Leopard (*Panthera pardus*) Prey Prediction Using Line Transect Sampling in the Western Soutpansberg Mountain Range, Limpopo Province, South Africa

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by

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Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Tübingen, den 29. April 2008

Diese Arbeit ist meinen Eltern gewidmet für ihre Unterstützung während meines Studiums und darüber hinaus.

Abstract

In the present study, density of leopard prey on Lajuma Mountain Retreat was estimated using the line transect methodology. Seventeen transects, with a total length of 16,2 km were established in an area of 246,5 ha. Each transect was walked six times between June and October 2007, resulting in a total sampling effort of 97,4 km. From 104 sightings, fifteen species were detected. The program DISTANCE was used for data analysis.

The calculated density estimation was 1,4 animals per ha, which led to a total of 346,92 animas per ha in the study area. However, failure in the study design led to an overestimation. Data for all potential leopard prey species were collected to account the highly variable leopard diet and to ensure that the required minimum of animal sightings, for a reliable density estimation using DISTANCE, could be guaranteed. There is a big difference in the detection probability of small and large animals and due to this difference more small animals were detected in the vicinity of the line. Resulting from that fact, an overestimation occurred. Double counts of animals supported this effect additionally, since the minor size of the sampling area made it impossible to buffer them.

Recording to hunting possibilities for leopards a habitat quality evaluation was made. The majority of detected Species weighted less than 10 kg and executed suboptimal prey, like the large species, which formed with 20% the minority. Species between 10 – 40 kg are considered to be optimal prey for leopards and were represented with 33 % Two leopards could be identified from camera traps, established in the sampled area. The area was always scanned for leopard tracks. Both leopards were found to roam seldom through the area. Due to the seldom visits of leopards and low number of optimal prey items one can suggest that the sampled area is not a favoured hunting ground.

Zusammenfassung

In der vorliegenden Studie wurde die Dichte potentieller Beutetiere des Leoparden unter Anwendung der Line Transect Methode im Lajuma Mountain Retreat bestimmt. Hierzu wurden 17 Transekte, mit einer Gesamtlänge von 16,2 km, in einem 246,5 ha großen Gebiet etabliert, und in der Zeit von Juni bis Oktober 2007 sechsmal abgeschritten. Somit belief sich die untersuchte Strecke auf 97,4 km. Fünfzehn Arten wurden aus insgesamt 104 Sichtungen bestimmt. Die Auswertung der gesammelten Daten erfolgte unter Nutzung des Programms DISTANCE.

Als Ergebnis wurde eine Dichte von 1,4 Individuen pro ha ermittelt, was zu einer Anzahl von 346,92 Beutetieren im untersuchten Gebiet führte. Allerdings bedingten Fehler im Studiendesign eine Überschätzung der Beutetierdichte. Es wurden alle Arten in Betracht gezogen, um zum einen das variable Beutespektrum des Leoparden zu berücksichtigen, und zum anderen, um die geforderte Mindestanzahl von 60 bis 80 Sichtungen, die für eine vertrauenswürdige Dichteschätzung unter zu Hilfenahme des Programms DISTANCE gefordert werden, zu gewährleisten. Da sich aber für kleine und große Tiere die Sichtungsverhältnisse auf größerer Entfernung stark unterscheiden, trat durch die Aufnahme kleinerer Arten eine Überschätzung der Beutetierdichte auf, bedingt durch die vermehrte Aufnahme kleiner Tierarten in der unmittelbaren Nähe des Transektes. Doppelzählungen von Individuen unterstützten diesen Effekt noch, da sie aufgrund der geringen Gebietsgröße nicht abgefangen werden konnten.

Anhand der gesichteten Arten, konnte eine Einschätzung der Gebietsgüte als Jagdgrund des Leoparden vorgenommen werden. Die Mehrzahl (47%) der Gesichteten Arten wog >10 kg und stellten somit suboptimale Beutetiere dar, ebenso wie die großen Beutetiere, welche mit 20% die Minderheit in dieser Studie bildeten. Arten, die zwischen 10 und 40 kg wiegen werden als optimale Beute angesehen, und waren mit 33% vertreten. Von Kamerafallen war bekannt, das zwei Leoparde das Gebiet durchstreifen. Während der Aufenthalte im Gelände, wurde auf Leopardenspuren geachtet und dadurch festgestellt, dass sie das Gebiet in längeren Abständen Aufsuchen. Das, und die geringe Anzahl optimaler Beutetiere lässt vermuten, dass die untersuchte Fläche kein favorisiertes Jagdgebiet, sondern ein Randgebiet der Territorien darstellt.

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1. Introduction

1.1. General aspects

With a length of 96–190 cm and a weight of 30–70 kg (EMANOIL, 1994), the leopard[1] is Africa's secondary biggest felid species (BOTHMA & LE RICHE, 1986). Extending throughout Russians Far East, China, South-East Asia, Indonesia, India, Arabia and sub-Saharan Africa, it is the most widely distributed cat worldwide (COPPARD, 1999). Due to its flexibility and adaptiveness this member of the big cats occupies a broad variety of habitats, from rainforests to deserts and from the fringes of urban areas to remote mountain ranges (MARKER & DICKMAN, 2005). As a result, behaviour and appearance are, influenced by the habitat, highly variable. The fur colour for example shows many different forms. Light–coloured individuals with spare small spots can be found in dry areas, leopards with golden fur occur in savannahs, and dark-coloured up to totally black individuals in rainforests, particularly in Asia (HAGEN *et al*., 1995). The black leopard, also known as black panther, is a melanistic form. Depending on the environment, its homerange differs in size. Leopards living in dry areas have a much bigger homerange then their relatives in forest or bushland habitats, due to prey abundance and loss of habitat diversity (BOTHMA *et al*., 1997; MARKER & DICKMAN, 2005).

Although the leopard is the most common agent of the genus *Panthera*, little work was done on this species until the 1970s, when the first steps toward leopard conservation were made, initiated by the awareness that the demand of fur of spotted felids has resulted in the exploitation of wild spotted cat species at an alarming rate. In 1968 e.g., the USA imported 9556 leopard skins (MYERS, 1976). Four years later, in 1972 the leopard was listed as an endangered species by the United States and India registered it in the same year as a Schedule I species of the Indian Wildlife Protection Act, which is the highest protection status in India. Since 1975 it is recorded under Appendix I of the Convention in International Trade in Endangered Species of Wild Fauna and Flora (CITES), a decision that led to controversial discussions, given that a species registered in Appendix I has

[1] See appendix A for scientific names of species mentioned in the text.

to be “threatened with extinction” (article 2, § 1 of CITES) which is not the case for the leopard. However, the arguments in favour of retaining the leopard under Appendix I were more convincing than the opponent ones. Its current status in the Red List of Threatened Species™ of the International Union for the Conservation of Nature (IUCN) is least concern (2002).

While the leopard is one of the cats with the largest and widest range, little was known about this felid in the 1970s, so that, in face of the declining population trend, the IUCN argued for intensive research on leopards. Together with the World Wildlife Found (WWF), the organisation commissioned NORMAN MYERS (1976) to undertake a status survey on leopards in Africa, south of the Sahara. Other status surveys followed, accomplished by TEER & SWANK (1977) and EATON (1977). Until today, numerous studies about this solitary cat were conducted, focused on observing its home range (GROBLER & WILSON, 1972; SEIDENSTICKER *et al.,*1974; NORTON & HENLEY, 1987; BOESCH *et al*., 1993; JENNY, 1996; BOTHMA *et al.,* 1997; KARANTH & SUNQUIST, 2000), density (HENSCHEL, 2001; KHOROZYAN, 2003; KOSTYRIA et al., 2003), and prey preferences (GROBLER & WILSON, 1972; NORTON *et al*., 1986; SATHYAKUMAR, 1992; JOHNSON *et al*., 1993; STUART & STUART, 1993; BODENDORFER, 1995; RAMAKRISHNAN, 1999; KARANTH & SUNQUIST, 2000; HENSCHEL, 2001).

After the threat to leopard population declining by fur trade was fended, and this animal started to gain scientific interest, other leopard population effecting problems received considerable attention. Apart from habitat destruction, prey loss and man-leopard conflict are the main threats to leopard populations. EDGAONKAR & CHELLAM (1998) published the first study about leopard human conflict in India, where leopards are implicated as the most common carnivore in man–carnivore conflict, implying not only livestock predation but also human deaths (ATHREYA *et al.*, 2004; EDGAONKAR & CHELLAM, 1998). A factor that brings carnivores in conflict with humans is the loss of natural prey (GINSBERG, 2002), so that the predator is forced to find new food resources to survive. Studies revealed that in areas where natural prey is limiting, leopards switch to feed on domestic animals (SEKHAR, 1998; OGADA, 2003; MARKER & DICKMAN, 2005). Since carnivores are known to show significant responses to losses in prey (GITTLEMANN *et al*., 2001), a wildlife management tool for carnivore conservation is to study their prey species, try to guarantee a healthy prey base, and to assess carnivore distribution and abundance.

A way to predict carnivore density is to estimate it from prey density. Data indicate that carnivore density is positively related with prey density, given that the potential density a population reaches is more generally understood to be a reflection of resource abundance. In the case of carnivores this usually means prey resources (FULLER & SIEVERT, 2001). KARANTH *et al*. (2004) developed a mechanistic model for predicting tiger density as a function of prey density. The results provide evidence of a functional relationship between abundance of large carnivores and their prey.

