

**AN ASSESSMENT OF DENSITY ESTIMATION METHODS  
FOR FOREST UNGULATES**

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

**MASTER OF SCIENCE**

of

**RHODES UNIVERSITY**

by

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November 2003

## ABSTRACT

The development of conservation and management programs for an animal population relies on a knowledge of the number of individuals in an area. In order to achieve reliable estimates, precise and accurate techniques for estimating population densities are needed. This study compared the use of direct and indirect methods of estimating kudu (*Tragelaphus strepsiceros*), bushbuck (*Tragelaphus scriptus*), common duiker (*Sylvicapra grimmia*), and blue duiker (*Philantomba monticola*) densities on Shamwari Game Reserve in the Eastern Cape Province, South Africa. These species prefer habitats of dense forest and bush for concealment and are therefore not easily counted in open areas. Herein direct observation counts were compared to indirect sampling via pellet group counts (clearance plots, line transects, variable-width transects, and strip transects). Clearance plots were examined every 2 weeks, while all other methods were conducted seasonally, from August 2002 until August 2003. The strip transect method provided the lowest density estimates (animals per ha) ranging from 0.001 for bushbuck to 0.025 for common duiker, while direct observations yielded the highest estimates, ranging from 0.804 for bushbuck to 4.692 for kudu. Also, a validation of methods was performed against a known population of kudu during which the DISTANCE method yielded the most accurate results, with an estimated density of 0.261 that was within the actual density of 0.246 to 0.282. In addition, the DISTANCE method was compared to helicopter counts of kudu and its estimates were found to be approximately 2.6 times greater than the helicopter count results. When the assessment of the methods was made, the cost, manpower and effort requirements, coefficient of variation, and performance against a known population for each method were taken into consideration. Overall, the DISTANCE method performed the best with low cost, minimal manpower and effort requirements, and low coefficient of variation. On Shamwari Game Reserve, the DISTANCE method estimated 0.300 kudu, 0.108 bushbuck, 0.387 common duiker, and 0.028 blue duiker per ha, which, when extrapolated to the total number of animals present within subtropical thicket habitat, estimated 1973 kudu, 710 bushbuck, 2545 common duiker, and 184 blue duiker.

## TABLE OF CONTENTS

ABSTRACT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF APPENDICES	x
ACKNOWLEDGEMENTS	xi
CHAPTER 1: INTRODUCTION	1
Habitat, Behavior, and Diet	2
<i>Blue Duiker</i>	2
<i>Common Duiker</i>	3
<i>Bushbuck</i>	4
<i>Kudu</i>	4
<i>Summary</i>	5
Population Estimation Methods	5
<i>Direct Sampling Methods</i>	6
<i>Indirect Sampling Methods</i>	9
Summary	11
CHAPTER 2: MATERIALS AND METHODS	18
Study Area	18
Methods	18
<i>Direct Methods</i>	19
<i>Direct Count Observations</i>	19
<i>Indirect Methods</i>	20
<i>Clearance Plots</i>	21
<i>Line Transects</i>	22
<i>Strip Transect</i>	25
<i>Habitat Assessment</i>	25
<i>Ground Cover Assessment</i>	26

<i>Validation of Methods</i>	27
<i>Shamwari's Breeding Center</i>	27
<i>Kwandwe Game Reserve</i>	27
<i>Statistical Analyses</i>	28
CHAPTER 3: RESULTS	35
Rainfall And Bush Density	35
Direct Methods	36
<i>Direct Count Observations</i>	36
Indirect Methods	37
<i>Decay and Defecation Rates</i>	37
<i>Clearance Plots</i>	38
<i>Line Transects</i>	39
<i>Variable Width</i>	39
<i>DISTANCE</i>	40
<i>Strip Transect</i>	40
Summary Of All Methods	41
<i>Man-hour requirements</i>	42
Validation Of Methods	43
<i>Shamwari Game Reserve</i>	43
<i>Shamwari's Breeding Center</i>	43
<i>Kwandwe Game Reserve</i>	43
CHAPTER 4: DISCUSSION	62
Direct Sampling Methods	63
<i>Direct Count Observations</i>	63
Indirect Sampling Methods	64
<i>Clearance Plots</i>	66
<i>Line Transects</i>	67
<i>Variable Width</i>	68
<i>DISTANCE</i>	69
<i>Strip Transect</i>	71
Summary	72

Management Implications	75
Future Research	76
Conclusions	78
CHAPTER 5: REFERENCES	83
APPENDIX 1: Guidelines for use of DISTANCE method	90
Data Collection	90
Downloading DISTANCE 3.5	92
Creating New Project	92
Data Analysis	94

## LIST OF TABLES

Table 3.1	Results of the habitat assessment at all sites using the point-centered quarter method to determine bush (tree) density.	45
Table 3.2	The relative frequency (%) of tree species at each site from the point-centered quarter habitat survey.	46
Table 3.3	Analysis of variance testing the effects of season, time, species, and associated interactions on the number of animals counted during an observation period.	47
Table 3.4	Analysis of variance by species testing effects of season (s), time (t), and season $\times$ time on the number of animals counted during an observation period	47
Table 3.5	Mean number of animals counted during a morning (AM) or evening (PM) observation for each season.	48
Table 3.6	The estimated number of animals per hectare for subtropical thicket habitat within Shamwari Game Reserve as determined by the tested methods.	49
Table 3.7	The estimated total number of animals present on Shamwari Game Reserve within subtropical thicket habitat as determined by the tested methods.	49
Table 3.8	Summary of decay and defecation rates for kudu, bushbuck, common duiker, and blue duiker used in this study to determine the number of animals per ha.	50
Table 3.9	Analysis of variance testing the effects of season, species, and season $\times$ species on the mean number of pellet groups which accumulated in a quad from clearance to return (approximately 2 weeks).	51
Table 3.10	Analysis of variance testing the effects of season, species, and season $\times$ species on the mean number of pellet groups counted during a line transect survey.	51

Table 3.11	Analysis of variance testing the effects of season, species, and season × species on the mean number of pellet groups counted during a strip transect survey.	51
Table 3.12	Analyses of variance by species testing the effects of method (without direct observations), and season, and associated interactions on animal density.	52
Table 3.13	The number of animals per hectare for riverine bush habitat (Site 1) within Shamwari Game Reserve as determined by the tested methods.	53
Table 3.14	The number of animals present on Shamwari Game Reserve within riverine bush habitat (Site 1) as determined by the tested methods.	53
Table 3.15	The estimated kudu densities and numbers from the test of all methods on Shamwari's Breeding Center.	54
Table 4.1	An assessment of methods tested in this study including the man-hours required to perform the method at each site for a season, whether the density estimates overall were high or low in comparison to the DISTANCE method, and the advantages and disadvantages of each method.	79
Table 4.2	The number of animals present on Shamwari Game Reserve as determined by the DISTANCE method and helicopter counts.	81

## LIST OF FIGURES

Figure 1.1	The blue duiker is approximately 30-35 cm at shoulder height and weighs 4-6 kg.	14
Figure 1.2	The blue duiker's distribution based on Skinner and Smithers (1990).	14
Figure 1.3	The common duiker is 60 cm at shoulder height and weighs 12-16 kg (Walker 1996).	15
Figure 1.4	The common duiker's distribution based on Skinner and Smithers (1990).	15
Figure 1.5	The bushbuck is 69-94 cm at shoulder height and weighs 32-64 kg (Walker 1996)	16
Figure 1.6	The bushbuck's distribution based on Skinner and Smithers (1990).	16
Figure 1.7	The kudu is 1.2 m at shoulder height and weighs 150-270 kg (Walker 1996).	17
Figure 1.8	The kudu's distribution based on Skinner and Smithers (1990).	17
Figure 2.1	Sites one through six at Shamwari Game Reserve showing the layout of each site with a center cut-line/road and bush on either side.	29
Figure 2.2	Vegetation map of Shamwari Game Reserve (O'Brien 2000) showing approximate locations of sites.	30
Figure 2.3	Observer conducting direct observation counts from vehicle using binoculars.	31
Figure 2.4	Example photographs of dung pellets used to identify pellet groups found at the study sites.	32
Figure 2.5	The indirect methods in the study utilized 5 by 5 m quadrats for clearance plots, 100 by 5 m strip transects, and 10 to 50 m line transects.	33
Figure 2.6	An observer conducting a line transect survey.	33
Figure 2.7	An observer carrying out a strip transect survey at Site 1 Shamwari Game Reserve.	34

Figure 2.8	Cut-line at the breeding center where all methods were tested against a known population of kudu.	34
Figure 3.1	The mean ( $\pm$ s. e.) number of kudu, bushbuck, and common duiker counted during an observation period for each season.	55
Figure 3.2	Mean ( $\pm$ s. e.) kudu (KU), bushbuck (BB), common duiker (CD), and blue duiker (BD) densities (animals per ha) estimated using DISTANCE, variable width, strip transect, clearance plots, and direct observation methods.	56
Figure 3.3	The power relationship for known ungulate defecation rates (pellet groups per day) and body weights (kg).	57
Figure 3.4	Mean ( $\pm$ s. e.) number of pellet groups deposited between visits to clearance plots for each species during each season.	58
Figure 3.5	Mean ( $\pm$ s. e.) number of pellet groups counted during a line transect survey (250 m straight-line length) for each species during each season.	59
Figure 3.6	Example graph of the detection function (line) fitted to the observations recorded (bars).	60
Figure 3.7	Mean ( $\pm$ s. e.) number of pellet groups counted during a strip transect survey for each species during each season.	61
Figure 4.1	Flowchart for selecting appropriate census method modified from Mayle et al. (1999).	82

## LIST OF APPENDICES

Appendix 1	Guidelines for use of DISTANCE method	88
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## ACKNOWLEDGEMENTS

I would like to thank Professor R. T. F. Bernard for his support, guidance, and supervision throughout my work for this project and thesis. Also, I would like to thank Shamwari Game Reserve for allowing me to conduct my project on the reserve and for providing me with accommodation, field assistants, and transportation. Special thanks are owed to J. Joubert and J. O'Brien for allowing me to work at Shamwari and coordinating and providing assistance when needed. Many thanks are due to I. Hargroves for helping me set-up my project, patiently working with me throughout the project, and coordinating whatever I needed. I also appreciate all the Shamwari staff that assisted me during my fieldwork and D. Parker and D. Brown who assisted in habitat assessment and plant identification. I also would like to thank Kwandwe Game Reserve, especially M. Galpin and the staff that assisted me in my fieldwork, for allowing me to test my methods there as well. Thanks also to T. Butterworth for providing technical assistance by customizing some of the equipment used in my study. Rhodes University provided funding. My deepest appreciation goes to my husband, J. D. Ellis Jr., who assisted me in all the many days of fieldwork, provided advice, and offered support throughout the work for this thesis.

## CHAPTER 1: INTRODUCTION

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The conservation and management of an animal population is dependent upon a reliable knowledge of the number of individuals in an area and the carrying capacity of the habitat (Mandujano and Gallina 1995). Thus, precise and accurate techniques for estimating population densities must be an essential management tool (Bowland and Perrin 1994, Marques et al. 2001). These techniques should not only detect the presence of an animal but also determine and monitor its abundance and demonstrate a reliable trend of population growth or decline, all of which are needed to make informed, justifiable management decisions (Bowland and Perrin 1994, Bothma 2001). Also, the sex ratio and age structure of a population may provide important insight into a population's recent history, current status, and likely immediate future trend (Dimmick and Pelton 1996). The population survey can be used to determine the status of a species and, then, the wildlife manager must decide what actions need to be taken to maintain or improve the situation (Conroy and Smith 1994, Reilly and Haskins 1999). Reliable estimation techniques are of particular interest and importance to managers of game reserves, who are working with a system in which they need reliable estimates of the number of animals for calculating stocking rates and determining the effect of these animals on the habitat (Peel and Bothma 1995).

The growing number of game reserves in the Eastern Cape Province, South Africa has created interest in the impact of management strategies on native flora and fauna. If there are too few animals of a certain species, then concerns about inbreeding and genetic diversity or loss of the species may develop. On the other hand, too many animals of a certain species may cause problems of disease, starvation, lack of suitable habitat, or habitat damage. Also, many of the reserves introduce species that are not native to the region, such as giraffe (*Giraffa camelopardalis*), or have been absent from the region for many decades, such as lions (*Panthera leo*). In order to assess the impacts of these species

on populations of other species, it is essential to have reliable methods of estimating population size.

This study attempts to establish reliable methods to estimate the numbers of forest ungulates present in their suitable habitats on Shamwari Game Reserve, Eastern Cape Province, South Africa. The forest ungulates within the study area include blue duiker (*Philantomba monticola*), common duiker (*Sylvicapra grimmia*), bushbuck (*Tragelaphus scriptus*), and greater kudu (*Tragelaphus strepsiceros*). These species are of special concern since the introduction of lions onto the reserve in 2000. They have all occurred on the reserve's lion kill list (kills that have been found), but the actual impact on these species cannot be determined without a knowledge of the numbers present on the reserve. Also, due to the small size of the common duiker and blue duiker, the likelihood of locating a lion kill is small; therefore, the impact of lions on the species may be underestimated.

