as cheetahs, leopards and African wild dogs is problematic. Genetically viable populations can be conserved in only the largest game reserves (Daly *et al.* 2005) yet the provision of additional space for conservation in Southern Africa is contentious. At the same time, Southern African has seen a development in small, private game reserves with more land set aside for wildlife, yet in most cases these make little contribution to predator conservation. Using this type of reasoning, several authors have suggested that the future of predator conservation lies in the management of these animals outside conservation areas. Woodroofe and Ginsberg (1998) have recommended that conservation practices must aim to maximise reserve size and reduce persecution on privately owned land. Mills (1991) highlighted the importance of proper livestock management in reducing depredation and thus the likelihood of persecution, and in Namibia the importance of privately owned land to the conservation of large predators is recognised (Marker *et al.* 2003, Lindsey *et al.* 2005; Marker and Dickman 2005). Except in the largest game reserves and the full fenced small reserves, it is the case that the large predators will occur across a mosaic of different land uses ranging from conservation areas on to land that is used for agriculture (Mizutani and Jewel 1998). Thus, conservation that is targeted only within the game reserve is an inefficient strategy to ensure long-term species conservation as the reserve will act as a source and the predators are likely to be persecuted as they disperse on to surrounding farm land (Woodroofe and Ginsberg 1998; Ngoprasert *et al.* 2007; Gavashelishvili and Lukarevskiy 2008).

The long-term survival of populations of large vertebrates is best achieved by protecting source populations and at the same time providing dispersal corridors and opportunities by linking with other populations (Gavashelishvili and Lukarevskiy 2008). It is therefore important to ensure the safety of the predators outside conservation areas, as identified by Mills (1991).

The above arguments have been presented for large predators in general but they apply very strongly to leopards. In addition, leopards are more capable than most predators of crossing fences and entering adjacent regions in which they may be considered a problem (Balme 2007). Historically, the method of choice for the control of problem predators in the Eastern Cape Province has been a legally sanctioned lethal one, and it has been argued that compensation schemes will not work (Stuart *et al.* 1985). However, the results from the present study suggest otherwise. The data suggest that alternative, 'holistic' livestock management strategies including the use of Anatolian dogs and protective collars can bring about a substantial reduction in livestock depredation. Furthermore, a simple costs analysis suggests that these approaches are financially viable. Livestock guarding dogs have been used for many years in the USA where they have been reported to bring about up to six fold reduction in stock losses (Andelt 2004). In Namibia, livestock guarding dogs have been introduced more recently where they have been very successful in reducing stock loss and are perceived to be economically beneficial (Marker *et al.* 2005).

However, the argument is not just a financial one and there are sound biological reasons for halting the use of gin-traps and other means of lethal control. Gin-traps kill non-target mammals thus affecting the biodiversity of the region.

Reducing the density, or removing the apex predator, in this case the leopard, from a region has the potential to have a significant effect on the community structure (see for example Pace *et al.* 1999; Schmitz 2003). In conclusion, the results from this study suggest that within the Baviaanskloof and GAENP, leopards occupied larger home ranges in comparison to elsewhere in the range and travelled longer distance each day. While the reason for the large home range is not known, it is suggested that it is probably an effect of prey density and perhaps levels of human activity. Home ranges in the Baviaanskloof were exclusive except that the home range of males overlapped that of several females. The large home ranges and absence of overlap within the sexes resulted in a relatively low density compared to what has been reported previously. As a result of the large home ranges, leopards occupy a mosaic of habitats ranging from game reserves to farmlands, and conservation efforts must ensure their safety across this mosaic. Under the existing paradigm of lethal predator control outside conservation areas, the conservation areas serve as sources with dispersing animals being subjected to persecution. Two case studies in the Baviaanskloof, in which more 'holistic' or 'biodiversity friendly' livestock husbandry methods were adopted, challenge this paradigm and suggest that the coexistence of farmers and leopards is possible.

Further adoption of these improved methods of animal husbandry would allow the development of dispersal corridors linking core leopard habitats (Gavashelishvili and Lukarevskiy 2008) such as the Baviaanskloof and will contribute to conservation of the species.

Ultimately management needs to be focussed on privately owned land. Conservationists and the relevant authorities need to educate, assist and work with the actual managers of biodiversity in South Africa, being the farmers and private landowners who manage 80% of the potential leopard range (Mackinnon and Mackinnon 1986). My research emphasises not only the need to safeguard protected areas, but to safeguard corridors that connect privately owned land adjacent to protected areas and beyond, by working with and incorporating private land owners in biodiversity management.