Distance sampling has proved to be an excellent method to predict animal density. It is a bundle of closely related methods for estimating the density and/or abundance of biological populations. The most popular methods are line transects and point transects (also known as variable circular plots). Both techniques have been used successfully in different taxa including amphibians, reptiles, insects, terrestrial and marine mammals, fish, birds, trees, herbs and shrubs (THOMAS *et al.,* 2002, BUCKLAND *et al.,* 1993). The fundamental concept is based on the probability density function *f(x).* With the aid of this function, it is possible to describe the density of any random quantity *x* (SILVERMANN, 1998). Density estimation is then the construction of an estimate of the density function from the observed data. Among the different distance sampling methods, line transect sampling is one of the most widely used methods for animal abundance assessment (MARQUES, 2004). This technique is an advancement of the strip transect survey. Burnham and Anderson (cited in BUCKLAND *et al*., 1993) advantaged the development of the technique as they recognized in 1976 the key problem, which was seen in modelling the function *f(x)*. The program DISTANCE is used to analyze line transect data.

Line transects have been used to estimate prey density in three of the four species of cat in the genus *Panthera*. Whereas several surveys were conducted to predict tiger prey densities (KARANTH & SUNQUIST, 1995; BISWAS & SANKAR, 2002; BAGCHI *et al*. 2003; JATHANNA *et al*., 2003; KARANTH *et al*., 2004; DAVID *et al*. 2005; PRACHI & KULKARNI, 2006) just a few studies exists for jaguar (NOVACK *et al*., 2005;

IUCN/SSC Cat Specialist Group: Cat Project of the Month – December 2007) and leopard (KARANTH & SUNQUIST, 1995) prey density determination.

1.2. The leopard and its prey

There were several studies conducted about leopard's prey preferences. The cat was found to prey on a broad range of species, and observations of hunting leopards revealed that they will attempt to kill any possible prey coming across (BOTHMA & LE RICHE, 1982; BAILEY, 1993; HAGEN *et al*., 1995). This behaviour reveals the leopard as an opportunistic feeder (BOTHMA & LE RICHE, 1982; GROBLER & WILSON, 1972; NORTON, 1986). And in fact, opportunistic feeding is one characteristic of widely distributed animals (ATKINSON *et al*., 2002).

HAYWARD *et al*. (2006) compiled leopard dietary and prey abundance data from various studies and found that leopards prey on over one hundred prey species, with 92 prey species recorded in sub-Saharan Africa (from small rodents and birds up to adult male elands) Its preferred prey weighs between 10 – 40 kg, with an optimum at 23 kg. Prey size is an important consideration for leopards when selecting prey (HAYWARD *et al*., 2006), since the energy output has to align with the energy the predator has to invest while searching, pursuing, and subduing its prey. There is a transition from feeding on small prey (less then half of the predator mass) to large prey (near predator mass), if the body mass of the predator exceeds 21,5 kg (CARBONE *et al.,* 1999). Leopards exceed this threshold although they have a highly variable body mass (adults weighing between 20 – 90 kg). However, leopards have the ability to feed for short periods on small vertebrates, when large prey is not available (HAYWARD *et al*., 2006). JOHNSON *et al.* (1993), conducted analysis of leopard scats over seven years in Wolong Reserve, China, and found that the frequency of the preferred tufted deer (weighing between 20 - 35 kg) in faeces decreased whereas the frequency of bamboo rats (ca. 1 kg) increased. Hyraxes (ca. 3,5 kg) are known as a preferred prey species in rugged areas (GROBLER & WILSON, 1972; NORTON *et al*. 1986; STUART & STUART, 1993; POWER, 2002; NEWANGAYA, 2002) and in African Rain Forest leopards prey mainly on small to medium sized ungulates (RAY & SUNQUIST, 2001; HENSCHEL *et al.*, 2005), with the main focus on duikers (RAY & SUNQUIST, 2001; BODENDORFER, 1995).

1.3. The leopard in South Africa

The leopard is well studied in South Africa. Theodore N. Bailey conducted research on leopards in the mid 1970s in the Kruger National Park and in the 1980s Bothma and le Riche started their study of leopard ecology in the Kalaharian Desert, which, continued in the 1990s, is the longest-running study of leopards in Africa (BAILEY, 2005). In 2002, the Mun-Ya-Wana Leopard Project was initiated in the Kwa Zulu-Natal province, to investigate the impacts of legal and illegal persecution of leopards, and to assess the long-term sustainability of the observed leopard population under increasing human pressure (IUCN/SSC Cat Specialist Group: Cat Project of the Month - November 2005). Another study is running in the Cape Province, arranged by the Cape Leopard Trust. This organisation is currently working on leopards in the Cape and elsewhere in South Africa. The studies include a comprehensive conservation genetics project estimating gene flow, genetic variability and genetic relatedness among South African leopard populations (http://www.capeleopard.org.za/). A forum for leopard management was set up in 2007 in the Limpopo Province, covering the Blouberg and Soutpansberg mountain ranges in the south, the Limpopo River in the north, and the area between the Mogalakwena River in the west and the N1 in the east. Its main objectives are to establish a discussion forum on leopard management, involving all stakeholders in the region, to publicize the sustainable management and conservation of leopard in the region and to make recommendations on leopard management to the National and Provincial Departments of Environmental Affairs and Tourism (for more information contact IAN GAIGHER).

The leopard can be found in nearly all South African provinces, with the exceptions of the central Natal Province and the Orange Free State (BOTHMA, 1989). This cat occurs mostly in protected areas, like the Kruger National Park and the Kgalagadi National Park, both of which have a healthy and stable leopard population of more than 1 200 animals. Approximately 67 000 km² of South Africa’s surface area is under formal protection, 52% of which are managed by

South African National Parks, and therefore represent good leopard habitat, since leopard populations in national parks are protected and no hunting or any other form of consumptive utilization is allowed. It is assumed that a high leopard density occurs in the Limpopo province. Approximately two thirds of South Africa's northern most province surface area can be considered as adequate leopard habitat. A population estimate for this area mounts up to ca. 3000 leopards (BOTHA & MEINTJES, 2004).

However, South Africa's estimated leopard populations are not supported by field data (I. GAIGHER, pers. comm.). Numerous studies have been executed on the ecology and behaviour of leopards, but the conservation needs of the species have never been addressed. Illegal hunting, leopards killed by farmers and pastoralists threaten leopard populations additionally to habitat and prey loss. Trophy hunting can be seen as a conservation chance for leopards, however, CITES has doubled the annual quota of trophy hunting permits issued for South Africa in 2003 from 75 to 150 (IUCN/SSC Cat Specialist Group: Cat Project of the Month - November 2005), without secured knowledge about the status of leopards in South Africa.

Studies of leopard density, habitat quality and prey base are needed to build up a proper base for intelligent future leopard conservation in South Africa. The present study was situated in the Limpopo Province and forms an attempt to predict leopard prey density on Lajuma Mountain Retreat.

2 Materials and methods

2.1 Study area

The study was conducted at the Soutpansberg mountain range, Limpopo Province, South Africa. It is the northern most mountain range of South Africa and lies between 23° 05’ S & 29° 17’ E and 22° 25’5 S & 31° 20’ E (HAHN, 2006).

Fig. 1: Map of Africa, South Africa and Limpopo Province. Red dot represents Lajuma Mountain Retreat

2.1.1 Climate

Tropical cyclones sometimes cause heavy rainfall but in general the area is relatively arid and targeted by periodic droughts caused by the El Niño effect (HAHN, 2006).

Moist air from the Indian Ocean deposits its rain in the mountain range. As the area lies in the summer rainfall zone, most of the annual precipitation occurs during the summer months from November to April. A strong rainfall gradient (east - west) is to be found across the mountain range, with the highest annual rainfall from 1800 mm at higher altitudes to 600 mm at lower altitudes (HAHN, 2006). The south facing slopes receive higher rainfall than the northern slopes (rain shadow). These rainfall gradients are the reason that a lot of different ecosystems and micro habitats can be found in this mountain range (GAIGHER & STUART, 2001).

Temperatures range from below 0 °C in winter to above 30 °C in summer and increase from higher altitudes to the foothills (Department of Water Affairs and Forestry - Republic of South Africa, 2003).

2.1.2 Fauna

The faunal diversity is high but great game herds that were historically present are now missing (I. GAIGHER, pers. comm.). The bird fauna is particularly rich in species. Two large carnivores occurre in this area, the leopard and brown hyaena.

Since the first Voorteker (Louis Trigardt) arrived at the foot of the Soutpansberg in 1836 uncontrolled hunting started which, together with destruction of habitat (farming and replacing of natural bush) led to decline and extinction of numerous species.

Twenty seven large mammalian herbivore species used to live in the Soutpansberg mountain range however, twelve of them are now extinct (HAHN, 2006), among them Africa's most important keystone herbivore, the African elephant.

Some farms reintroduce the following game species: burchell's zebra, eland, giraffe, impala, nyala and sable (I. GAIGHER, pers. comm.).

2.1.3 Flora

The Soutpansberg range is a floristic hotspot with approximately 2500 – 3000 vascular plant taxa comprising 1066 genera and 240 families. More then 500 species of tree and bush have been recorded. Among these species a number are endemic. Most of the plants are drought resistent.
There are five biomes classified (HAHN, 2006)

I. Forest
II. Grassland
III. Savannah
IV. Arid savannah
V. Moist savannah

Since 1836, a lot of environmental changes occurred. Natural bush was replaced by exotic planatation and farmland and caused by the extinction of large herbivores grassland has been transformed into secondary shrub-land (HAHN, 2006).

2.1.4 Mineralogy

The main rock formation comprises of basalt and sedimentery rocks (sandstone, quartz sandstone and quarzite) with intrusions mainly of dolerite. Wethered sandstone and quarzite forms nutrient poor and acidic sandy soils. Relatively nutrient rich clay soils have come into existence from wethered dolerite and basalt (HAHN, 2006).