Many forest animals, such as the ungulates in question, exhibit solitary and secretive behavior making direct observation and counts difficult (Koster and Hart 1988). In order to determine which method will work best for this study, the habitat, diet, and behavior of each species, knowledge that is an essential requirement to any management program, must be taken into consideration (Dekker et al. 1996).

### **Habitat, Behavior, and Diet**

#### ***Blue Duiker***

The smallest and most obscure animal in question is the blue duiker (Figure 1.1), which inhabits a wide range of forest and wooded habitats, utilizing rainforests, coastal sand-dune, riverine, and montane forests (Stuart and Stuart 2000). It is widespread, occurring in virtually all forested habitats and preferring forests and dense stands of bush with little undergrowth (Stuart and Stuart 1988, Estes 1991). The species distribution, which is discontinuous and patchy due to specialized habitat requirements, stretches from the eastern coastal areas of South Africa to parts of West Africa (excluding Namibia, Botswana, and most of Zimbabwe; Figure 1.2; Skinner and Smithers 1990).

The blue duiker adult is about 35 cm in height and has an average weight of about 4 kg (Koster and Hart 1988, Stuart and Stuart 1988). The blue duiker usually occurs as a solitary individual (73 % of the time when encountered), or in mated pairs on small,

permanent territories (Crawford 1984, Stuart and Stuart 1988). The mean permanent territory size for blue duiker pairs is about 0.70 ha and its home range is about 3 - 4 ha (Estes 1991, Bowland and Perrin 1994).

The blue duiker feeds both night and day and uses regular pathways to feeding and drinking sites and is most active shortly after dawn and just before dusk (Stuart and Stuart 1988, Bowland and Perrin 1995). It is a browser with a diet including leaves and fruits (Walker 1996). The blue duiker is very timid and rarely seen, except for its pellet groups (Stuart and Stuart 1988). Studies have suggested a clumped distribution of pellet groups for blue duiker, implying the use of middens (von Gadow 1978, Schmidt 1983).

### *Common Duiker*

The common duiker (Figure 1.3) is larger than the blue duiker, being about 50 cm in height and 20 kg in weight (Stuart and Stuart 1988). The species distribution is wide in Africa south of the Sahara (excluding most of Zaire, Congo Republic, Gabon, and Equatorial Guinea; Figure 1.4; Skinner and Smithers 1990). It is relatively common with populations flourishing under conditions that have caused other species to decline, such as land development, farming, and timber plantations (Schmidt 1983). The common duiker can live in any habitat that provides enough cover for concealment, preferring scrub and bush-covered areas that provide shelter and shade (Stuart and Stuart 1988, Estes 1991). It does not venture onto open plains (Estes 1991, Stuart and Stuart 2000).

The common duiker is territorial and usually solitary but can be found in monogamous pairs (Estes 1991). Its mean home range size is about 21 ha, varying between 12.1 and 27.4 throughout the year (Skinner and Smithers 1990). The main periods of activity for the common duiker are in the early morning and late afternoon, but it is also known to be active at night in areas in which it is subjected to continued disturbance or hunting (Skinner and Smithers 1990, Estes 1991, Walker 1996).

The common duiker is independent of water, but will drink when water is available (Walker 1996, Stuart and Stuart 2000). Its diet consists of browse including leaves, fruits, twigs, flowers, seeds, and agricultural crops (Stuart and Stuart 1988, Skinner and Smithers 1990, Walker 1996). It will also dig for tubers and roots and nibble at bark (Skinner and Smithers 1990). Pellet group heaps are deposited in close proximity to each other, indicating the use of middens (Stuart and Stuart 2000).

### *Bushbuck*

Like the common duiker, bushbuck (Figure 1.5) populations have prospered in disturbed areas (Schmidt 1983). The bushbuck prefers habitats of riverine woodland and bush associated with water, from coastal dune bush to montane forest, but can be found in a variety of natural vegetation types as well as exotic timber plantations (Schmidt 1983, Stuart and Stuart 1988, Simbotwe and Sichone 1989). Its distribution, limited to where there is suitable habitat, stretches from south of the Sahara (excluding most of Namibia and Botswana) to the eastern coastal areas of South Africa (Figure 1.6; Skinner and Smithers 1990).

The mean height and weight of the adult bushbuck is about 70 cm and 40 kg, respectively (Stuart and Stuart 1988). The bushbuck is nonterritorial, polygynous, and solitary but can be found in pairs or in a small group of the female and her latest offspring (Estes 1991, Stuart and Stuart 2000). The home range size varies with recordings from 25 ha to 600 ha (Odendaal and Bigalke 1979, Stuart and Stuart 2000). Home ranges overlap but each adult has an exclusive lying-up place, usually a thicket where it rests and ruminates (Estes 1991, Stuart and Stuart 2000). The bushbuck is mainly nocturnal but can be seen in the late evening and early morning when it walks in open habitat toward its night range before nightfall and returns to its thicket at the approach of dawn (Stuart and Stuart 1988, Walker 1996).

The bushbuck is largely a browser feeding mostly on leaves but also takes herbs, tender new grass, and shrubby leguminous plants (Odendaal 1983, Skinner and Smithers 1990, MacLeod et al. 1996). Bushbuck diet has been found to be composed of approximately 85% browse, 5% grass, 5% fungi, and 5% other material (Odendaal 1983). It also feeds on flowers, figs, and other fruits (Estes 1991, Walker 1996). A variety of plant species have been found in fecal analysis, but the diversity of the diet was low, with a few plant species dominating (MacLeod et al. 1996). Studies have suggested a clumped distribution of pellet groups for bushbuck (von Gadow 1978, Schmidt 1983).

### *Kudu*

The largest ungulate under question in this study is the kudu (Figure 1.7) with an adult height of 2.3 to 2.9 m and weight for female and male of 180 and 250 kg, respectively (Stuart and Stuart 2000). It is widely distributed south of the Sahara along

through eastern countries and below Zaire, preferring a habitat of wooded savanna with stands of bush that provide cover and food (Figure 1.8; Stuart and Stuart 1988, 2000). It has been found to prefer low closed woodland and low thicket, as well as habitats with *Acacia* species present (Dekker et al. 1996, Stuart and Stuart 2000, Dörgeloh 2001).

The kudu is gregarious and is found in small herds from 3 to 10 animals, which usually comprise 1 to 3 females and their offspring (Estes 1991, Stuart and Stuart 2000). The home range of female groups varies from 1.0 to 25.0 km<sup>2</sup>, and the bachelor groups have a larger range of up to 50 km<sup>2</sup> (Skinner and Smithers 1990). Outside of the midwinter rutting period, adult bulls are either solitary or join small bachelor herds from 2 to 10 males (Stuart and Stuart 1988). During the rut, an adult bull will associate with a group of females and their young (Stuart and Stuart 2000). Females will move away from their group to calve alone in thickets (du Toit 1995). The kudu is usually active in early mornings and late afternoons, but in hunted or disturbed areas activity is nocturnal (Stuart and Stuart 2000).

The kudu is nearly a pure browser with a diet of leaves, herbs, fallen fruits, succulents, vines, tubers, flowers, and new grass (Stuart and Stuart 1988, Estes 1991). It can be considered a pest in some areas where it feeds upon agricultural crops, such as corn and vegetables (Stuart and Stuart 1988). It is mostly independent of water (Walker 1996).

### ***Summary***

The forest ungulates within the study area are elusive, preferring habitats of dense forest and bush for concealment. They are not easily counted in the open areas, being easily overlooked. All species in question are predominantly browsers with similar diets and are most active early in the morning and late in the afternoons with some activity at night.

### **Population Estimation Methods**

Population estimation methods can be classified as direct sampling, which involves counting individual animals, or indirect sampling, in which animal signs, such as dung or tracks, can be used as indices of animal presence, or can be used to calculate animal density (Eberhardt 1978). The use of cull data is another method but is not an option on a game reserve where hunting is prohibited (Mayle et al. 1999).

### *Direct Sampling Methods*

There are several direct methods involving counting individual animals that have been employed in population census studies. These include drive counts (Downing et al. 1965, Schmidt 1983, Koster and Hart 1988, Mayle et al. 1999, Bothma 2001), road and field strip counts (Hirst 1969, Dinerstein 1980, Underwood 1982), aerial counts (Maddock 1991, Peel and Bothma 1995, Reilly 2003), water hole counts (Bothma et al. 1990), and line transects (Bowland and Perrin 1994, Mandujano and Gallina 1995, Focardi et al. 2002, Lannoy et al. 2003). Each method has its pros and cons for use within different habitat types and with different animal species under question.

Drive counts are suited to relatively small areas with open grassland and open bushveld and have been found to work best for larger species (Mayle et al. 1999, Bothma 2001). They cover entire areas and require sufficient manpower to identify game species (Bowland and Perrin 1994, Bothma 2001). In small areas, the method can be used to count all individuals present in an area. A modified method, in which sample areas are covered, can be used to extrapolate an estimate for larger areas (Bothma 2001). Drive counts involve counters beginning in a straight line across one boundary fence, spaced according to the visibility of the habitat, and moving together across the area to the opposite boundary (Bothma et al. 1990, Bothma 2001). Observers are positioned such that each person only views in one direction and can see the next observer (Mayle et al. 1999). This method has been used to estimate ungulate populations in many southern Africa studies, such as Schmidt (1983), Koster and Hart (1988), Bothma et al. (1990), and Bowland and Perrin (1994). The assumptions that must be met when conducting a drive count are that no animal is counted more than once and that all animals within the delineated area will be counted (Schmidt 1983).

Waterhole counts have also been utilized, during which animals are counted by observers from vehicles parked near a waterhole (Bothma et al. 1990). Counts are done simultaneously at all waterholes throughout a reserve for a 24 hour time period (Bothma et al. 1990). This method assumes that all animals within the area will visit a water hole during the 24 hour observation period.

Another method commonly used by game reserve managers is aerial surveys. Aerial surveys can be conducted by a microlight, fixed-wing aircraft (low-wing or high-wing), or helicopter (Maddock 1991, Peel and Bothma 1995, Bothma 2001). It is relatively

expensive but can save in terms of the amount of time it takes to conduct a survey over a large area (Mayle et al. 1999, Bothma 2001). Two teams of observers (2 to 4 people), one on each side, count animals seen as the aircraft flies predetermined transects over an area (Mayle et al. 1999, Bothma 2001). Infrared photography has also been used as a means of counting the number of animals from an aircraft (Bailey and Putman 1981). It has been found that the helicopter yielded the most accurate population estimate when compared to microlight and fixed-wing aircraft (Peel and Bothma 1995). Evidence also has been provided that observations decline over time during the course of an aerial count due to changing sightability and observer fatigue and this must be taken into account in order to calculate an accurate density (Reilly and van Hensbergen 2002). Aerial surveys work well for large, darkly colored game that inhabit open areas but not for more camouflaged game in woodland areas (Hirst 1969). The method is also suitable for large populations and large areas but is not recommended for small populations and small areas (Mayle et al. 1999).

The road and field strip census methods also involve the direct counts of animals. In a road strip census the mean visibility distance is determined for a specific road and habitat beforehand and used as the width, or width can be calculated by recording the perpendicular distance of animals from the center of the road (Hirst 1969, Dinerstein 1980, Bothma 2001). Designated roads are driven by motor vehicle while observers count the number of animals encountered. This method assumes that no animals move into or out of the observer's range of visibility before detection, no animals are counted more than once, and the sighting distances are accurate (Bowland and Perrin 1994).

There are also several methods that can be employed for night road surveys, such as spotlight counts and thermal imaging. Spotlight counts use the same basic concepts as the road strip census. Counts are conducted from the back of a vehicle by observers positioned on either side, using a spotlight to locate animals (Schmidt 1983, Mayle et al. 1999). The spotlight count method has limited applications because it is restricted to areas with good road systems, good visibility, and animal populations that are not disturbed at night (Mayle et al. 1999). A thermal imager, which detects the long-wave radiant energy emitted by warm-blooded animals, can also be used at night to provide counts and species and sex identification (Mayle et al. 1999). This method is not suitable within woodland areas, since thermal energy will not penetrate foliage, and the equipment required is still relatively expensive (Mayle et al. 1999).

The field strip technique uses an area of predetermined length and width and requires the observer to sit and count the number of animals that cross the area during a set time (Bowland and Perrin 1994). The density (number of animals per ha) is calculated by dividing the number of animals observed crossing the strip by the area of the strip, yielding a number of animals counted for a known area. There are many variations of this method, including fixed width transects and vantage point counts (Bowland and Perrin 1994, Mayle et al. 1999). The assumptions for this method are the same as those of the road strip census.