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APPENDIX A: Morphological Data Capture Sheet

Capture Log Sheet				
Collar number:		**Date:**	**Time:**	
Place Captured		Place Released Same site		
Tissue sample taken: yes no		GPS:		
Sex	Male	Female	Adult	Sub
Measurements				
Weight kg	Chest girth cm		Radio collar frequency	
Tail length cm	Shoulder height cm			
Stomach size /5	Neck girth cm			
Nose to tip of tail: cm				
	Top right canine	**Top left canine**		
	cm	cm		
	Bottom right	Bottom left		
	cm	cm		
Distance between top canines	cm			
Distance between lower canines cm			**Immobilisation**	
F/R Paw Pad length cm left toe to right toe Bottom left pad to top left toe	Pad width cm		Drug/dose: Dart in time Animal down time Top ups (time/dose) 1 2 3 4	
Photo Checklist: Face r I Teeth r I Body r I Tail r I Samples: Tissue Hair Blood Feaces Tooth Ectoparasites				
Distinguishable characteristics and comments:				

APPENDIX B. Common and scientific names of mammalian species identified from camera traps and tracks and signs in the GAENP and Baviaanskloof.

Order Primate	
Chacma Baboon	*Papio ursinus*
Vervet Monkey	*Cercopithecus aethiops*
Order Lagomorpha	
Scrub Hare	*Lepus saxatilis*
Order Rodentia	
Cape Porcupine	*Hystrix africaeaustralis*
Order Hyracoidea	
Rock Hyrax	*Procavia capensis*
Order Tubulidentata	
Aardvark	*Orycteropus afer*
Order Carnivora	
Small Grey Mongoose	*Galerella pulverulenta*
Suricate	*Suricata suricatta*
Large Spotted Genet	*Genetta genetta*
Cape Fox	*Vulpes chama*
Bat-eared Fox	*Otocyon megalotis*
Caracal	*Felis caracal*
Leopard	*Panthera pardus*
Order Perissodactyla	
Burchell's Zebra	*Equus burchelli*
Order Artiodactyla	
Bushpig	*Potamochoerus porcus*
Bushbuck	*Tragelaphus scriptus*
Greater Kudu	*Tragelaphus strepsiceros*
Eland	*Taurotragus oryx*
Red Hartebeest	*Alcelaphus buselaphus*
Blesbok	*Damaliscus dorcas phillipsi*
Steenbok	*Raphicerus campestris*
Grey Duiker	*Sylvicapra grimmia*
Springbok	*Antidorcas marsupialis*
Cape Grysbok	*Raphicerus melanotis*
Gemsbok	*Oryx gazella*
Mountain reedbuck	*Redunca fulvorufula*
Grey Rhebuck	*Pelea capreoulus*
Red Hartebeest	*Alcelaphus buselaphus*
Blue Wildebeest	*Connochaetes taurinus*
Steenbok	*Raphicerus campestris*
Grey Duiker	*Sylvicapra grimmia*

APPENDIX C: A survey form to obtain economic feasibility of holistic husbandry practises.

The purpose of this survey form is to provide us with a better understanding of your views

The information gained from these forms will remain anonymous

A) General Information

Closest Town to your farm ____________________

Farm size (ha) ____________________

Terrain

Mountainous		Flat						
Vegetation present:		Grassland		Fynbos		Forest		Thicket
Are rivers present:		Yes	No	Perennial		Non Perennial		
Wild game is present on my farm:			Yes	No				
If yes, list species you are aware of:			Dassies		Porcupine		Duiker	
			Bush buck		Kudu		Other	

B) Questions and Answeres

Ek Boer met:/I farm with:			Losses per year		Season most losses occur
	Total	Losses per year	juveniles	adults	
Sheep					
Cattle					
Goats					
Ostriches					
Large game					
Small game					

Other					

I have the following predators on my farm:

Jackal ☐ Caracal ☐ Leopard ☐ Other ☐

I currently make use of the following methods to protect and control my livestock:

Dogs/alpacas ☐ Herdsmen ☐ Collars ☐ Kraals ☐

Leg-held traps ☐ Poisons ☐ Cage traps ☐ Other (please specify) ____________

My stock losses are mainly due to:

Theft ☐ Caracal ☐ Climate ☐ Other: ____________

Disease ☐ Jackal ☐ Leopard ☐

The support I get from local conservation body is:

Sufficient ☐ Ineffective ☐ Non-existent ☐

I would like to manage my stock losses:

Yes ☐ No ☐

I am prepared to pay to protect my livestock:

Yes ☐ No ☐

Hours spent to monitor livestock daily: ☐