2.2 Study site

Lajuma Mountain Retreat is situated in the Soutpansberg mountain range, between Vivo (25 km east) and Makhado (45 km west). It has a surface area of 430 ha and is characterised by high cliffs and deep valleys. The annual rainfall is 730 mm but it varies from year to year (I. GAIGHER, pers. comm.).

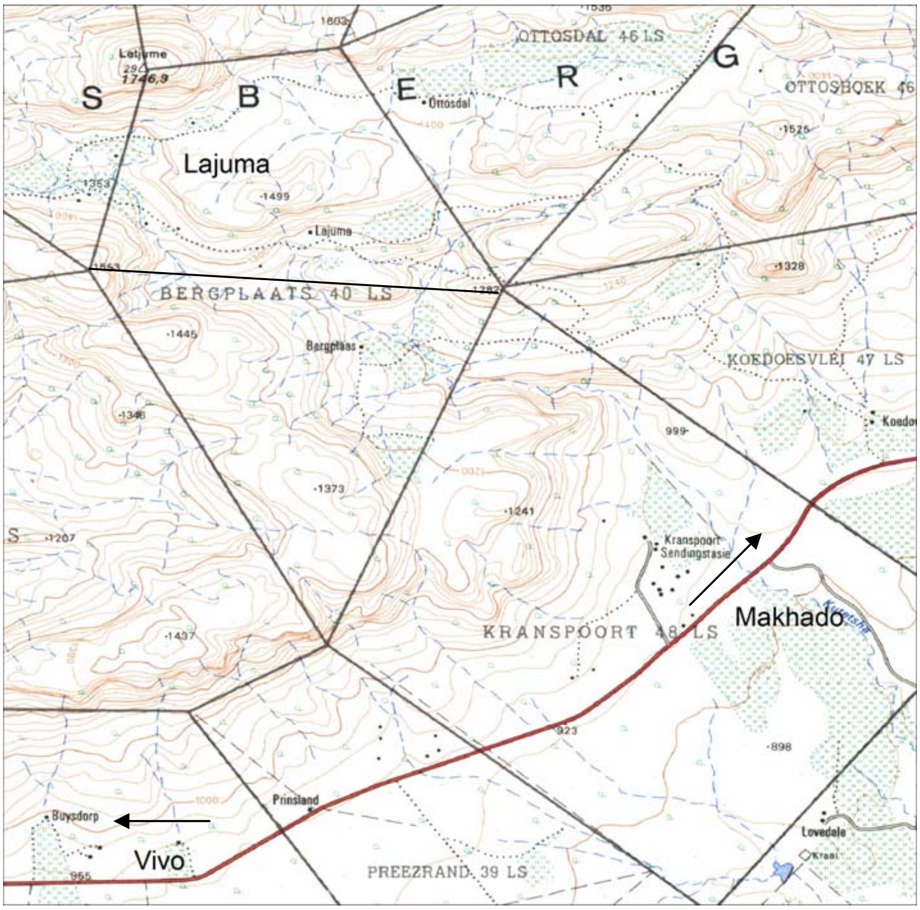


Fig. 2: Ground plan of Lajuma with adjoining farms.

Two of the above mentioned biomes occur on Lajuma:

I. Forest: Nothern Mistbelt Forest, with two ecological subtypes: a) Moist evergreen forest, typically at higher altitudes dominated by *Xymalos monospora* and b) Semi-deciduous forest, often regrowth forest in former wood- or grassland dominated by *Acacia ataxacantha* (Department of Water Affairs and Forestry - Republic of South Africa, 2003).

Special type: "Patches", small pieces of mistbelt forest with grassland in between.

II. Grassland: Soutpansberg Sourveld Grassland, dominated by *Loudetia simplex.*

Both large carnivores, leopard and brown hyaena live on Lajuma. The biggest antelope is greater kudu.

Lajuma is surrounded by eight other farms. Most of them are tourist or holiday farms, except Koedoesvlei (hunting farm), Ottosdal and Ottoshoek (cattle, donkeys and goats).

Since 1996 Lajuma has been used as a research centre. Before this time it was a farm, with cattle and a plantation of macadamia, orange, banana and avocado. Fences and plantation trees were all removed in 1996 (I. GAIGHER, pers. comm.).

2.3 Line transect theory

In the line transect method, an observer or team of observers walks *k* lines of lengths l_i (i = 1, 2, …, k), which are established in an area *A,* with a total length of $\sum l_i = L$. For every sighted object of interest *n*, the perpendicular distance x_i (i = 1, 2, …, n) is detected. There are two possible ways to record the distance (Fig. 3):

I) Direct measuring of perpendicular distance x_i from observer to animal

II) Measuring radial distance r_i and the angel of sighting θ_i from the observer's path to the animal

During the walks, all animals seen on the survey are recorded within an undefined width *w.* The width *w* will be defined after finishing the survey by the furthermost received distance or can be set by truncation (see *Outlier truncation,* p. 19) at the data analysis. So, an area of size $a = 2wL$ is censused.

In line transect sampling, not all objects in the surveyed area *a* are detected. In fact, a survey can fail to detect perhaps 60–90% of the objects of interest, but still deliver accurate estimates of population density. Based on the distance data recorded, it is possible to calculate a correction factor denoted as μ. This is the reason why distances are the key to the estimation of density when some of the objects remain undetected.

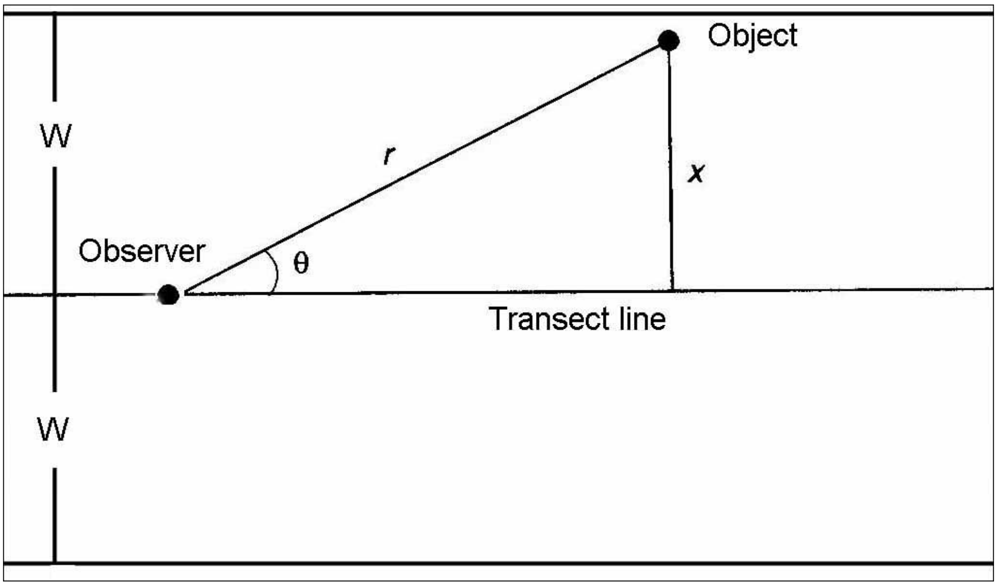


Fig. 3: Basic measurements that could be taken in line transect surveys. If r_i and θ_i are taken, x_i is then found by simple trigonometry: $x_i = r_i \cdot \sin(\theta_i)$.

The proportion of objects detected in *a* is described by P_a. Using P_a, the estimate of density can be written as

$$\hat{D} = \frac{n}{2wL\hat{P}_a}$$

A framework for estimating P_a is given by the detection function *g(x)*.

2.3.1 Detection function

g(x) = describes the probability of detecting an object, given that it is at distance *x* from the random line, $0 \leq x \leq w$.

The probability of detecting an animal decreases with increasing distance from the transect, i.e. the detection function is assumed to be nonincreasing (TURNOCK & QUINN, 1991). Thus, the probability to detect an animal is highest at the least range, i.e. directly on the line. This is described by *g(0)=1*, objects on the line are seen with certainty.

At first in modelling the detection function, the perpendicular data are plotted in a histogram. The detection function is then formed by the best possible fit with the course of the histogram. The unconditional probability of detecting an object in *a* is described by

$$P_a = \frac{\int_0^w g(x)dx}{w}$$

Density estimation then becomes

$$\hat{D} = \frac{n}{2L\int_0^w g(x)dx}$$

The term $\int_0^w g(x)dx$ is denoted μ for simplicity. Therefore, the constant μ is simply the total area under the detection function *g(x).*

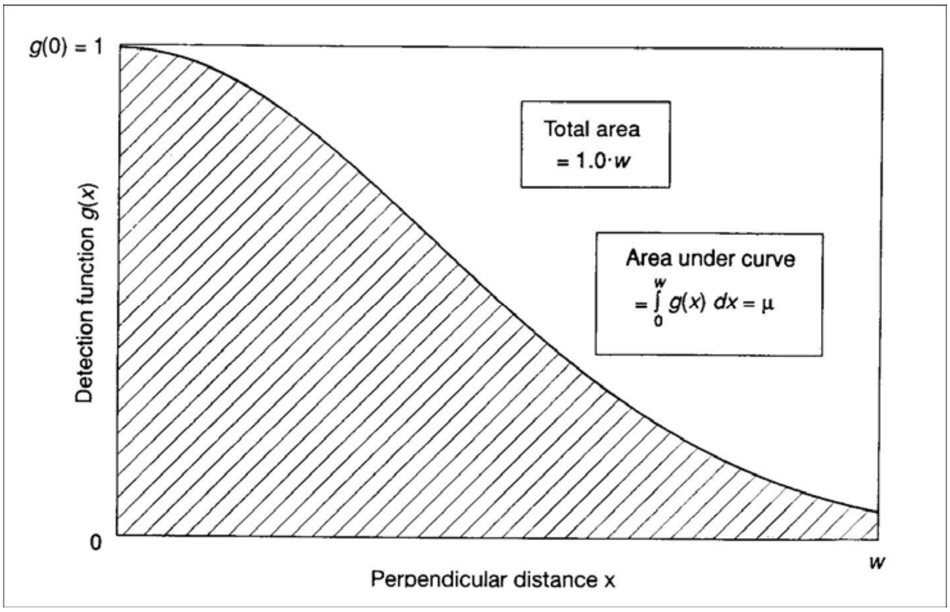


Fig. 4: The unconditional probability that an animal within distance *w* of the line is detected is the area under the detection function *μ* divided by the area of the rectangle 1.0 *w* (BUCKLAND *et al.,* 1993).