A variation of the strip census is the line transect sampling method which utilizes a one-dimensional sampling line from which the observer records the perpendicular distance or the sighting distance and angle to the animal from the line (Eberhardt 1978, Anderson et al. 1979, Bowland and Perrin 1994). Population estimation by the use of line transects has been used since at least the early 1930s and has proven to be practical, efficient, and inexpensive (Anderson et al. 1979, Burnham et al. 1980). This method assumes that animals are detected at their initial location, all animals on the centerline are detected with certainty, and their distance from the line is recorded accurately (Burnham et al. 1980, Burnham and Anderson 1984, Focardi et al. 2002). It does not assume perfect detectability, an assumption that may result in incomplete counts and bias in strip counts (Barry and Welsh 2001, Burnham and Anderson 1984). Data can be processed and a population estimate calculated using a software program, such as DISTANCE (Laake et al. 1998), which calculates a probability density function specific to the samples taken in the field that models the decrease in the number of animals encountered with the increase in distance from the line (Anderson et al. 1979, Plumptre 2000). The line transect method has been applied to many species of animals over many habitat types throughout the world.

An alternative method to obtain information about the population in question is to use infrared-triggered cameras to photograph animals. Information about a population can be obtained without lengthy observations (Carthew and Slater 1991). Infrared-triggered cameras have been used to survey small and large animals alike, ranging from birds and small mammals (Carthew and Slater 1991) to large herbivores (Jacobson et al. 1997). The cameras have been used to photograph white-tailed deer (*Odocoileus virginianus*) and calculate sex and age ratios and the size of a population (Jacobson et al. 1997). In order to obtain information about sex and age ratios, the study was conducted at a time of year

when males, females, and fawns were easily distinguished. A limiting factor in the use of this method is the cost of equipment since a large number of cameras would be necessary to sufficiently cover an area (Jacobson et al. 1997).

### *Indirect Sampling Methods*

The behavior and habitat preference of some species prohibit the use of direct sampling methods or make these methods inaccurate; therefore, indirect methods, such as pellet (dung) counts (Downing et al. 1965, Dinerstein 1980, Schmidt 1983, Bowland and Perrin 1994), track counts (Koster and Hart 1988, Mandujano and Gallina 1995, Mayle et al. 2000), territorial marking (scrapes or rubs) counts (Mayle et al. 1999), or browsing and grazing impact levels (Mayle et al. 1999) have been developed. Each method has its limitations based upon the species being studied and the habitat types in which it will be utilized. The presence of these various signs can be used as an index to animal presence, or counts can be converted into an actual number of animals, which is often necessary for species that are difficult to census directly (Fuller 1991). The use of signs, such as pellet counts, also provides estimates of average abundance over several months, instead of an estimate for the day of the survey when using direct counts (Marques et al. 2001).

Pellets or dung offer information about a population's distribution, size, and diet, information that can be difficult to obtain for elusive species (Putman 1984). There are several techniques for estimating population size by counting pellet groups. Some are based on standing crop, in which all pellet groups within the sample plots are counted, and others are based on the clearance plot method, which is based on the number of pellet groups deposited within sample plots that were initially cleared of all pellets (Marques et al. 2001). In order to calculate density from the counts, the defecation rate of the animal and decay time of the pellets must be known (Aulak and Babińska-werka 1990). Pellet or dung counts have been used to estimate population numbers of a range of animals, including lizards, rabbits, large and small ungulates, kangaroos, and elephants (Barnes 2001).

The clearance plot method has been utilized in numerous studies beginning with Bennett et al. (1940). Old pellet groups are removed from the designated area or marked by the use of paint (Kufeld 1968). The areas are then revisited at a later time and the number of pellet groups that have accumulated are counted. If the time period between

clearing and counting pellet groups is short enough, then the decay time will not be important, and this reduces the number of variables needed to calculate the number of animals (Marques et al. 2001).

The shape and size of plots used has varied from quadrats (Bennett et al. 1940, Dzieciolowski 1976, Bailey and Putman 1981), to rectangular plots (Dinerstein 1980, Rowland et al. 1984, Fuller 1991, Bowland and Perrin 1994), to circular areas (Rogers et al. 1958, Wallmo et al. 1962, Van Etten and Bennett 1965, Smith 1968, Batcheler 1975, Freddy and Bowden 1983, Weckerly and Ricca 2000). It has been found that smaller plots tend to give large estimates due to the fact that more borderline pellet groups are counted, or that pellet groups are more likely to be missed in larger plots (Smith 1968, Batcheler 1975). However, small plots may be beneficial because many small sampling units have the same sampling accuracy as a few large units, even though less total area sampled is required (Neff 1968).

The use of strip transects, which are long, narrow plots 1-2 m wide, has been recommended because the plot can be covered in a single sweep (Marques et al. 2001). This would be more efficient but the number of pellet groups located on the edge would be greater; therefore, a clear definition of countable groups must be set beforehand (Marques et al. 2001). One study, utilizing transects 1 km long and 1 m wide, addressed the problem by counting and rejecting alternate pellet groups that were found on the edge (Mayle et al. 2000).

A method that deals best with borderline pellet groups is the line transect method which involves measuring the distance of pellet groups from the transect line (Koster and Hart 1988, Marques et al. 2001). This allows a wider strip to be surveyed and the potential bias of the edge is reduced. Since it is independent of plot size, search time will depend on the pellet group density and will be lower at high densities, especially if limits are set for the maximum search distance (Quayle 1998). The line transect method utilizes the standing crop of pellet groups; therefore, sample area and habitat specific estimates of length of time to dung decay and defecation rates are required. The method also requires only one visit to the site; therefore, a greater area can be surveyed (Plumptre and Harris 1995). When sampling an area using line transects, many short transect lines are preferred because they give better spatial coverage and more reliable estimates of precision (Marques et al. 2001). In areas where the population density is known to be high, 50 m

transects are recommended, but where the density is low, longer transects may work best (Marques et al. 2001). It is also recommended that 10-20 separate transect lines are used within each area of land (Marques et al. 2001).

There are several sources of inaccuracy in methods relying upon pellet group counts, including differences in habitat use, mobility, defecation rates, and pellet decay rates in different habitats (Bailey and Putman 1981). To improve the method, it is necessary to determine the daily defecation rates for each season of the year and to assess the weathering and decomposition rate of pellets under various habitat types (Dzięciołowski 1976, Rogers 1987). The most difficult of the parameters to estimate is the defecation rate of a free-living population, which is necessary in calculating population numbers from pellet group counts (Batcheler 1975, Rollins et al. 1984). Pellet count surveys are also labor intensive, which can make them costly, but they are most efficient in areas of high pellet group density (Neff 1968, McClanahan 1986). It is also important to validate the use of pellet counts as a reliable estimate of population numbers (White 1992).

Another indirect method which has been used is track and trackway counts (Downing et al. 1965, Mooty and Karns 1984, Mandujano and Gallina 1995, Mayle et al. 2000). One study prepared the road surface the day before counts by grading, erasing old tracks and disturbing the surface to make new tracks more visible (Mooty and Karns 1984). The following day, an observer counted tracks, distinguishing between young and adult, from a slow moving vehicle. Similar techniques have also been employed in other studies in which transects were cleared the day before counts but counts were conducted by foot (Downing et al. 1965, Mandujano and Gallina 1995). One study established 1 ha circular stations in which they looked for tracks as a sign of presence (Weckerly and Ricca 2000). Trackway counts have also been conducted by walking the perimeter of woodland areas and recording the number of obvious pathways crossing the edge (Mayle et al. 2000). A correlation between track counts and pellet-group surveys has been found (Mayle et al. 2000). Track and trackway counts can only provide an index of presence or activity and cannot be converted to numbers of animals (Mayle et al. 1999).

### **Summary**

The ultimate decision of which method works best for a certain species will need to take into account cost to employ the method, size of the study area, type of habitat, animal

behavior, available manpower, and the purpose of the count (Bothma 2001). For the present study, it was necessary to keep costs low, thus prohibiting the use of aerial surveys. Also, it was not possible to purchase the equipment needed for thermal imaging surveys and the quantity of infrared-triggered cameras needed to effectively cover the study area. The size of the study area was too great to obtain reliable estimates from drive counts. Also, due to the presence of lions, buffalo (*Syncerus caffer*), black rhino (*Diceros bicornis*), and elephants (*Loxodonta africana*), it was considered unsafe to conduct drive counts within the thick bush. Furthermore, the thick bush prohibited the use of road strip and spotlight counts. These methods would only count animals on the edge of the habitats, possibly underestimating the true numbers. The species under question in the study do not require water; therefore, waterhole counts would not be practical. One objective of the study was to obtain an estimate of the number of animals on the study area; as a result, track counts would not be useful since they only provide an index of presence. Also, track counts would be difficult to employ in this study area due to the low rainfall and hard ground, which make it difficult for tracks to be produced.

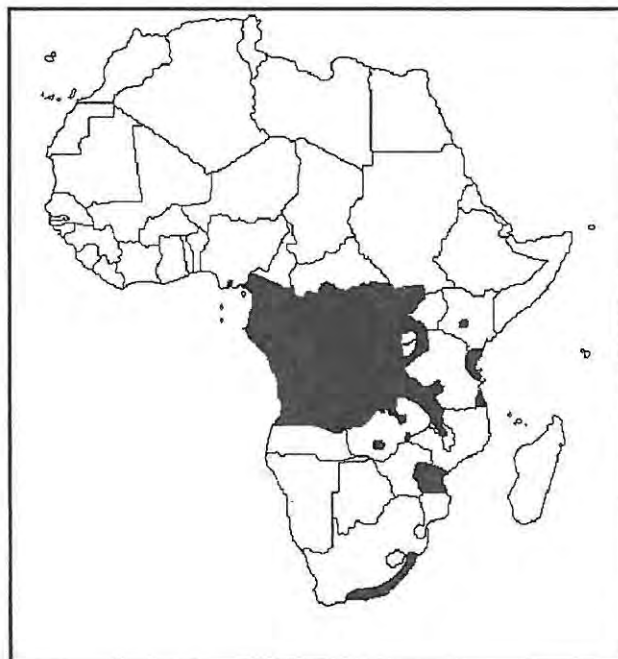
The objective of this study was to find a method of density estimation that was easy for managers to apply, yielded the most accurate results, and worked well for all species in question. Taking all of this information into account, as well as the limitations discussed above, I decided to compare a direct method and a variety of indirect methods, which included: field strip direct observations, pellet count clearance plots, and line transect and strip pellet counts using standing crop. By using these methods, this study attempted to determine which methods worked best for all species and establish a population estimation method that can be applied by game managers. The study also yielded an estimate for the number of kudu, bushbuck, common duiker, and blue duiker present on the study area. Seasonal variations in abundance, defecation rates, and decay rates also were assessed.

It was hypothesized that methods not involving direct observation may work best in this study because of the habitat preferences and behavior of the animals in question. In a previous study in South Africa, von Gadow (1978) found pellet counts to be a useful tool for estimating the numbers of bushbuck and blue duiker in dense forest areas. From a thorough review of the existing literature, pellet counts utilizing line transects exhibit the greatest applicability to the study. Line transects also would cover the area more

thoroughly than established plots. Overall, the usefulness of the indirect methods will depend upon the accuracy of the defecation and decay rates determined from the study.



**Figure 1.1.** The blue duiker is approximately 30-35 cm at shoulder height and weighs 4-6 kg. It is the smallest antelope in southern Africa (Walker 1996). Photograph is from Walker (1996).



**Figure 1.2.** The blue duiker's distribution based on Skinner and Smithers (1990).



**Figure 1.3.** The common duiker is 60 cm at shoulder height and weighs 12-16 kg (Walker 1996). Photograph is from Walker (1996).



**Figure 1.4.** The common duiker's distribution based on Skinner and Smithers (1990).



**Figure 1.5.** The bushbuck is 69-94 cm at shoulder height and weighs 32-64 kg (Walker 1996). Photograph of male (left) is from Stuart and Stuart (2000) and photograph of female (right) is from Walker (1996).