An estimate $\hat{\mu}$ of μ is needed. This is given by the probability density function.

2.3.2 Probability density function (pdf)

The *pdf*, denoted *f(x)*, can simply be thought of as the underlying form from which the observed distance data were generated. It can be shown that *f(x)* and *g(x)* are related by

$$f(x) = \frac{g(x)}{\int_0^w g(x)dx}$$

This result follows, because the expected number of objects (including those that are not detected) at distance *x* from the line is independent for *x*. *Pdf* and detection function are identical in shape.

If, *g(0) = 1* (i.e. highest probability to detect an animal), then

$$f(0) = \frac{1}{\int_0^w g(x)dx}$$

$$= 1/\mu$$

The parameter $\mu = \int_0^w g(x)dx$ is a function of the measured distances. Thus, the general estimator of density for line transect sampling is simply written as

$$\hat{D} = \frac{n \cdot \hat{f}(0)}{2L}$$

$$= \frac{n}{2L\mu\hat{}}$$

So, the problem is reduced to developing an appropriate model for *f(x)*, and evaluating the fitted function at *x = 0*, since this is the most important distance.

2.4 Study design

For the present study, four weeks were spent to get an idea of occurring species, define the study area and perceive the environment to prepare the study design.

2.4.1 Some thoughts before transect placement

2.4.1.1 Transect layout

The chosen layout for this study was a favoured and practical one, based on a grid of parallel transects with a randomly start line. In this case, transects extend from boundary to boundary across the study area and are of unequal length.
Transect lines (or a grid of parallel lines) have to be placed randomly with respect to the distribution of animals. Usually, the distribution of objects with respect to the transect line is assumed to be uniform (Turnock & Quinn, 1991). However, this assumption is restricted to the search strip, there is no need for uniformity throughout the whole area (FEWSTER *et al*., 2005). It is not necessary to make assumptions about the distribution of the animals themselves, since the interferences will be valid regardless of the underlying pattern of spatial distribution of animals (BUCKLAND *et al*., 1993; THOMAS & KARANTH, 2002).

2.4.1.2 Physical or biological features, density gradients and existing trails

One must avoid using existing paths or trails, since this will lead to an overestimation and therefore unrepresentative evidence of animal density, as the possibility of sighting an animal is much higher while using such structures.
It is also important that the direction of transect lines do not parallel some physical (e.g. fences, roads) or biological (e.g. rivers, corridors) features. Such structures

will affect the distribution of animals and hence create density gradients. Generally, placement of transects should be randomly or perpendicular to density contours but if there is a known density gradient perpendicular to a linear physical feature, then a design in which lines are parallel to this gradient and perpendicular to the linear feature should be considered (BUCKLAND *et al.,* 1993; THOMAS & KARANTH, 2002).

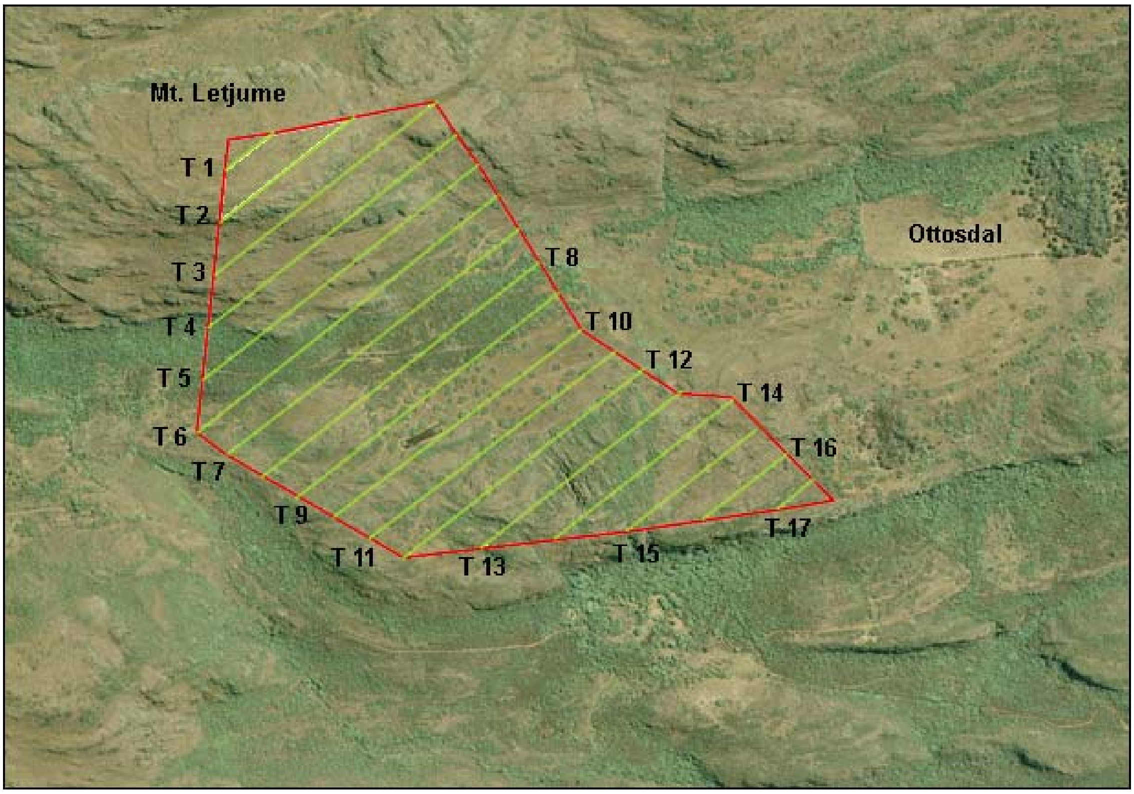


Fig. 5: Air photograph of the sampled area. Red contour, sampled area A=246,5 ha, green lines, transects T1 - T17.

2.4.2 Placement and marking of transects

After settling the sampling area, transect lines were first marked on a digital map of Lajuma using the program ESRI®ArcMap™9.2. The coordinates of every start and endpoint were taken for each line and, in the face of their accessibility, located in the field by GPS. In the case that a point turned out to be difficult to reach, coordinates of a better approachable point nearby were taken to replace the old ones and fix the final position of transect lines.

Marking of transects were done by using flagging tape. Marks were put on branches and bunches of grass at which care was taken that they were well visible to ease the orientation during the walks.

While placing the track lines in the field, one must keep in mind that with placing transects it is possible to create some trails which could be attractive for animals to use. That would inflate the detection probability and lead to an overestimation of abundance. So it is important in, e.g. forested habitats to do as little cutting as possible, just enough to move quietly along the line (THOMAS & KARANTH, 2002). Therefore, cutting was done in the forested parts of the sampling area, whereas it was as far as possible avoided in the patches and rocky areas. However, it was not possible to do just little cutting in few parts of the forested habitat, since the thicket was to thick and keeping in mind that the dominant tree species were acacia trees, it was necessary to cut a clear path so that one could concentrate on scanning ahead, looking out for animals in the vicinity of the line and not get distracted by looking after acacia branches. To get stuck on acacias is not only painful, but can also lead to spontaneous cries, which could scare away objects of interest.

2.4.3 Transect details

A total of seventeen transect lines were established in the sampling area with the lengths varying from 175,8 m to 1439,1 m. Each line was walked six times between June and October 2007, investing a total sampling effort of 97,4 km. Tab. 1 gives a summary description of transect and area details.

Tab. 1: Transect and area details

Area *A* [ha]	No. of transects	Total walks per transect	Minimum transect length [m]	Maximum transect length [m]	Total transect length [km]	Total [km] walked
246,5	17	6	175,8	1439,1	16,2	97,4

2.4.4 Recorded leopard prey species

Three studies about leopard prey (STUART & STUART, 1993; NEWANGAYA, 2002; POWER, 2002) on the basis of scat analysis, conducted in the western Soutpansberg, were used to get an idea of important leopard prey species. A list of identified prey species for leopards in the western Soutpansberg is attached in appendix B. Bailey's (2005) study on leopard prey in Kruger Park was used for further orientation. The exploratory phase was used to get information about occurring species on Lajuma. It was decided to record distance data for all occurring ungulate species, little carnivore species, monkey species, hyraxes, hares, francolin and guinea fowl.

Camera traps, which formed part of an other study, independent of the present one, were established on Lajuma. Photographs, taken from January to April 2007, from four in the study area established cameras were used to determine the best time for data collection (daytime of every photo was recorded automatically by the camera). Since no night walks were planned in this study, only day active species were considered. Between 17:00 and 19:00 and 07:00 and 11:00 animals showed the highest activity (Fig. 6). Based on these results, and the time for sunrise and sunset, it was concluded to collect field data between 07:00 and 10:00 and 16:00 and 18:00.

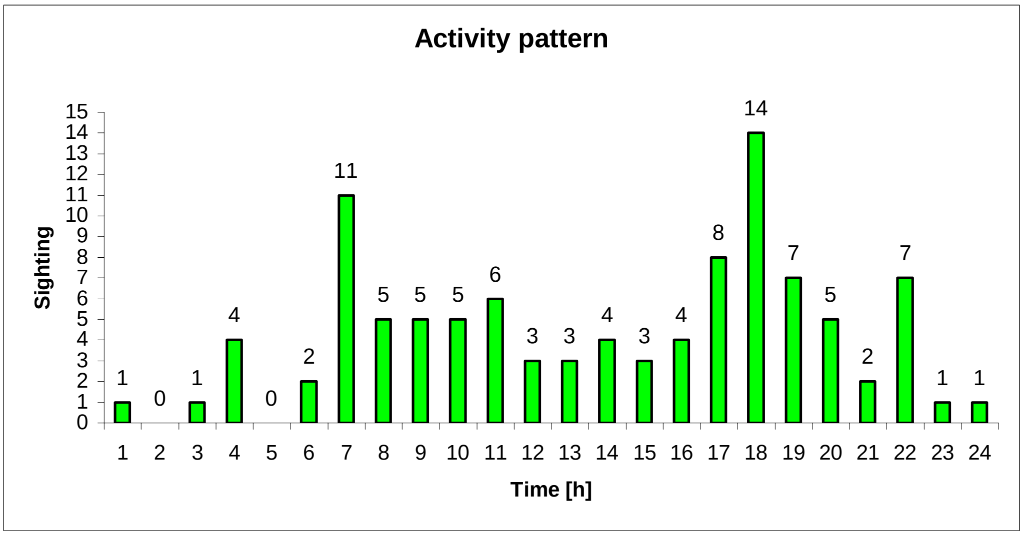


Fig. 6: Activity pattern of five identified species (warthog, bushpig, bushbuck, grey and red duiker), based on 102 photographs of four camera traps established in the study area.

2.4.5 Data collection

A rangefinder (WeTeLux-LS010 laser rangefinder) was used for distance measuring. Its measurement range spanned from 15 to 600m. Exercises in distance estimation between the ranges of 0 to 15 m were done in distance rating with following check using measure rope, until the ability for distance rating became reliable.

The following variables were recorded: (1) species, (2) perpendicular distance or sighting angel and radial distance, (3) begin and end of every transect walk, (4) weather conditions.

Three important assumptions exist for data collection, to ensure reliable density estimation:

1) Animals on the line are detected with certainty

   A fundamental part of the derivation of the density estimator is *g(0) = 1*, all objects at zero perpendicular distance are detected. The density will be underestimated if objects on the line are missed.

   Bias is a simple function of *g(0)* for example if 10% of the animals are missed on the line then density estimate will be on average 10% too low (THOMAS & KARANTH, 2002).

2) Animals are detected at their initial location

   If animals move in response to the observer before being detected, then the distribution will not be uniform and the estimation of abundance will be biased (TURNOCK & QUINN, 1991). When animals sense the observer, they can move either away from the transect line, which would lead to an underestimation of abundance or move closer. If movement towards the transect line occurs, then overestimation of population abundance results due to the observed higher density of animals close to the transect line. Therefore it is important that the observer moves as silently as possible along the track line and concentrates on detection of the animals to avoid evasive movement prior to detection.

Movements do not cause a serious problem, when they are randomly distributed – i.e. not in response to the observer and when the observer is moving at least 3-4 times faster than the animal (BUCKLAND, 1993). The level of bias depends on the speed of the animal with respect to the speed of the observer.

3) Measurements are correct

   The effect of inaccurate measurements can often be reduced by careful analysis. However, it is better to gather good data in the field rather than to have them corrected by analytical methods.

   One problem that sometimes occurs is 'heaping'. Heaping means rounding error in support to shorter distances. When this happens, the data shows a 'spike' at short distance categories.

2.5 Analysis guidelines

Complexity in survey design and data lead to the demand of a broad range in data analysis. There is no specific strategy, following guidelines however, have turned out to be useful for orientation, when planning the analysis of dataset (BUCKLAND, 1993).

A) First, it is important to understand the collected data well and to determine them in terms of potential errors in data acquisition like heaping or evasive movements. This can be done by the preparation of histograms of the distance data under several groupings. As a general rule one should use 10-20 groups to get a well structured picture of the distance data. Such histograms can provide insight into the presence of 'outliers' as well.

   Outlier truncation

   It is highly probable to record outliers, when data collection is carried out without a defined width *w.* Outliers will not be useful in the final analysis, since they deliver little information about density and tend to complicate the modelling of the detection function, thus they should be truncated (discarded). Common use is to discard 5–15 % of the observations with the largest distances (THOMAS & KARANTH, 2002).

B) Once a data set has been properly prepared by truncation and, where appropriate, grouping the model selection can be conducted. Four properties are desired for a model of the detection function. They are, in order of importance, model robustness, pooling robustness, shape criterion and efficiency.

Model robustness

A model has to be robust means that it has to be able to take variety of shapes which are likely for the unknown true detection function, hence, as it is important that the model is a rather flexible function, single parameter models are excluded.

Pooling robustness

A model is pooling robust if it is robust to variation in detection probability for any given distance. Models with two or three parameters proved to require the concept of pooling robustness of *g(x),* i.e. the data can be pooled over many factors that affect detection probability (e.g. time, observer, habitat, behaviour of the object) and still bear a reliable estimate of density. Models that are robust approximately satisfy the pooling robustness.

Shape criterion

The detection probability decreases with increasing distance, as one expects the detection function to have a ‘shoulder’ at small perpendicular distances from the line. Thus, functions which are spiked near zero distance are excluded from further analysis. This criterion makes sure that detection remains certain near the line. It reveals the nature of the sighting process.

Estimator efficiency

An efficient estimator should be considered only if it satisfies the first three criteria. Efficiency means that the model provides estimates that are relatively precise i.e. have small variance.

Variance

The variance in counts among lines is generally used to calculate the variance of numbers of animals seen. For a reliable estimation at least 15 – 20 lines of equal length are needed.

C) Final analysis and inference

In some cases, there may be several competing models that seem to fit the dataset equally good. The estimation of D under these models will be quite similar. To decide which model is to prefer, one can compare the coefficient of variation (CV) between studies. The study with the lowest CV is considered to be the best choice.

2.5.1 Aids in objective model selection

2.5.1.1 Akaike's Information Criterion (AIC)

The AIC provides a quantitative method for model selection (for hierarchical or non-hierarchical models) and attempts to find a model that fits the data well with using only few parameters. This test is conducted for each possible model and the model with the lowest AIC is selected. It treats model selection within an optimization rather then a hypothesis testing framework and is the preferred test in model selection.

2.5.1.2 Likelihood ratio test

Another way to select a model is given by using likelihood ratio test. It provides a good possibility for checking the models efficiency by testing if an addition of adjustment terms improves the adequacy of a model significantly. First it tests if the key function alone fits well and then adds another term to test whether the model efficiency is improved by this term or not. If it improves the fit, then another term will be added and the test will be carried out once more. The process is repeated until the test is not significant, or until a maximum number of terms have been attained.

2.5.1.3 Goodness of fit test

A possible criterion is to calculate chi square goodness fit divided by its degrees of freedom (u-q-1 degrees of freedom) for each model, and to select the model which gives the smallest value of the chi-square statistic. It depends on arbitrary decisions about the number of groups into which the data are divided and on where to place the cutpoints between groups.

The test compares the observed frequencies n_i with the estimated expected frequencies of the model. Before fitting a model with q parameters to the data set, distance data have to be split up in u groups with sample sizes $n_1, n_2, \ldots, n_u$ and cutpoints between groups $c_1, c_2, \ldots, c_u = w$.

The goodness of fit test is the only available test to explore the model fit but unfortunately it does not provide a good test, since real distance data are often biased by heaping which leads to the result that no model fits the data set well. However, a significantly poor fit needs not be of great concern, the test can be a useful tool to detect problems in the data or the selected detection model structure which should be investigated through closer examination of the data or by exploring other models and fitting options.

As mentioned before, the most critical aspect and most important to fit is the distance near zero. None of the introduced tests gives special emphasis at this region. Usually analysis will suggest additional exploratory work, so that the process is iterative. A better fit of the model could be reached by selecting a different truncation point w or by changing choice of group intervals for grouped data.

3. Results

Normally, the analysis of line transect data should be carried out separately for every single species. This was, unfortunately, not possible for the present study, as the survey area was to small to ensure that the required minimum of animal sightings could be guaranteed. Forty observations are at least needed for statistically reliable density estimation with line transect data (KARIBUHOYE, 2004), and ideally 60 to 80 observations if using the computer software DISTANCE (BUCKLAND, 1993). However, there was no option in sampling a bigger area, since the study was accomplished by a single person on foot, without the possibility of using motorized vehicles. So, the investment had to be within the bounds of possibility of what could be handled by one person.

3.1 Transect walks

Tab. 2: Species, total sighted animals and their relative frequency for the line transect survey on Lajuma. The relative frequency was evaluated as follows: relative frequency=r/R*100, with r=individual species number; R=total of all animal sighted.

Species	Total animal sighted	Relative frequency [%]
Hyrax	27	25,96
Francolin	16	15,38
Chacma baboon	13	12,5
Klipspringer	13	12,5
Grey duiker	8	7,69
Warthog	5	4,81
Bushbuck	4	3,85
Guinea fowl	4	3,85
Greater kudu	3	2,88
Red duiker	3	2,88
Vervet monkey	3	2,88
Dwarf mongoose	2	1,92
Bushpig	1	0,96
Scrub hare	1	0,96
Slender mongoose	1	0,96
Total:	**104**	**100**

For the entire transect walk exercises on Lajuma, 15 prey species were detected from a total of 104 animals sightings. Among these species were five of the family of antelopes, two pigs, mongoose, monkey species respectively and one hare species. Francolin and guinea fowl were also seen. Given that a differentiation of rock and yellow-spot hyrax in the field is nearly impossible (APPS, 2000), no attempt was made to distinguish between these two species in this survey, although both occur in the western Soutpansberg (STUART & GAIGHER, 2001). Tab. 2 gives a summary of all detected species. Hyraxes were the most sighted species (25,96%) followed by francolin (15,38%), chacma baboon and klipspringer (both with 12,5%).