**Figure 1.6.** The bushbuck's distribution based on Skinner and Smithers (1990).

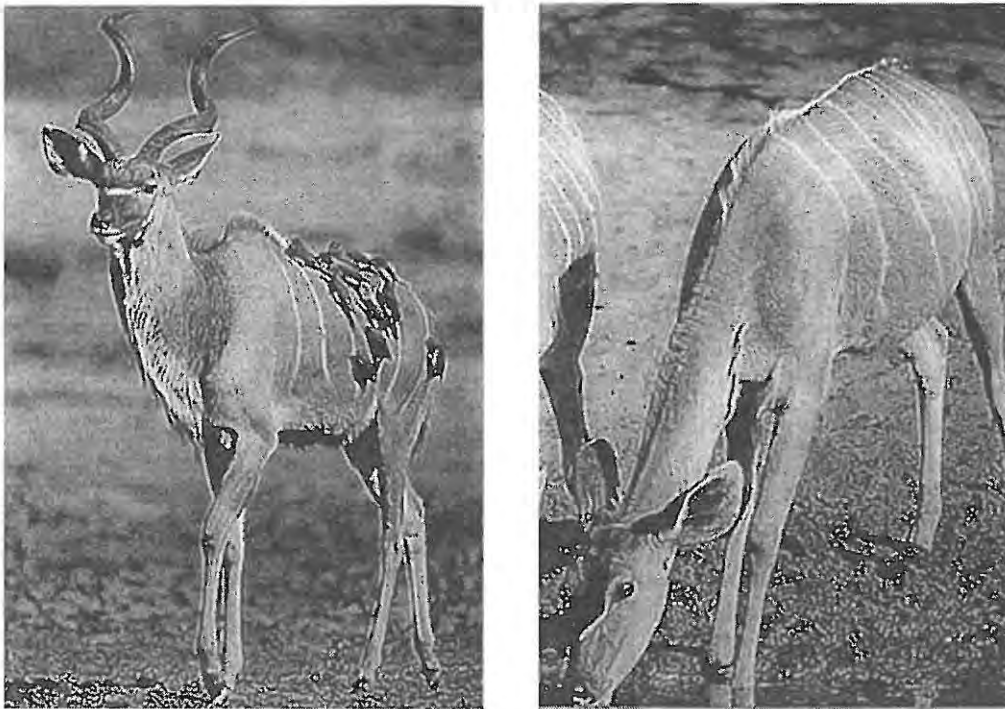


Figure 1.7. The kudu is 1.2 m at shoulder height and weighs 150-270 kg (Walker 1996). The photograph of kudu male (left) is from Walker (1996). The photograph of kudu female (right) is from Stuart and Stuart (2000).

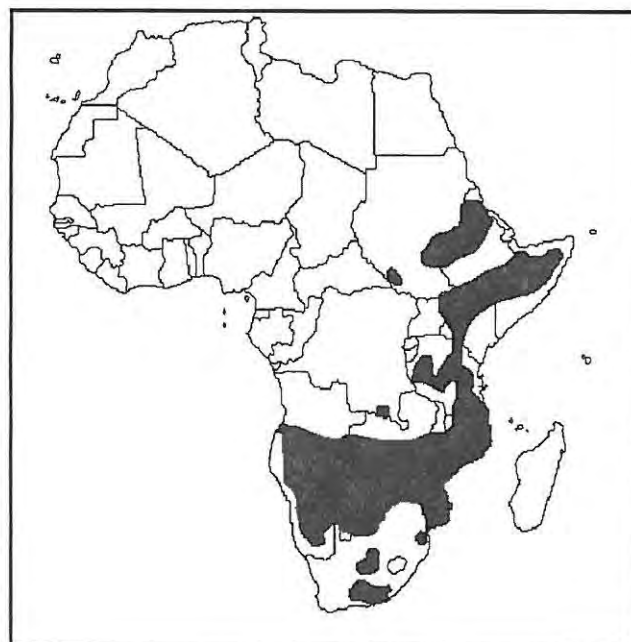


Figure 1.8. The kudu's distribution based on Skinner and Smithers (1990).

## CHAPTER 2: MATERIALS AND METHODS

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### Study Area

Shamwari Game Reserve is located approximately 72 km northeast of Port Elizabeth along the Bushman's River in the Eastern Cape Province of South Africa (33°20'-33°32'S; 26°01'-26°10'E). The reserve was opened in 1992 and today comprises approximately 20,000 ha. The rainfall for the area varies from south to north with the median annual rainfall being 420mm and 530mm, respectively (Burroughs and Palmer 1992).

Shamwari Game Reserve incorporates six vegetation biomes (Forest, Thicket, Savanna, Fynbos, Nama Karoo, and Grassland), representing 13 vegetation units (O'Brien 2000). Because of the specific question asked in the study, the areas of interest were those covered by subtropical thicket and riverine bush vegetation units. For the study, the North and South of the reserve were treated separately due to the variation in rainfall, allowing for more accurate pellet group decay rate and population estimates. The North and South have equal amounts of subtropical thicket, totaling 6575 ha. Riverine bush occurs across a larger area in the South than in the North (375.25 and 19.75 ha, respectively).

### Methods

The study was conducted from August 2002 to August 2003 and included four seasons, spring (August to October), summer (November to January), fall (February to April), and winter (May to July). Monthly rainfall measurements (mm) were recorded each month in the North and South regions from August 2002 to July 2003. Study sites were chosen based on accessibility, habitat type, and the presence of a cut-line, which was an old fence-line, existing access road, or firebreak. Each site consisted of a cut-line with bush thickets on either side (Figure 2.1). Three sites in the North and three in the South were chosen in order to cover the reserve thoroughly and to obtain region specific

population estimates (Figure 2.2). The distance between each site within a region ranged from 350 m to 5.27 km.

The manpower requirements for each method were measured by recording the smallest number of workers and approximate time required to conduct each method. Measurements from each season were used to calculate the man-hours required to perform each method.

### *Direct Methods*

#### *Direct Count Observations*

Direct count observations were conducted using fixed width transects (Bowland and Perrin 1994) at each site for three consecutive days each season (November 2002 and February, May, and August 2003). The cut-line was used as a transect and its length and width were measured to calculate its area (m<sup>2</sup>). The length was measured by driving the transect and obtaining a reading from the vehicle odometer. An average width was calculated by measuring the width at 5 random points along the transect. Observations began approximately one hour after sunrise and one hour before sunset. The beginning times differed with season, depending on the times for sunrise and sunset. The duration of each observation was one hour. Observations were conducted simultaneously at all three sites within either the North or South regions of the reserve, thus requiring three observers and three vehicles. Observations for the other region (North or South) were conducted within a few days of the first observations to minimize the effects of weather changes. An observer equipped with binoculars and seated within a vehicle was positioned at the end of the cut-line (Figure 2.3). All animals that crossed the area within the hour were recorded. Sex and age were also noted if possible.

The density of animals per hectare was calculated from observations based on the number of animals counted and the area of the cut-line. The following equation was used (modified from Collinson 1985):

$$D = \frac{n \times 10,000}{A}$$

Where  $n$  = number of animals counted crossing transect

$A$  = area of transect ( $m^2$ )

10,000 = conversion factor to express area in ha

$D$  = density expressed in number of animals per ha

A density estimate was calculated for each hour of observation at each site. A mean density for each site was calculated by averaging density estimates for the three morning and three evening observations for that site.

### *Indirect Methods*

The indirect methods used in this study involved pellet group counts. The clearance plot and standing crop methods were utilized (Marques et al. 2001). A pellet group was defined as a dung-heap of 10 or more pellets of similar shape that appeared to have been deposited at the same time. Advice from reserve rangers and a field guide (Walker 1996) were used to assist in species identification (Figure 2.4).

Defecation rates were necessary to calculate population density from pellet group counts. An attempt was made to obtain defecation rates for kudu during a game capture for relocation purposes. Beforehand, all pellet groups were cleared from the enclosure. Three females and one male were darted and placed in enclosures separated by sex, and the animals remained in the enclosure for seven days. After the animals were removed, the number of pellet groups that had been deposited was counted. It was difficult to distinguish pellet groups because the animals had trampled and disturbed the ground. It was decided that the counts were unreliable because the animals had been darted, possibly altering natural defecation rates, and the enclosures were small, creating the problem of trampled pellet groups.

Defecation rates of pellet groups per day were found in the literature for blue duiker (4.9 groups/day; Koster and Hart 1988) and bushbuck (19.0 groups/day; Plumptre and Harris 1995). The defecation rates for common duiker and kudu were estimated using a regression based on a relationship between body size and defecation rate (Blueweiss et al. 1978). A summary of ungulate defecation rates (y-value) by Plumptre (2000) and additional blue duiker estimates from Bowland and Perrin (1994) and von Gadow (1978)

were plotted against average body weights (x-value) which were calculated as the average of female and male body weights. Data were fitted to a power relationship using Microsoft Excel 1997, which provided an equation of the line and the coefficient of determination,  $r^2$ .

In order to determine if the kudu defecation rate estimated by the equation was feasible, defecation rates for kudu were also determined by direct observations. Groups of kudu were located in open areas and observed for as long as the animals would remain within visibility. The observers counted the number of animals present in the group and the number of defecation events that occurred during the time period. It was assumed that one defecation event equaled one pellet group deposition. The average number of pellet groups per animal was then calculated. This value was extrapolated to the number of pellet groups deposited per day by one animal using an approximated estimate of 16.8 hours of activity (70% of the day) in 24-hours (Owen-Smith 1979). This assumed that animals did not defecate while resting.

Decay rates were also necessary and determined for the study area by marking fresh pellet groups from all species under question. A fresh pellet group was defined as having 10 or more glossy black or brown pellets. Pellets also had to be soft enough to press between one's fingers and slightly moist to touch. An attempt was made to locate fresh groups on the sites throughout the study. Each fresh pellet group was marked with a metal peg and ribbon to aid in relocation. Marked pellet groups were relocated every two weeks and the progress of decay recorded. The group was counted as decayed when there were less than 10 pellets remaining and pellets were unidentifiable (dried out and crumbled).

#### *Clearance Plots*

In order to test the clearance plot method (Marques et al. 2001), three 25 m<sup>2</sup> (5 x 5 m) quads were established at each site in August 2002 (Figure 2.5). Because of the thickness of the bush, smaller quads were chosen as opposed to larger rectangular plots. Quads were established in open spaces among the bush and were at least 10 m apart. The corners of each quad were marked with 30 cm steel rods painted bright pink to aid visibility and relocation. To ensure that quads were exact 5 x 5 m squares, the measured distance was checked from diagonal corners to equal 7.07 m. A nearby tree also was marked with caution ribbon to aid in relocating and identifying quads.

Quads were initially cleared by removing all pellet groups present. Every two weeks thereafter plots were checked and cleared of any accumulation. The species represented by each pellet group within the boundaries of the quad were recorded. A pellet group was counted as “in” if over half of the pellets were within the boundary. All pellets were then removed from the quad.

Density of animals per hectare for each species was calculated using the following equation (modified from Bowland and Perrin (1994)):

$$D = \frac{n \times 400}{t \times d}$$

Where n = number of pellet groups within quad

t = number of days between when quad is cleared and checked

d = defecation rate expressed in number of groups deposited per day

400 = constant to express density per ha

D = density expressed in number of animals per ha

The number of days between when the quads were cleared and checked ranged from 10 to 28 days, with 14 days as the mode. A density estimate for each quad was calculated.

Seasonal site means were obtained by averaging the density estimates for the three quads within a site during the season.

### *Line Transects*

Line transects were conducted seasonally using methods outlined by Marques et al. (2001). This method utilized the standing crop of pellet groups thus requiring the use of decay and defecation rates to obtain a population density estimate (Marques et al. 2001). In each site, a total straight-line length of 250 m, which consisted of lines of varying length (10 to 50 m) due to habitat constraints, was covered (Figure 2.5). In some cases, a series of connected straight-line segments that totaled the desired length was used to accommodate

the terrain (Anderson et al. 1979). Line transects were measured with a 50 m tape and the perpendicular distance of pellet groups from the line was measured with a 9 m steel tape measure.

The line transect method involved one observer and one recorder. The observer walked the line and looked for pellet groups on either side (Figure 2.6). When a pellet group was sighted, the species and perpendicular distance (nearest cm) from line to the center of the pellet group were recorded (Figure 2.6). When a pellet group was observed on the line, the distance was recorded as zero. The observer and recorder checked to make certain no groups were missed on the line.

Two methods of calculating density, variable-width transect (Bowland and Perrin 1994) and the software program DISTANCE 3.5 (Laake et al. 1998), were used to analyze data collected from the line transects. The variable-width transect method involved calculating an average of measured perpendicular distances from the line for each species. Density for each species was calculated with the following formula (modified from Bowland and Perrin (1994):

$$D = \frac{n \times \left[ \frac{10,000}{L \times (2x)} \right]}{d \times t}$$

Where n = number of pellet groups

L = length (m) of line transect

x = mean distance (m) of pellet groups from line transect

d = defecation rate expressed in groups per day

t = decay rate expressed in days

10,000 = conversion factor to express area in ha

D = density expressed in number of animals per ha

A density estimate was calculated for each line. The mean density estimate for each site was calculated by averaging estimates from all lines within a site.

The software program DISTANCE 3.5 (Laake et al. 1998) was also used to analyze the data collected from the line transect survey. This method assumes that all pellet groups located on the line are detected with certainty and calculates a probability of detection as the distance from the line increases. The density of pellet groups in the area surveyed is estimated with the following equation (Buckland et al. 1993):

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

Where  $n$  = number of pellet groups detected

$L$  = length of line (m)

$f(0)$  = the probability density function of the perpendicular distances evaluated at zero

$D$  = density of pellet groups per hectare

The density of animals per hectare was obtained by dividing the density of pellet groups by the decay and defecation rates.