3.2 Truncation

Plotting histogram of the dataset using different distance categories revealed extreme outliers in the distances between 91-104 m and 121-126 m. A truncation point at *w* = 55 m was suggested to be sufficient, so that 9,6% of the sampled data were discarded. Hence, 10 animal sightings were truncated leaving 94 sightings from a total of 104.

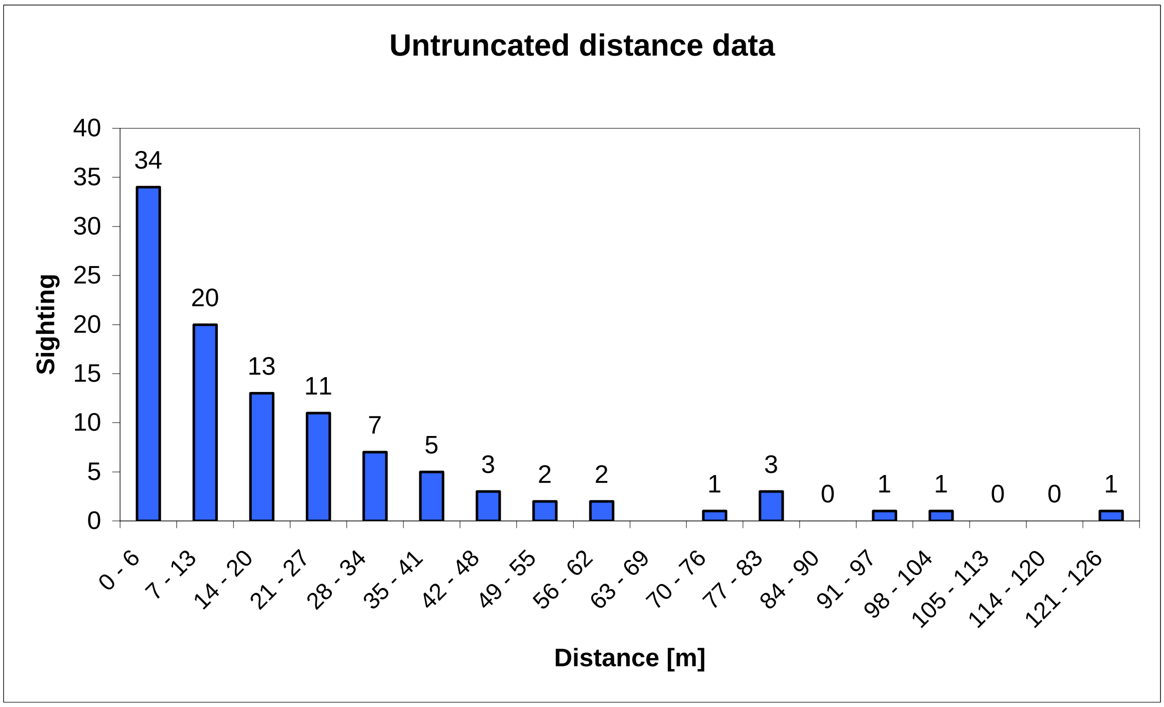
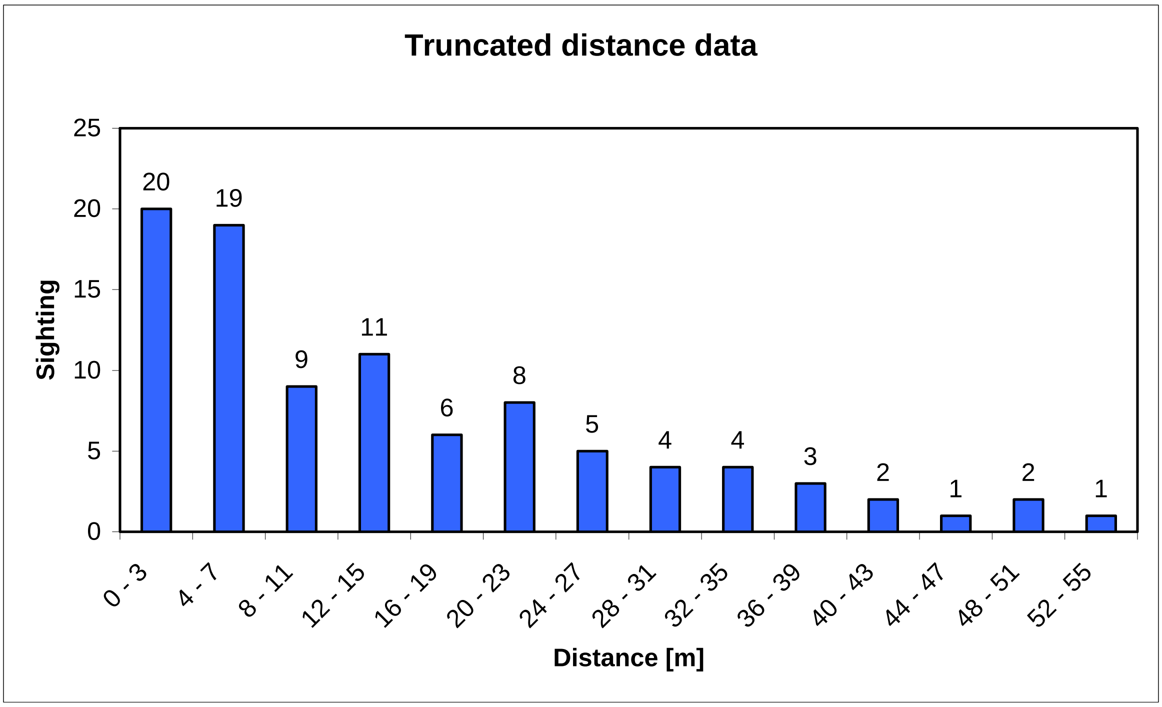


Fig. 7: a) Histogram of untruncated (*w* = 126 m) distance data, using 18 distance categories.



b) Histogram of truncated (*w* = 55 m) distance data, using 14 distance categories.

3.3 Model selection

Three models were favoured for further model examination by visually judging the fit of the model to the observed distance data close to the track line. By *p*- value comparison of untrunctated and truncated dataset, one can see that all three selected models indicated a better fit to the dataset after discarding outliers at 55 m (Tab. 3). An improvement in model fit after truncation is also given by leaving out parameters. This was the case for the half-normal key + cosine adjustment term and the uniform key + cosine adjustment term.

Based on comparisons of AIC values of truncated and untruncated data, the half-normal key function with cosine adjustment term proved to be the best fit for the dataset. Three parameters were required for this model to fit the untruncated data whereas two were required for a good model fit at *w* = 55 m. The model selection was supported by *p*-value relation, in which the best fit of both truncated and untruncated data were shown for the selected model.

Tab. 3: a) Summary of AIC values, p-values and total parameter of DISTANCE analysis of untruncated dataset, *w* = 126 m, for three different models.

Key function + adjustment	Total parameters	AIC	*p*- value *
Uniform + cosine	4	852,09	0,11
Half-normal + cosine	3	851,17	0,20
Half-normal + simple polynomial	3	855,94	0,08

b) Summary of AIC values, p-values and total parameter of DISTANCE analysis of truncated dataset, *w* = 55 m, for three different models.

Key function + adjustment	Total parameters	AIC	*p*- value*
Uniform + cosine	3	696,56	0,85
Half-normal + cosine	2	694,45	0,91
Half-normal + simple polynomial	3	696,62	0,86

*Goodness of fit test

By fitting the chosen model to the histogram (Fig. 8), one can see the presence of a broad shoulder and no indication of evasive movement prior to detection. However, heaping occurred in the first two distance categories which comprise the distances from 0 to 7 m (see appendix C for cutpoints).