Separate estimates of  $f(0)$  were obtained for each site and species. Six models were considered: Uniform-cosine, Uniform-simple polynomial, Half normal-hermite, Half normal-cosine, Hazard rate-cosine, and Hazard rate-simple polynomial (Buckland et al. 1993). Extreme observations (outliers) are difficult to model and provide little information for estimating the density function at zero distance, which is the most critical part of the curve; therefore truncation is necessary (Ruelle et al. 2003). Measurements were truncated at the largest 10% to remove any outliers (Buckland et al. 1993). A model was chosen based on a combination of a low Akaike's information criterion (AIC), a low variance, and nonsignificant goodness-of-fit value ( $\chi^2$ ) (Marques et al. 2001, Focardi et al. 2002).

*Strip Transect*

The strip transect method utilized the standing crop of pellet groups (Marques et al. 2001). One 500 m<sup>2</sup> (100 m by 5 m) strip transect was established along the cut-line at each site (Figure 2.5). Each season, two observers walked together along a 100 m line to cover a total width of 5 m (2.5 m on each side of the line; Figure 2.7). The pellet groups encountered were counted and identified to species. The following equation was used to calculate a density of animals per ha (modified from Marques et al. 2001):

$$D = \frac{n \times \left[ \frac{10,000}{A} \right]}{d \times t}$$

Where n = number of pellet groups

A = area of strip transect (m<sup>2</sup>)

d = defecation rate expressed in groups per day

t = decay rate expressed in days

10,000 = conversion factor to express area in ha

D = density expressed in number of animals per ha

Since only one strip transect was established per site, density estimates were used only for comparison to determine how the simple strip transect method would perform compared to the other methods.

*Habitat Assessment*

In order to compare the habitats and quantify the bush density at each of the six sites, the point-centered quarter method outlined by Cottam and Curtis (1956) was utilized. This allowed for the determination of the density of the thicket and the relative frequency of each tree species present. Thirty points were sampled at each site, which Cottam and Curtis (1956) found to be sufficient to achieve a standard error of less than 10% of the

mean. The points were placed in 3 rows of 10 points with each point and row being 10 paces apart. At each point, 4 quarters were established in constant directions.

Two people were required, one to record and one to measure distances and identify species. The distance (to the nearest cm) to the nearest shrub or tree over 1 m high in each quarter and the species were recorded. A field guide (van Wyk and van Wyk 1997) was used as an aid in identifying shrub/tree species. The following equation (Laycock and Batcheler 1975) was used to calculate the density of trees/shrubs:

$$D = \frac{1}{(x)^2}$$

Where x = average measurements of all distances (m)

D = average number of trees/shrubs per square meter

The relative frequency for each species was determined using the following equation (Cottam and Curtis 1956):

$$\text{Relative frequency} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

### *Ground Cover Assessment*

An attempt was made to quantify the amount and types of ground cover at each site by using a 10-pin frame to determine the frequency of occurrence of different ground covers. This information could be used when comparing pellet group counts among sites. For example, at sites where the ground cover was predominately grass, the ability of the observer to find pellet groups would be lower than a site with mostly bare ground. Types of ground cover recorded included grass, rock, dung, leaf, woody debris, and bare ground. Grieg-Smith (1964) recommended that when using the 10-pin frame at least 100 sampling units (1000 points) be read to obtain reliable estimates for comparison between sites and over time.

A trial was carried out at one site and the method was found to take a substantial amount of time and it was not possible to survey all sites in one day. For this method to be beneficial to the study, it was necessary to perform surveys at the same time as line transect surveys and for each season. However, because of the labor requirements and the extreme ground cover changes that occurred after rain events, the method was abandoned.

### *Validation of Methods*

#### *Shamwari's Breeding Center*

A test of all methods was conducted on Shamwari Game Reserve's Breeding Center. The area is located outside of the southwestern boundary of Shamwari with approximately 355 ha enclosed and a population of 35 to 40 kudu. This estimate was obtained by night drive counts during which animals were counted by spotlight. The area is small enough that most animals are accounted for and the estimates are reasonable. The vegetation types for the area are 30% bonteveld, 30% subtropical thicket, 30% cleared lands, and 10% *Acacia* thicket. The *Acacia* and subtropical thicket areas overlapped; therefore, the total thicket area of 142 ha was utilized in the test of methods.

The area was treated as one site and all methods were repeated as for one season. In June 2003, three 5 x 5 m quads were established in the thicket for the clearance plot method. The plots were cleared initially and checked and cleared for three 2-week periods. In July 2003, a line transect survey was conducted with straight-line lengths totaling 250 m. In August 2003, direct observations were carried out on one cut-line (Figure 2.8) for three consecutive days, morning and evening.

Data collected for all methods were treated as described earlier. Estimated population numbers for each method were compared to the actual number of kudu present. The density estimates were extrapolated to an estimated number of animals by multiplying by the area of thicket habitat, 142 ha.

#### *Kwandwe Game Reserve*

The DISTANCE method was also tested against a helicopter survey on Kwandwe Game Reserve in the Eastern Cape Province of South Africa. The 15,800 ha reserve is dominated by subtropical thicket with *Euphorbia* spp., *Aloe* spp., and *Portulacaria afra* among the characteristic plants. The mean annual rainfall is approximately 430 mm. A

game count by helicopter was conducted in August 2003, yielding an estimate for the number of kudu on the reserve. Line transect surveys were carried out in late August and early September in two areas of the reserve, one considered to have a high density of kudu and the other a low density. Two sites were surveyed in each area, with a total straight-line length of 250 m being covered at each site. The high-density area covered approximately 3700 ha, while the low-density area covered about 2700 ha. The DISTANCE method was compared to the helicopter survey to determine if it displayed the same trends and yielded a similar kudu estimate as the helicopter counts.

### *Statistical Analyses*

The average monthly rainfall for the North and South regions was compared using a dependent sample t-test. The bush density at the six sites was analyzed by ANOVA recognizing site (sites 1-6) as the main effect. The effect of species (kudu, bushbuck, or common duiker) on pellet group decay rates also was tested using ANOVA.

For direct observations, the effects of season (spring, summer, fall, or winter), time (morning or evening), and species (kudu, bushbuck, common duiker, or blue duiker) on number of animals counted during an observation period were tested by ANOVA. The effects of season and species on the number of pellet groups deposited between visits to clearance plots, counted by line transect survey, and counted by strip transects were tested using ANOVAs.

Seasonal averages of animal density (average of sites 2 to 6 for each season) were compared within each species using ANOVAs recognizing method (direct observation, variable width, DISTANCE, strip transect, or clearance plots) and season as main effects. Within each method, the effects of species and season on density averages were tested using ANOVAs.

Methods were compared and evaluated using the coefficient of variation for each site (Marques et al. 2001). Every season, this was calculated for each method by dividing the standard deviation by the mean of the density estimate. The coefficient of variation was expressed as a percentage by multiplying by 100. The DISTANCE software program calculated the coefficient of variation for the DISTANCE method.

1)



2)



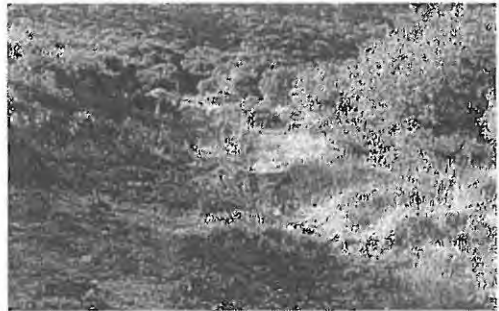
3)



4)



5)



6)



**Figure 2.1. Sites one through six at Shamwari Game Reserve showing the layout of each site with a center cut-line/road and bush on either side.**

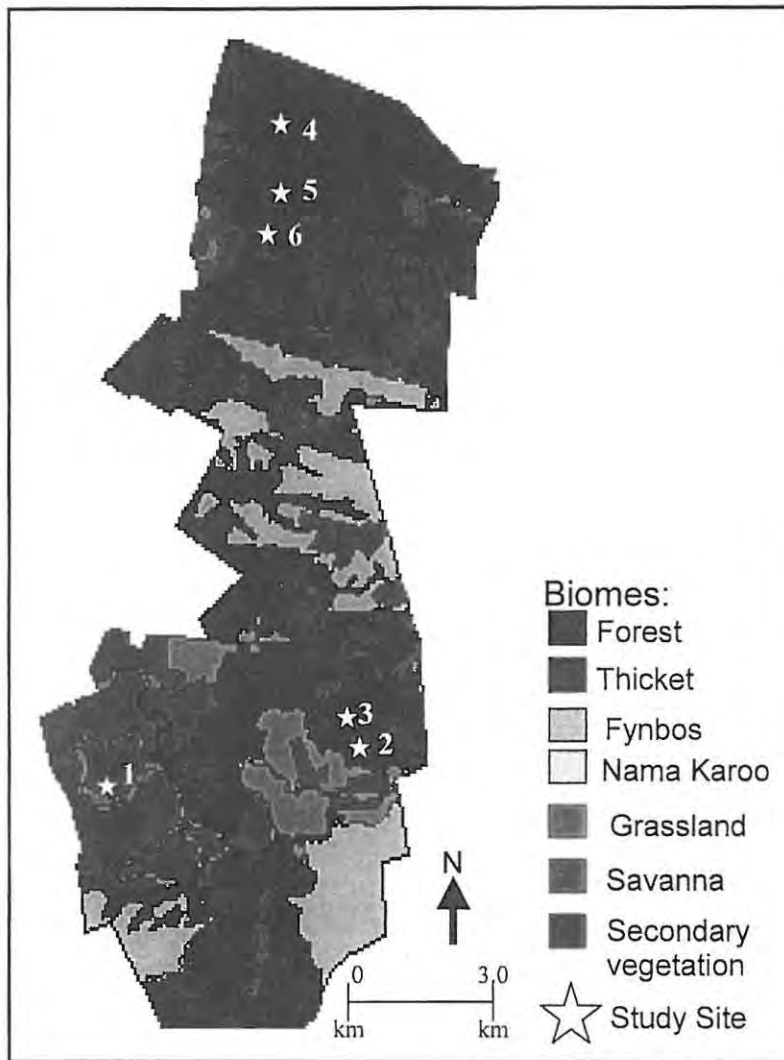
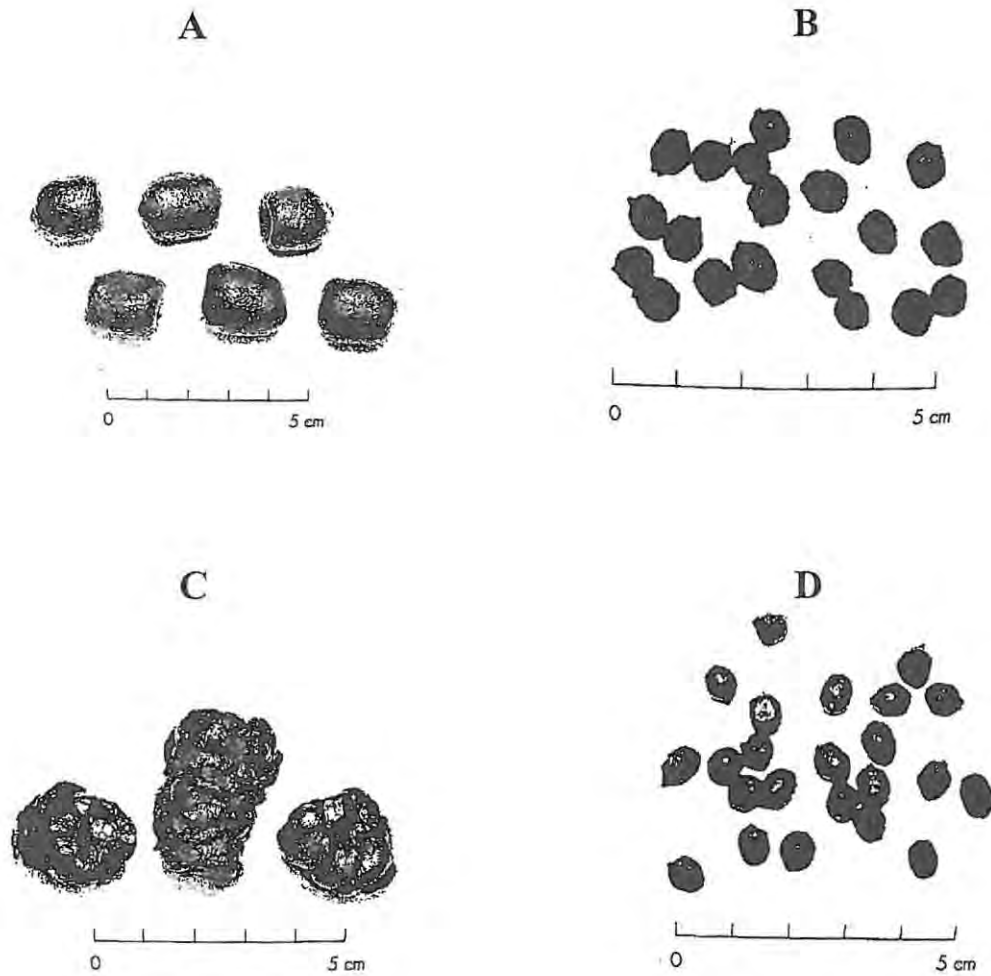


Figure 2.2. Vegetation map of Shamwari Game Reserve (O'Brien 2000) showing approximate locations of sites.