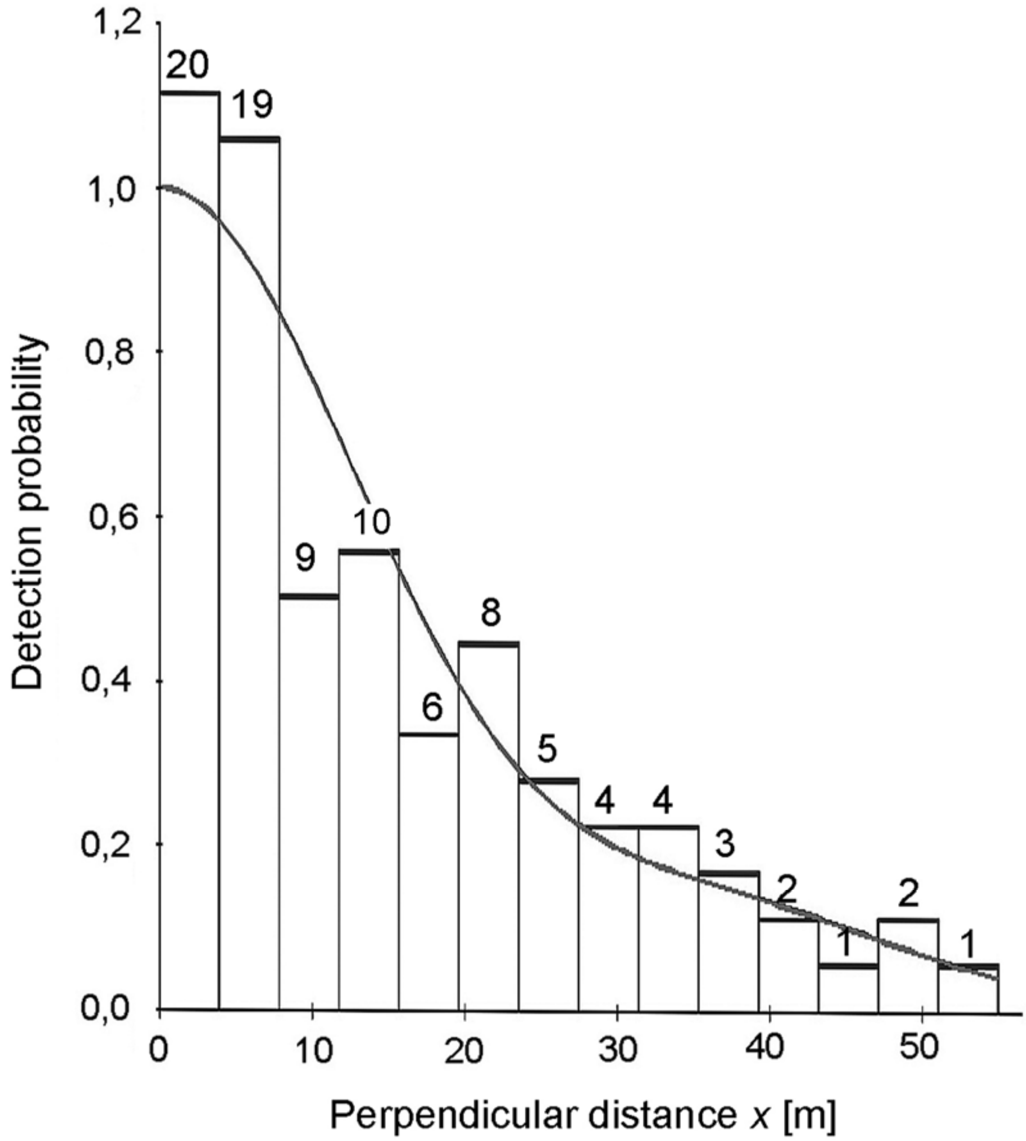


Fig. 8: Histogram of the truncated data using 14 distance categories. Cutpoints chosen by DISTANCE. The fitted detection function *g(x)* is a half-normal key with cosine adjustment term.

3.4 Density estimates

Tab. 4 shows the estimated density and encounter rate of animals. The related coefficients of variation and 95% confidence intervals are presented. By data truncation the coefficient of variation increased by 3,6 % relative to untruncated data. This means that the uncertainty in *D^* increased so precision was lost due to truncation. The abundance of leopard prey amounts to N^ = 346,92 (*N^* = *A* · *D^*).

Tab. 4: Estimated leopard prey density in Lajuma Mountain Retreat for truncated dataset. D^, density of individuals; CV (D^), per cent coefficient of variation for truncated and untruncated data; 95% CI, 95% confidence interval; ER, Encounter rate – number of animals seen per km transect. Total effort 16,24 km.

D^ (ha)	CV (D^) %		95% CI (D^)	ER (No./km)
	w = 126 m	*w* = 55 m		
1.4074	26.19	29.80	0.76645 - 2.5844	0,58

4. Discussion

4.1 Survey method

The line transect technique has proved to be effective and reliable in estimating density of ungulates in India (KARANTH *et al.,* 2004) and the African tropical rainforests (KARIBUHOYE, 2006). No problems occurred in collecting distance data for ungulate species in the present study. However, given that e.g., klipspringers form lasting pair bonds and sometimes team up in groups consisting of up to six individuals (DRUCE, 2005), it would be appropriate to collect distance data for clustered populations. A definition of clustered populations is given by Karanth and Sunquist (cited in JATHANNA, 2003) for animals aggregating within a 30 m radius. Observed species also living in groups were warthog, kudu, guinea fowl, dwarf mongoose, vervet monkey, and chacma baboon. Distance data collection should be done for these species for clustered populations as well.

The line transect methodology is not to recommend for collecting data for hyraxes. Hyraxes occupy rugged rocky areas, a habitat that makes it difficult to detect them, since they are well camouflaged (they are small grey coloured animals). Furthermore, they preferre to stay in cover (DRUCE *et al*., 2006), a behaviour which makes it more difficult to detect them. Another point to take in consideration is that the observer has to pay attention while wandering or climbing in rocky terrain, so that it is impossible to concentrate properly on searching for objects of interest. Hyraxes live in colonies, consisting of a territorial male, several adult females and their offspring (APPS, 2000) and post lookouts. One alarm call by the lookout or any other individual sends the whole colony scurring for cover (DRUCE, 2005). In the present study, hyraxes were much to often rather heard then seen. The only chance to collect data during the walks was given by breaks of 10 minutes duration, while scanning the area with binoculars. Ten minutes are the maximum time span for a break while travelling a transect line, because an observer has to walk with an average speed of 1,5 km/h (KARANTH *et al*., 2002), and unfortunately too little time is left to wait until fled hyraxes would reappear. Point transects or line point transects sampling would be the better choice for data collection to estimate hyrax density. BARRY & MUNDY (1998) and MIZUTANI (1999) successfully used observation points to gather data for rock hyraxes and tree hyraxes.

Heaping occurs if collected data are rounded in preference to shorter distances. In the present study, heaping was found in the first two distance categories, comprising distances between 0–7 m. However, it is not caused by rounding errors but occurs due to data collecting of small and large animal species. The detection probability decreases with increasing distance and large animals have a much higher detection probability at larger distances than small animals, which lead, in consequence of this difference to a broader distance range for data. Small animals miss the equivalent detection chance at larger distances, so that more animals will be detected at shorter ranges. An example is given by the francolin. This bird was mostly seen in grassy areas. It is a small brown bird and well camouflaged in high dry grass, so that it was nearly impossible to detect it. The only chance of seeing francolins during the walks was when the observer entered a critical distance and flushed them out. All sixteen sightings of francolins were made at distances between 0–6 m. This is comparable with the study from BALPH *et al.* (1977) in which most bird counts were made between distances of 0–10 m. DIEFENBACH (2003) compared 75 different studies about bird density estimation and found that the detection probabilities were < 1.0 at distances > 25 m for most species. Other studies (JARVIS & ROBERTSON, 1999; KOPIJ, 2002) about bird density estimation including francolin species in Africa used line transect sampling to collect distance data, and DIEFENBACH (2003) found that with 32% the most commonly used method for bird distance data collection were fixed-width transects. So this procedure is to recommend for bird distance data collection but not in combination with other animal species. Another problem consisted in the high sighting events of francolins. The more sightings occur the more the dataset will be biased. Furthermore, other small animal species (dwarf mongoose, scrub hare and guinea fowl) were seen during the survey. Due to these animals, the percentage between the distances shifted the data towards short ranges. Thus an overestimation occurred, as more animals were detected near the centre line. The situation is comparable with the incidence of evasive movement towards the transect line.

Overestimation was not only caused by the previous discussed failures but also by the minor size of the sampling area, which made it impossible to buffer double counts of animals. Individuals of one species were frequently seen during different walks at nearly the same places on the same transect line. This is not astonishing, since all occurring species were territorial and transects were crossing their territories. Therefore it is reasonable to say that all these sightings comprised probably the same individuals. This observation was most obvious for klipspringers. Thirteen klipspringers were seen during the study at four different transects (T1, T2, T15, T16; see Fig. 5). Given that this result in two pairs of transect lines on the opposite sides of the sampling area and that klipspringers were seen once in both parts of the sampling area during a day, it is highly possible to say that two klipspringer groups occur on Lajuma. The highest aggregation of klipspringers observed on the transects consists of three individuals, so that a possible maximum of six individuals is thinkable. This implies that seven sightings can be considered to be double counts. Grey duiker and hyraxes were also sometimes recorded on the same places. However, according to hyrax scats, which were found on almost every, transect, the suggestion that hyraxes occur in high numbers on Lajuma is appropriate and double counts should not constitute a problem.

Attention was paid to detect fresh animal scats and tracks during the walks to exclude the possibility that animals get attracted in using the transect lines. However, fresh scats and tracks were rarely observed and it is therefore assumed that animals do not actively avoid or use the lines.

Since the leopard is preying on a broad range of animals it would be the best to focus prey density estimation upon ungulate species in areas where they are abundant when using line transects sampling. Areas, which provide less optimal prey for leopards and where leopards are urged to feed on small prey, one should first carry out a pilot study to discover possibly emerging problems in collecting distance data. Then, when it is required, one can select optimal field techniques for the observed species. In closing, it is to mention that distance data should always be analyzed separately for every single species. Hence it is possible to estimate densities individually and pooling can be done just for data with similar properties.

4.2 Habitat quality

It is possible to evaluate the habitat quality of the sampled area, with regard to hunting possibilities for leopards. As mentioned before, this felid species preferred prey, weighting between 10–40 kg. Out of fifteen detected species, small species (> 10 kg) represented with 47 % the majority, 33 % were weighting between 10–40 kg, and large prey (< 40 kg) was represent with 20 % (see appendix D for information about weight of species). The leopard is morphologically adapted to hunt large animals but kills of large prey are rare events (HAYWARD *et al*., 2006). Since the leopard is a solitary predator, it has to avoid injuries, as even a minor injury can be life threatening. With increasing prey size, the risk of injury is also increasing and the probability of subduing the prey decreases due to the greater strength of large prey.

Greater kudu was the largest possible prey species seen during sampling occasions. BAILEY (2005) found in his study on leopard prey that greater kudu was rarely taken by leopards due to the involved danger of hunting such a big prey item. Other species, which are absolutely capable to maim or kill leopards, are also rarely hunted. On Lajuma, this comprised species like chacma baboon and pigs. Baboons have long been considered to be preferred prey of leopards (HAGEN *et al*., 1995; HAYWARD *et al*., 2006). In areas where other prey species are scarce leopards prey on primates, however, in general leopards renounce to hunt baboons (HAGEN *et al*., 1995; LINNENBERG, 2003; BAILEY, 2005), since these primates are known to react aggressively towards leopards (BAILEY, 2005).

In India, wild boar is suggested to be too aggressive and dangerous to become leopard's prey (RAMAKRISHNAN *et al.,* 1999) and HAYWARD (2006) assumed that this might apply to all Suidae. He found in his study that leopards kill warthog and bushpig less frequently. Warthogs were seen many times, not only on sampling occasions, however, this species was never verified as leopard prey in the Western Soutpansberg.

Bushbuck and grey duiker are species that satisfy the criteria for leopard predation and hence constitute formidable prey. Similar in size and weight are Impala, which BAILEY (2005) found to be the most hunted prey species in Kruger National Park, the same applies to chital and sambar deer in India (KARANTH & SUNQUIST, 1995) and tufted deer in China (JOHNSON *et al*., 1993).

All three studies of scat analysis conducted in the Western Soutpansberg displayed bushbuck as second popular leopard prey for this area. POWER (2002) found that leopards in the Western Soutpansberg selectively predate on bushbuck, when the density of small ungulates exceeds 10 animals/km^2 but feed non-selectively when small ungulate density reaches 8,1 animals/km^2. NEWANGAYA (2002) found small seasonal variations in food habits. Bushbuck was consumed during all seasons but more frequently in spring and summer. Other antelope species, like klipspringer and red duiker, were just present in spring and summer. He concluded that antelopes are less vulnerable in winter and autumn, because of more complicated hunting conditions due to dry grass and leaves, which hinder noiseless stalking.

Most of the small prey species (dwarf-/slender mongoose, hare) are seldom hunted by leopards. Game birds are rarely taken by leopards as well (JOHNSON *et al.*, 1993; STANDER *et al*., 1997; BAILEY, 2005), although the cat is known as a good bird hunter (HAGEN *et al*., 1995). Hyraxes proofed to be a preferred prey species in the Western Soutpansberg, which is a clear reflection of their abundance in this area (STUART & STUART, 1993). NEWANGAYA (2002) found that hyraxes were more present in scats during winter, and he concluded that this adverts to increased vulnerability when hyraxes sun themselves during this season. Since leopards come across with complicated hunting conditions for antelopes, it is also thinkable that leopard are hunting hyraxes more frequently during winter due to this fact.

Most of the detected prey species provide less optimal prey for leopards. Just bushbuck, grey duiker, klipspringer, red duiker and hyrax can be considered as good prey items. Observations of leopard tracks and analysis of camera pictures revealed that two individuals seldom roam through the sampled area. Tracks were only found on roads so it is thinkable that this area is just an outlying district of the main territory, which is visited to renew their territorial scent marks and not because of providing a good hunting area. Bushbuck, red duiker, guinea fowl and monkey species were common and in much higher numbers seen in the forested parts of Lajuma and the surrounding farms. Hyraxes could be observed in the forested parts near cliffs as well. This led to the assumption that subtropical forest may provide a much better habitat for leopards, due to higher numbers of optimal prey and should be considered as favoured territory in this area.

5. Conclusion

The results are biased due to failures in the study design and do not represent a reliable estimation of leopard prey density. However, the study showed that estimating density of leopard prey is difficult, given that leopards prey on a broad range of different animal species and therefore unequal detection possibilities occurs. Collecting data for all possible prey species should not be done without a pilot study. A pilot study can help to detect possible problems in data collection for the animal species and based on this knowledge one can choose adequate sampling methods. Furthermore, line transect sampling is not to recommend for rocky terrains, since the observer is distracted by wandering or climbing safely and can not focus on scanning the area for possible objects of interest. For this kind of terrain, point or line point transects would be the better choice.

Most of the sighted animal species provide suboptimal prey. Higher numbers of optimal prey (mainly bushbuck and red duiker) were seen in lower forested parts of Lajuma and evidences of leopard presence were also more prominent in these parts as in the sampled area. Forested parts can therefore be considered as favoured leopard habitat.

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Lajuma Mountain Retreat: http://www.lajuma.com

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Appendix A

Common and scientific names of mammals and birds mentioned in the Text.

Class Mammalia

Order Primata

Chacma baboon	*Papio ursinus*
Vervet monkey	*Cercopitheticus aethiops*

Order Lagomorpha

Scrub hare	*Lepus saxatilis*

Order Rodentia

Bamboo rat	*Rhizomys sinensis*

Order Carnivora

Tiger	*Panthera tigris*
Leopard	*Panthera pardus*
Jaguar	*Panthera onca*
Brown hyaena	*Hyaena brunnea*
Dwarf Mongoose	*Helogale parvula*
Slender Mongoose	*Herpestes sanguineus*

Order Hyracoidea

Tree hyrax	*Dendrohyrax arboreus*
Rock hyrax	*Procavia capensis*
Yellow-spot hyrax	*Heterohyrax brucei*

Order Proboscidae

African elephant	*Loxodonta africana*

Order Perissodactyla

Burchell's zebra	*Equus burchelli*

Order Artiodactyla

Wild boar	*Sus scrofa*
Bush pig	*Potamochoerus porcus*
Warthog	*Phacochoerus aethiopicus*
Tufted deer	*Elaphodus cephalophus*
Sambar deer	*Cervus unicolor*
Chital	*Axis axis*
Giraffe	*Giraffa camelopadalis*
Bushbuck	*Tragelaphus scriptus*
Nyala	*Tragelaphus angasi*
Greater kudu	*Tragelaphus strepsicerus*
Eland	*Tragelaphus oryx*
Sable antelope	*Hippotragus niger*
Impala	*Aepyceros melampus*
Red duiker	*Cephalophus natalensis*
Grey duiker	*Cephalophus grimmia*
Klipspringer	*Oreotragus oreotragus*

Class Aves

Crested guinea fowl	*Guttera pucherani*
Natal francolin	*Francolinus natalensis*

Appendix B

Summary of the different leopard prey species found in the western Soutpansberg, based on analysed scats and located kills (STUART & STUART, 1993; POWER, 2002; NEWANGAYA, 2002)

Hyrax	*Procavia*
	Heterohyrax
Antelopidae	
Bushbuck	*Tragelaphus scriptus*
Duiker	
Grey	*Silvicapra grimmia*
Red	*Cephalopus natalensis*
Eland	*Taurotragus oryx*
Hartebeest	*Alcelaphus buselaphus*
Impala	*Aepycerus melampus*
Klippspringer	*Oreotragus oreotragus*
Kudu	*Tragelaphus strepsicerus*
Reedbuck	
Mountain	*Redunca fulvorufula*
Southern	*Redunca arundinum*
Sharp's Grysbok	*Raphicerus sharpei*
Wildebeest	*Connochaetes taurinus*
Primata	
Chacma Baboon	*Papio ursinus*
Greater Galago	*Otolemur crassicaudatus*
Samango monkey	*Cercopithecus mitis*
Vervet monkey	*Cercopithecus aethiops*

Rodentia

Porcupine	*Hystrix africae-australis*
Cane-rat	Thryonomyidae
Murids	Muridae

Lagomorpha

Jameson's red rock hare	*Pronolagus randensis*
Scrub hare	*Lepus saxatilis*

Carnivora

Aardwolf	*Proteles cristatus*
African civet	*Civettictis civetta*
Caracal	*Caracal caracal*
Water mongoose	*Atilax paludinosus*

Tubulidentata

Aardvark	*Orycteropus afer*

Suidae

Bushpig	*Potamocherus larvatus*

Aves

Crested guinea fowl	*Guttera pucherani*

Appendix C

Cut points, observed and expected values for the histogram distance categories, chosen by DISTANCE.

Cell i	Cut Points		Observed Values	Expected Values
1	0.00	3.93	20	17.71
2	3.93	7.86	19	16.33
3	7.86	11.8	9	13.92
4	11.8	15.7	10	11.06
5	15.7	19.6	6	8.33
6	19.6	23.6	8	6.14
7	23.6	27.5	5	4.62
8	27.5	31.4	4	3.68
9	31.4	35.4	4	3.11
10	35.4	39.3	3	2.69
11	39.3	43.2	2	2.27
12	43.2	47.1	1	1.82
13	47.1	51.1	2	1.37
14	51.1	55.0	1	0.95

Appendix D

Weight of detected species.

Species	Smither's – Mammals of Southern Africa Middle Weight [kg] Male	Female	Both gender	Bailey – The African Leopard Middle weight [kg]	Middle weight [kg]
Bushbuck	42	28	35	29,5	32,25
Bushpig	62	59	60,5	—	60,5
Chacma baboon	27 - 43	15 - 17	25,25	15,5	20,38
Duiker - grey	20,7	18,7	19,7	14,4	17,05
- red	—	—	12	—	12
Francolin	—	—	—	0,3	0,3
Greater kudu	230	157	193,5	172	182,75
Guineafowl	—	—	—	1,8	1,8
Hyrax	3,7	3,4	3,55	—	3,55
Klipspringer	10,6	13,2	11,9	10,2	11,05
Mongoose - dwarf	—	—	0,267	—	0,267
- slender	0,637	0,460	0,549	—	0,549
Scrub hare	—	—	—	2,2	2,2
Vervet Monkey	5,5	4,1	4,8	3,3	4,05
Warthog	80	56	68	29,5	48,75