**Figure 2.3. Observer conducting direct observation counts from vehicle using binoculars.**



**Figure 2.4.** Example photographs of dung pellets used to identify pellet groups found at the study sites. The species are as follows: A = Kudu, B = Common Duiker, C = Bushbuck, and D = Blue Duiker (from Walker 1996).

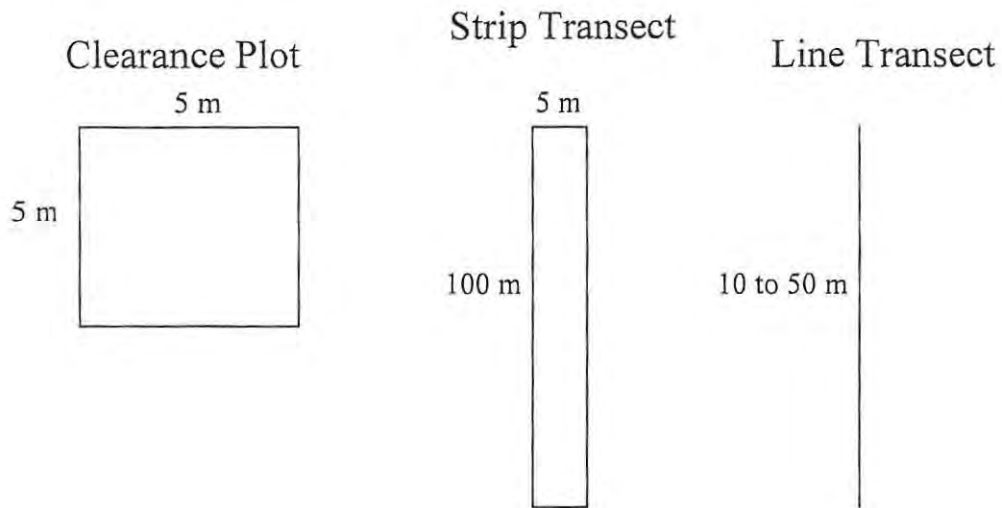


Figure 2.5. The indirect methods in the study utilized 5 by 5 m quadrats for clearance plots, 100 by 5 m strip transects, and 10 to 50 m line transects.

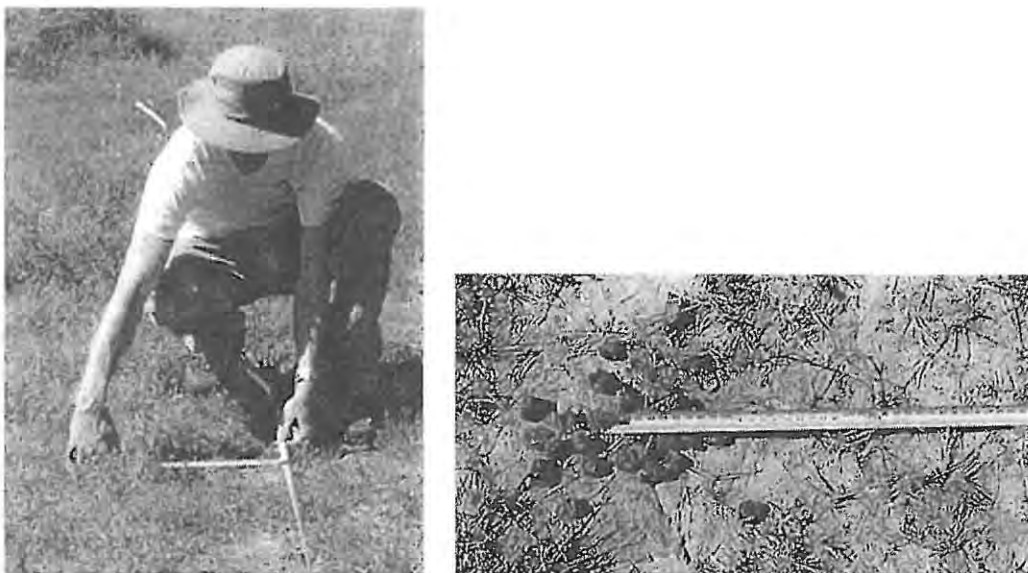


Figure 2.6. An observer conducting a line transect survey. He is measuring the perpendicular distance from the line to the center of a kudu pellet group.



**Figure 2.7.** An observer carrying out a strip transect survey at Site 1 Shamwari Game Reserve. The cutline/road was used for the 100 m by 5 m strip.



**Figure 2.8.** Cut-line at the breeding center where all methods were tested against a known population of kudu.

## CHAPTER 3: RESULTS

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### Rainfall and Bush Density

The average monthly rainfall (mm) for the North ( $57.33 \pm 13.8$  (12), mean  $\pm$  s. e. (n), and South ( $61.67 \pm 12.4$  (12)) of the reserve was not significantly different ( $|t| = 0.896$ ;  $df = 11$ ;  $P = 0.390$ ). The original basis for dividing the reserve into two regions was that the North and South were expected to receive different amounts of rain. Since rainfall was not significantly different during the study period, the sites have been pooled to represent samples taken throughout the reserve.

There were site effects on the bush density ( $F = 53.85$ ;  $df = 5, 714$ ;  $P < 0.01$ ) and bush density at site 1 was significantly lower than that at all other sites (Table 3.1). Site 1 was predominantly riverine bush vegetation type with *Acacia* thicket affinities with low bush density. The five other sites consisted of subtropical thicket with statistically similar bush densities (Table 3.1). Because of this, results from the 5 subtropical thicket sites were used to compare the 5 methods. Since site 1 was riverine bush, its mean density estimates were used to compare data between vegetation types (riverine bush and subtropical thicket).

The tree species recorded at site 1 were predominantly *Acacia karroo* (32.5%) and *Rhus longispina* (38.3%; Table 3.2). The other sites (sites 2 – 6) had a larger variety of tree species present with no main species dominating (Table 3.2). The most common species at these sites were *Azima tetracantha*, *Euclea undulata*, *Grewia robusta*, *Gymnosporia polyacantha*, and *Portulacaria afra*, all of which are characteristic of the subtropical thicket vegetation type.

## Direct Methods

### *Direct Count Observations*

During the year-long study, a total of 24 hours was spent at each site conducting direct observations during which 48 kudu, 17 bushbuck, and 37 common duiker were observed. The initial analysis of the effects of season, time (morning and evening), species, and associated interactions on the mean number of animals counted during an observation period yielded a significant interaction between time  $\times$  species, as well as significant season and species effects (Table 3.3). Since no blue duiker were counted throughout the study, the analysis was performed again without blue duiker data to see if it was responsible for the interaction. The effect of species ( $F = 1.83$ ;  $df = 2, 336$ ;  $P = 0.161$ ) was no longer significant, but the season effect ( $F = 3.06$ ;  $df = 3, 336$ ;  $P = 0.028$ ) and time  $\times$  species interaction ( $F = 3.18$ ;  $df = 2, 336$ ;  $P = 0.043$ ) remained significant. All other effects and interactions remained insignificant ( $P > 0.05$  for all). Since the time  $\times$  species interaction remained, analyses were run separately for each species (kudu, bushbuck, and common duiker).

All effects of season, time, and season  $\times$  time were insignificant for each species, except common duiker, for which there was a significant season effect (Table 3.4). The mean number of common duiker counted during an observation period in summer ( $0.50 \pm 0.14$  (30)) was higher than fall ( $0.07 \pm 0.05$  (30); Figure 3.1). Overall (all seasons and all species), there was no significant difference between the mean number of animals counted during morning ( $0.15 \pm 0.03$  (240)) and evening ( $0.25 \pm 0.07$  (240)) observations. The mean number of kudu, bushbuck, and common duiker counted during morning and evening observations for each season is summarized in Table 3.5.

The conversion of direct observation counts to a measure of animal density (animals per ha) gave values from zero for blue duiker to  $4.69 \pm 2.67$  (20) for kudu (Table 3.6; Figure 3.2). Species ( $F = 2.10$ ;  $df = 3, 64$ ;  $P = 0.109$ ), season ( $F = 1.01$ ;  $df = 3, 64$ ;  $P = 0.393$ ), and species  $\times$  season ( $F = 0.60$ ;  $df = 9, 64$ ;  $P = 0.790$ ) did not have a significant effect on density means. When density estimates were converted to the total number of animals within subtropical thicket habitat (6575 ha) on Shamwari Game Reserve, direct

observations yielded 30837 kudu, 5260 bushbuck, 12295 common duiker, and zero blue duiker (Table 3.7).

The coefficient of variation (%) for site averages for each season ranged from 167.33 – 244.95% for kudu, 109.54 – 244.95% for bushbuck, and 90.33 – 244.95% for common duiker.

Direct observations required coordinating 3 observers and vehicles, twice a day for six days each season. Additionally, it also introduced the factor of observer bias since there were different people observing at each site.

## Indirect Methods

### *Decay and Defecation Rates*

Decay rates were recorded for kudu, bushbuck, and common duiker pellet groups located throughout the reserve (Table 3.8). Throughout the study, 7 kudu, 8 bushbuck, 3 common duiker, and zero blue duiker fresh pellet groups were marked. There were no species effects on the days to complete decay for the pellet groups ( $F = 0.35$ ;  $df = 2, 8$ ;  $P = 0.715$ ). The mean number of days until complete pellet group decay for each species was  $185.4 \pm 22.0$  ( $n = 5$ ) for kudu,  $222.5 \pm 49.7$  (4) for bushbuck, and  $237.5 \pm 98.5$  (2) for common duiker. The recorded minimum and maximum decay rates were 117 and 351 days, with both values coming from bushbuck pellet groups. Even though decay rates were not significantly different, the specific rate of decay for each species was used in converting pellet group counts into density estimates (Table 3.8). Since no blue duiker pellet groups were marked, the decay estimate for common duiker was used.

Unknown defecation rates (i.e. for kudu and common duiker) were estimated using the equation of the line fitted to a power relationship for known defecation rates and body weights ( $y = 1.146x^{0.5748}$ ;  $r^2 = 0.727$ ; Figure 3.3). Defecation rates for kudu and common duiker were estimated to be 24.77 and 5.22 pellet groups per day, respectively, and these values were used to convert pellet group counts into density estimates.

Observations to determine kudu defecation proved to be difficult. Most kudu were disturbed by vehicles and observers, freezing initially and then moving out of visibility after 5 minutes. One successful observation was made in winter on a group of 13 male and

female kudu. The group frequented an open area beside a lodge and was not disturbed by viewing. The observation lasted for 50 minutes with a total of 15 defecation events recorded. It was difficult to distinguish between individuals, except for one large male for which 3 defecation events were recorded. Using these data, the defecation rate for an individual kudu was estimated at 23.3 pellet groups per day, which is consistent with the above estimation based on the equation.

### *Clearance Plots*

Throughout the study, sites were visited and quads cleared on an approximate bi-weekly basis. Thus each season, quads were visited between 4 and 7 times and the overall number of clearance events for the five subtropical thicket sites were 78 for spring, 66 for summer, 81 for fall, and 89 for winter. Clearance plots yielded a total of 200 kudu, 90 bushbuck, 52 common duiker, and 12 blue duiker pellet groups. When analyzing the mean number of pellet groups deposited at a quad from clearance to return visit (approximately 2 weeks), there were significant species and season effects (Table 3.9). There was not a significant species  $\times$  season interaction (Table 3.9). Kudu ( $0.60 \pm 0.06$  (314)) deposited significantly more pellet groups than all other species, while bushbuck ( $0.26 \pm 0.03$  (314)) deposited more than blue duiker ( $0.04 \pm 0.01$  (314); Figure 3.4). The mean number of pellet groups deposited by common duiker ( $0.15 \pm 0.04$  (314)) was not different from the other species. When data for all species are pooled, there were significantly more pellet groups deposited in spring ( $0.41 \pm 0.05$  (312)), than in summer ( $0.23 \pm 0.04$  (264)), fall ( $0.24 \pm 0.04$  (324)), or winter ( $0.17 \pm 0.03$  (356)).

For density estimates (animals per ha) based on the clearance plot method (Table 3.6), there was no species effect ( $F = 1.50$ ;  $df = 3, 64$ ;  $P = 0.222$ ; Figure 3.2) or species  $\times$  season interaction ( $F = 1.00$ ;  $df = 9, 64$ ;  $P = 0.447$ ). There was a significant season effect ( $F = 3.45$ ;  $df = 3, 64$ ;  $P = 0.022$ ). The average density combined for all species was significantly greater in spring ( $0.928 \pm 0.314$  (20)) than in summer ( $0.237 \pm 0.090$  (20)) and winter ( $0.270 \pm 0.089$  (20)). Fall ( $0.350 \pm 0.100$  (20)) was not significant from the other seasons. When density estimates were converted to the number of animals within subtropical thicket habitat, the clearance plot method numbers ranged from 1393 for blue

duiker to 4445 for common duiker (Table 3.7). The coefficient of variation (%) for site density averages for each season ranged from 103.72 – 424.26% for kudu, 125.54 – 424.26% for bushbuck, 135.94 – 424.26% for common duiker, and 160.45 – 424.26% for blue duiker.

### *Line Transects*

During the study, approximately 6.0 km were covered with line transect surveys, during which a total of 1580 kudu, 397 bushbuck, 682 common duiker, and 66 blue duiker pellet groups were counted. The encounter rates (number of pellet groups counted per km of line transect) were 263.30 for kudu, 66.17 for bushbuck, 113.67 for common duiker, and 11.0 for blue duiker. The analysis of the effects of season, species, and species  $\times$  season on the mean number of pellet groups counted per 250 m of straight-line transect yielded significant effects of season and species (Table 3.10). There was no species  $\times$  season interaction (Table 3.10). There were more pellet groups counted in spring ( $63.0 \pm 15.6$  (20)) than in summer ( $29.5 \pm 7.5$  (20)), fall ( $18.85 \pm 5.8$  (20)), or winter ( $22.2 \pm 5.0$  (20); Figure 3.5). There were significantly more kudu pellet groups ( $73.6 \pm 12.5$  (20)) than all other species, while common duiker ( $38.5 \pm 9.3$  (20)) was significantly higher than blue duiker ( $3.6 \pm 1.4$  (20)). The mean number of pellet groups counted for bushbuck ( $17.9 \pm 5.5$  (20)) was not different from the other species.

### *Variable Width*

Species had a significant effect on the density estimates (animals per ha) based on the variable width method ( $F = 21.64$ ;  $df = 3, 64$ ;  $P < 0.001$ ; Figure 3.2). The estimated density of common duiker was significantly greater than the densities for all other species (Table 3.6). Estimated kudu density was greater than bushbuck and blue duiker densities. Bushbuck and blue duiker densities were not different. The season effects were also significant ( $F = 7.09$ ;  $df = 3, 64$ ;  $P < 0.001$ ). The average density combined for all species was significantly higher in spring ( $0.55 \pm 0.10$  (20)) than in summer ( $0.31 \pm 0.08$  (20)), fall ( $0.23 \pm 0.06$  (20)) and winter ( $0.25 \pm 0.06$  (20)). There was no species  $\times$  season interaction ( $F = 1.46$ ;  $df = 9, 64$ ;  $P = 0.183$ ). The variable width method estimated 4241 common

duiker, 2860 kudu, 1032 bushbuck, and 638 blue duiker within subtropical thicket habitat on Shamwari Game Reserve (Table 3.7).

The coefficient of variation (%) for site density averages for each season throughout the study ranged from 41.44 – 185.52% for kudu, 43.74 – 223.61% for bushbuck, 58.76 – 223.61% for common duiker, and 140.31 – 244.95% for blue duiker. The effective strip width (m), which was the average distance of observations from the line transect, ranged from 0.54 – 1.53 m for kudu, 0.34 – 1.31 m for bushbuck, 0.26 – 1.74 m for common duiker, and 0.28 – 4.58 m for blue duiker.

### *DISTANCE*

Models were chosen for site density estimates based on the fit of the probability density function to the measured distances of pellet groups from the line (Figure 3.6). If the number of observations (pellet groups) was less than 10, then DISTANCE would not provide reliable results. When this was the case, no DISTANCE density estimate was made for that species for that particular site and season.

Within DISTANCE density estimates (Table 3.6), the effect of season ( $F = 1.75$ ;  $df = 3, 44$ ;  $P = 0.171$ ) was not significant, but the effect of species was ( $F = 7.95$ ;  $df = 3, 44$ ;  $P < 0.001$ ). The estimated densities for kudu and common duiker were greater than for bushbuck and blue duiker densities (Figure 3.2). There was no species  $\times$  season interaction ( $F = 0.32$ ;  $df = 9, 44$ ;  $P = 0.964$ ). The estimated total number of animals within subtropical thicket habitat ranged from 184 for blue duiker to 2545 for common duiker (Table 3.7).

The coefficient of variation (%) for site averages each season ranged from 13.17 – 44.14% for kudu, 15.41 – 67.11% for bushbuck, 33.06 – 111.80% for common duiker, and the only estimate obtained for blue duiker was 83.32%. The effective strip width (m) ranged from 0.63 – 2.83 m for kudu, 0.59 – 2.26 m for bushbuck, 0.57 – 4.72 m for common duiker, and 1.69 m for blue duiker.

### *Strip Transect*

Using the strip transect method, 70 kudu, 6 bushbuck, 37 common duiker, and 8 blue duiker pellet groups were counted over a total of 2.5 km of strip transects (Figure 3.7). The analysis of the effects of species, season, and species  $\times$  season interactions on the

mean number of pellet groups counted within a strip transect found significant species and season effects (Table 3.11). There was no species  $\times$  season interaction (Table 3.11). The mean number of pellet groups counted for kudu ( $2.9 \pm 0.6$  (20)) was significantly greater than bushbuck ( $0.3 \pm 0.1$  (20)) and blue duiker ( $0.4 \pm 0.3$  (20)). The mean pellet group counts for common duiker ( $1.6 \pm 0.7$  (20)) were not significantly different from the other species. Also, the mean number of pellet groups combined for all species counted in spring ( $2.7 \pm 0.7$  (20)) was significantly greater than fall ( $0.8 \pm 0.5$  (20)) and winter ( $0.4 \pm 0.2$  (20)), but not summer ( $1.3 \pm 0.4$  (20)).

There were species ( $F = 2.98$ ;  $df = 3, 64$ ;  $P = 0.038$ ) and season ( $F = 4.04$ ;  $df = 3, 64$ ;  $P = 0.011$ ) effects for strip transect density (animals per ha) estimates (Figure 3.2). The estimated density of bushbuck was significantly lower than for all other species (Table 3.6). The spring mean density combined for all species ( $0.028 \pm 0.011$  (20)) was significantly higher than fall ( $0.004 \pm 0.002$  (20)) and winter ( $0.002 \pm 0.001$  (20)). The summer density estimate ( $0.012 \pm 0.005$  (20)) was not significantly different from any other season. There was no species  $\times$  season interaction ( $F = 1.38$ ;  $df = 9, 64$ ;  $P = 0.216$ ). The estimated total number of animals within subtropical thicket habitat on Shamwari Game Reserve ranged from 7 for bushbuck to 164 for common duiker (Table 3.7).

### Summary of all methods

Initial analyses of animal density for each species by all methods and seasons did not show clear relationships between the methods. Direct observations, which had high variation, behaved as an outlier in relation to the other methods so that relationships between the other methods could not be detected. Because of this, the analyses were repeated without direct observations.

Between the density estimates (animals per ha) for each species, there was a significant method effect for kudu, bushbuck, and common duiker (Table 3.12). Within kudu density estimates, the variable width and DISTANCE methods estimated significantly higher kudu densities than did the strip transect method (Table 3.6). Kudu density estimates from clearance plots were significantly higher than estimates by both the DISTANCE and strip transect methods (Table 3.6). For bushbuck, the clearance plot method yielded a significantly higher density estimate than did all other methods (Table

3.6). For common duiker, the variable width and clearance plot methods yielded significantly higher density estimates than did the strip transect method (Table 3.6). No other methods were significantly different.

There were no season effects for kudu, bushbuck, or blue duiker density estimations (Table 3.12). There was a significant season effect for density estimates of common duiker (Table 3.12). The common duiker density mean combined for all methods for spring ( $0.892 \pm 0.308$  (20)) was significantly higher than fall ( $0.215 \pm 0.076$  (18)), but not summer ( $0.302 \pm 0.085$  (20)) or winter ( $0.303 \pm 0.097$  (19)). There were no method  $\times$  season interactions for any species (Table 3.12). There also was no significant method effect for density estimates of blue duiker (Table 3.12).

Density estimates for all species and methods were also calculated for site 1 (Table 3.13) but not included in the overall analysis since the site was riverine bush habitat and the vegetation was significantly different. These values were extrapolated to the total number of animals within 395 ha of riverine bush habitat (Table 3.14). The density estimates for all species and methods within riverine bush habitat were less than those for the subtropical thicket habitat.

When the density estimates for the tested methods at sites 2 – 6 were ranked from lowest to highest, the order was as follows: strip transect, DISTANCE, variable width, clearance plots, and direct observations. This ranking was true for kudu, bushbuck, and common duiker density estimates. The ratios between the estimates were 1 : 24.6 : 35.7 : 47.0 : 385.2 (strip transect : DISTANCE : variable width : clearance plots : direct observations) for kudu, 1 : 76.1 : 110.3 : 228.6 : 566.1 for bushbuck, and 1 : 15.2 : 25.4 : 26.6 : 73.7 for common duiker. For blue duiker the trend (1 : 4 : 13.9 : 30.3) was the same except for direct observations, which estimated zero blue duiker per ha. Also, the trends were similar for kudu and common duiker on site 1 except that clearance plot density estimates were less than variable width estimates for kudu and less than DISTANCE estimates for common duiker.

### *Man-hour requirements*

It took approximately 15 minutes to clear 3 clearance quads, 15 minutes to survey 1 strip transect, 1 hour for line transect surveys, and 1 hour for direct observations for each

visit to a site. A minimum of 1 fieldworker was needed to conduct clearance plots and direct observations and 2 field workers for strip and line transects. In this study, the total man-hours spent each season at each site was 1.5 man-hours for clearance plots (approximately 6 visits per season), 0.5 man-hour for strip transects, 2 man-hours for line transects, and 6 man-hours for direct observations. Since direct observations were conducted at 3 sites simultaneously, the required man-hours were 18.

### Validation of Methods

#### *Shamwari Game Reserve*

Density estimates will be compared to Shamwari's 2003 game census in the discussion.

#### *Shamwari's Breeding Center*

The line transect, strip transect, clearance plots, and direct observation methods were tested on Shamwari's Breeding Center where there was a known number of kudu. Clearance plot quads ( $n = 3$ ) were checked and cleared three times. Direct observations were conducted morning and evening for three consecutive days. The line transect and strip transect methods were conducted once each. The clearance plots, strip transect, and line transect methods yielded 1, 6, and 116 pellet groups, respectively. During direct observations, a total of 18 kudu were counted. Density estimates varied from 0.026 to 6.45 animals per ha for the different methods (Table 3.15).

The DISTANCE method estimate for kudu density was within the predicted range for the actual kudu density (35 - 40; Table 3.15). The relationships between each method's density estimates on the breeding center was similar to those on the reserve except that clearance plot estimates were lower than those of DISTANCE and variable width. The ratios of the density estimates were 1 : 10.0 : 15.7 : 4.6 : 248.1 (strip transect : DISTANCE : variable width : clearance plots : direct observations).

#### *Kwandwe Game Reserve*

The DISTANCE method was tested for kudu against helicopter counts on Kwandwe Game Reserve. Using the line transects, 84 and 129 pellet groups (sites 1 and 2)

were counted in the low-density area, while 339 and 146 pellet groups (sites 3 and 4) were counted in the high-density area. The pellet groups per ha estimates were converted to animals per ha using the estimated defecation rate of 24.77 pellet groups per day and the decay estimate of 185.4 days.

The estimated kudu density for the low-density site 1 was 0.128 animals per ha with a coefficient of variation of 18.16%. For site 2 the estimated density was 0.172 with a coefficient of variation of 14.81%. For the high-density area, the estimated density at site 3 was 0.659 with a coefficient of variation of 13.56% and site 4 was 0.269 with a coefficient of variation of 27.83%. The average kudu density (animals per ha) for the low-density area was  $0.150 \pm 0.022$  and  $0.464 \pm 0.195$  for the high-density area.

When extrapolated to the estimated number of kudu for the areas, DISTANCE estimated 405 kudu in the low-density area (2700 ha) and 1717 kudu in the high-density area (3700 ha). The helicopter counts estimated 135 kudu in the low-density area and 750 kudu in the high-density area. The DISTANCE estimates were approximately 2.3 times greater than the helicopter counts in the high-density area and 3 times greater in the low-density area. The density estimate ratios (low-density : high-density) were 1 : 5.6 for helicopter counts and 1 : 4.2 for the DISTANCE method.

**Table 3.1. Results of the habitat assessment at all sites using the point-centered quarter method to determine bush (tree) density.**

	Site					
	1	2	3	4	5	6
Distance to nearest tree (m)	5.62 ± 0.54 <sup>a</sup>	1.44 ± 0.19 <sup>b</sup>	1.54 ± 0.14 <sup>b</sup>	0.79 ± 0.05 <sup>b</sup>	1.30 ± 0.09 <sup>b</sup>	1.18 ± 0.08 <sup>b</sup>
Density (trees/m <sup>2</sup> )	0.03	0.48	0.42	1.60	0.59	0.72

Data are mean ± s.e.  $n = 120$  for all values. Row means with the same letter are not different at the  $\alpha \leq 0.05$  level. Means were compared using Tukey's test.

**Table 3.2. The relative frequency (%) of tree species at each site from the point-centered quarter habitat survey.**

Species	Site					
	1	2	3	4	5	6
<i>Acacia karroo</i>	32.50					
<i>Azima tetracantha</i>	12.50	23.33	5.00	5.00	5.83	10.0
<i>Euclea undulata</i>	0.83	10.83	1.67	19.17	16.67	23.33
<i>Grewia robusta</i>		5.00	27.50		1.67	0.83
<i>Gymnosporia polyacantha</i>	2.50	17.50	18.33	17.50	10.83	0.83
<i>Portulacaria afra</i>		17.50	15.83	17.50		25.00
<i>Rhus longispina</i>	38.33		1.67			
<i>Capparis sepiaria</i>		1.67	3.33	6.67	10.00	2.50
<i>Maytenus capitata</i>					7.50	2.50
<i>Plumbago auriculata</i>		1.67		10.00	2.50	1.67
<i>Putterlickia pyracantha</i>			1.67	4.17	5.83	5.83
<i>Schotia afra</i>		9.17	9.17	4.17	2.50	6.67
<i>Rhus crenata</i>				5.83	1.67	9.17
<i>Rhus pterota</i>	1.67	6.67	1.67			
<i>Brachylaena ilicifolia</i>					12.50	0.83
<i>Pappea capensis</i>			3.33			5.00
<i>Rhoicissus digitata</i>				0.83	5.00	0.83
Other spp.	11.67	6.66	10.83	9.16	17.50	5.00

“Other spp.” Include all species with relative frequency values less than 5%. These included *Asparagus* sp., *Carissa haematocarpa*, *Cassine aethiopica*, *Cassine crocea*, *Ehretia rigida*, *Cadava* sp., *Lycium* spp., *Gymnosporia buxifolia*, *Maytenus peduncularis*, *Olea europaea*, *Phyllanthus verrucosa*, *Ptaeroxylon obliquum*, *Rhigozum obovatum*, Other *Rhus* spp., *Schotia latifolia*, and *Scutia myrtina*.

**Table 3.3. Analysis of variance testing the effects of season, time, species, and associated interactions on the number of animals counted during an observation period.**

source	df	<i>F</i>	<i>P</i>
season	3	3.06	0.028
time	1	1.64	0.201
species	3	4.74	0.003
season × time	3	0.43	0.729
season × species	9	1.51	0.143
time × species	3	3.01	0.030
season × time × species	9	0.73	0.683

**Table 3.4. Analysis of variance by species testing effects of season (s), time (t), and season × time on the number of animals counted during an observation period.**

Species	source	df	<i>F</i>	<i>P</i>
Kudu	s	3	1.57	0.201
	t	1	3.33	0.071
	s × t	3	0.60	0.619
Bushbuck	s	3	1.63	0.186
	t	1	0.41	0.522
	s × t	3	2.24	0.087
Common Duiker	s	3	3.72	0.014
	t	1	0.19	0.667
	s × t	3	0.24	0.867

**Table 3.5. Mean number of animals counted during a morning (AM) or evening (PM) observation for each season.**

Season	Kudu		Bushbuck		Common Duiker	
	AM	PM	AM	PM	AM	PM
Spring	0.27 ± 0.15	1.27 ± 0.86	0.13 ± 0.13	0.20 ± 0.14	0.53 ± 0.27	0.33 ± 0.16
Summer	0	0.47 ± 0.26	0.47 ± 0.19	0.07 ± 0.07	0.53 ± 0.19	0.47 ± 0.22
Fall	0.27 ± 0.21	0.73 ± 0.49	0.07 ± 0.07	0.13 ± 0.09	0.07 ± 0.07	0.07 ± 0.07
Winter	0	0	0	0.07 ± 0.07	0.07 ± 0.07	0.13 ± 0.13

Data are mean ± s.e.  $n = 15$  for all values.

**Table 3.6. The estimated number of animals per hectare for subtropical thicket habitat within Shamwari Game Reserve as determined by the tested methods.**

Method	Species			
	Kudu	Bushbuck	Common Duiker	Blue Duiker
Variable Width	0.435 ± 0.052 (20) <sup>a,c</sup>	0.157 ± 0.028 (20) <sup>a</sup>	0.645 ± 0.105 (20) <sup>a</sup>	0.097 ± 0.030 (20) <sup>a</sup>
DISTANCE	0.300 ± 0.038 (20) <sup>a</sup>	0.108 ± 0.017 (15) <sup>a</sup>	0.387 ± 0.070 (17) <sup>a,b</sup>	0.028 ± 0.028 (8) <sup>a</sup>
Strip Transect	0.012 ± 0.003 (20) <sup>b</sup>	0.001 ± 0.001 (20) <sup>a</sup>	0.025 ± 0.011 (20) <sup>b</sup>	0.007 ± 0.005 (20) <sup>a</sup>
Clearance Plots	0.572 ± 0.102 (20) <sup>c</sup>	0.325 ± 0.080 (20) <sup>b</sup>	0.676 ± 0.319 (20) <sup>a</sup>	0.212 ± 0.126 (20) <sup>a</sup>
Direct Observations	4.692 ± 2.667 (20)	0.804 ± 0.247 (20)	1.872 ± 0.680 (20)	0 (20)

Data are overall mean ± s.e. (*n*). Column means with the same letter are not different at the  $\alpha \leq 0.05$  level. Means were compared using Tukey's test. Direct observation density estimates were not included in the statistical analyses.

**Table 3.7. The estimated total number of animals present on Shamwari Game Reserve within subtropical thicket habitat as determined by the tested methods.**

Method	Species			
	Kudu	Bushbuck	Common Duiker	Blue Duiker
Variable Width	2860	1032	4241	638
DISTANCE	1973	710	2545	184
Strip Transect	79	7	164	46
Clearance Plots	3761	2137	4445	1393
Direct Observations	30837	5260	12295	0

**Table 3.8. Summary of decay and defecation rates for kudu, bushbuck, common duiker, and blue duiker used in this study to determine the number of animals per ha.**

Species	Decay Rate	Defecation Rate
	(# of days until decay)	(# of pellet groups deposited per day)
Kudu	185.4 ± 22.0	24.77
Bushbuck	222.5 ± 49.7	19.0 (Plumptre and Harris 1995)
Common Duiker	237.5 ± 98.5	5.22
Blue Duiker	237.5 ± 98.5	4.9 (Koster and Hart 1988)

**Table 3.9. Analysis of variance testing the effects of season, species, and season  $\times$  species on the mean number of pellet groups which accumulated in a quad from clearance to return (approximately 2 weeks).**

source	df	<i>F</i>	<i>P</i>
season	3	7.04	< 0.001
species	3	39.65	< 0.001
season $\times$ species	9	1.31	0.224

**Table 3.10. Analysis of variance testing the effects of season, species, and season  $\times$  species on the mean number of pellet groups counted during a line transect survey.**

source	df	<i>F</i>	<i>P</i>
season	3	7.50	< 0.001
species	3	16.91	< 0.001
season $\times$ species	9	1.07	0.401

**Table 3.11. Analysis of variance testing the effects of season, species, and season  $\times$  species on the mean number of pellet groups counted during a strip transect survey.**

source	df	<i>F</i>	<i>P</i>
season	3	4.76	0.005
species	3	6.78	< 0.001
season $\times$ species	9	0.82	0.603



**Table 3.12. Analyses of variance by species testing the effects of method (without direct observations), and season, and associated interactions on animal density.**

source	Species											
	Kudu			Bushbuck			Common Duiker			Blue Duiker		
	df	<i>F</i>	<i>P</i>	df	<i>F</i>	<i>P</i>	df	<i>F</i>	<i>P</i>	df	<i>F</i>	<i>P</i>
method	3	15.2	<0.001	3	8.7	<0.001	3	3.4	0.024	3	1.8	0.161
season	3	2.0	0.128	3	1.1	0.351	3	3.5	0.021	3	2.6	0.060
season × method	9	0.37	0.947	9	0.6	0.806	9	1.1	0.372	9	1.4	0.208

**Table 3.13. The number of animals per hectare for riverine bush habitat (Site 1) within Shamwari Game Reserve as determined by the tested methods.**

Method	Species			
	Kudu	Bushbuck	Common Duiker	Blue Duiker
Variable Width	0.205 ± 0.037	0.068 ± 0.034	0.295 ± 0.079	0
DISTANCE	0.070 ± 0.023	-	0.193 ± 0.098	0
Strip Transect	0.015 ± 0.006	0	0.023 ± 0.010	0
Clearance Plots	0.163 ± 0.045	0.135 ± 0.091	0.190 ± 0.076	0.04 ± 0.04
Direct Observations	1.488 ± 1.488	0	1.982 ± 0.810	0

**Table 3.14. The number of animals present on Shamwari Game Reserve within riverine bush habitat (Site 1) as determined by the tested methods.**

Method	Species			
	Kudu	Bushbuck	Common Duiker	Blue Duiker
Variable Width	81	29	117	0
DISTANCE	28	-	76	0
Strip Transect	6	0	9	0
Clearance Plots	64	53	75	16
Direct Observations	588	0	783	0

**Table 3.15. The estimated kudu densities and numbers from the test of all methods on Shamwari's Breeding Center.**

Method	Estimated density (animals per ha)	Estimated number of kudu
DISTANCE	0.261	37
variable width	0.408	58
strip transect	0.026	4
clearance plots	0.12	13
direct observations	6.45	916
Actual Estimate <sup>1</sup>	0.246 – 0.282	35 to 40

<sup>1</sup>Provided by reserve management

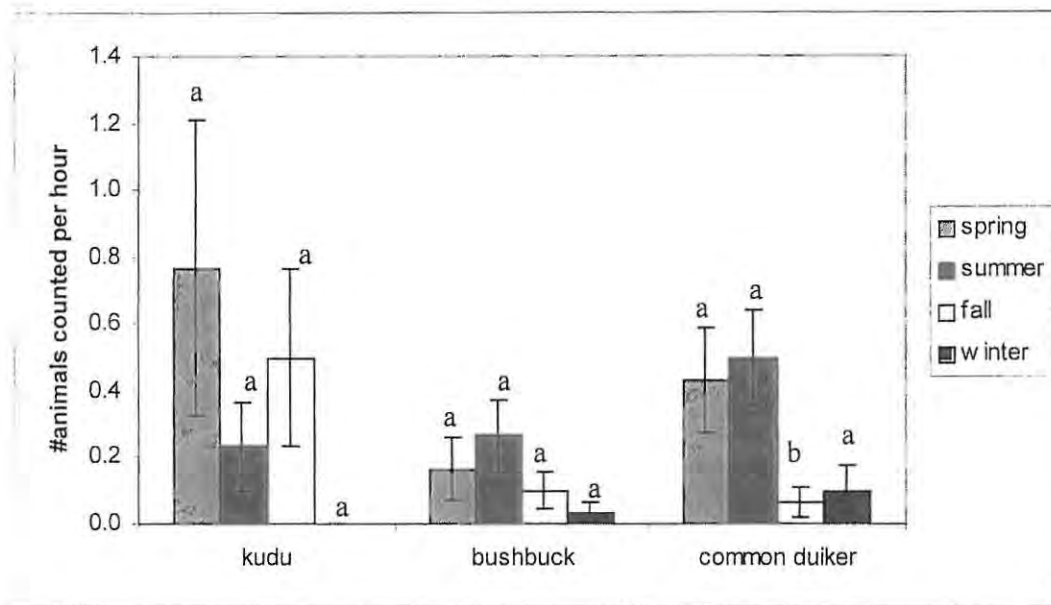


Figure 3.1. The mean ( $\pm$  s. e.) number of kudu, bushbuck, and common duiker counted during an observation period for each season. Bars within each species with the same letter are not different at the  $\alpha \leq 0.05$  level. Means were compared using Tukey's test.

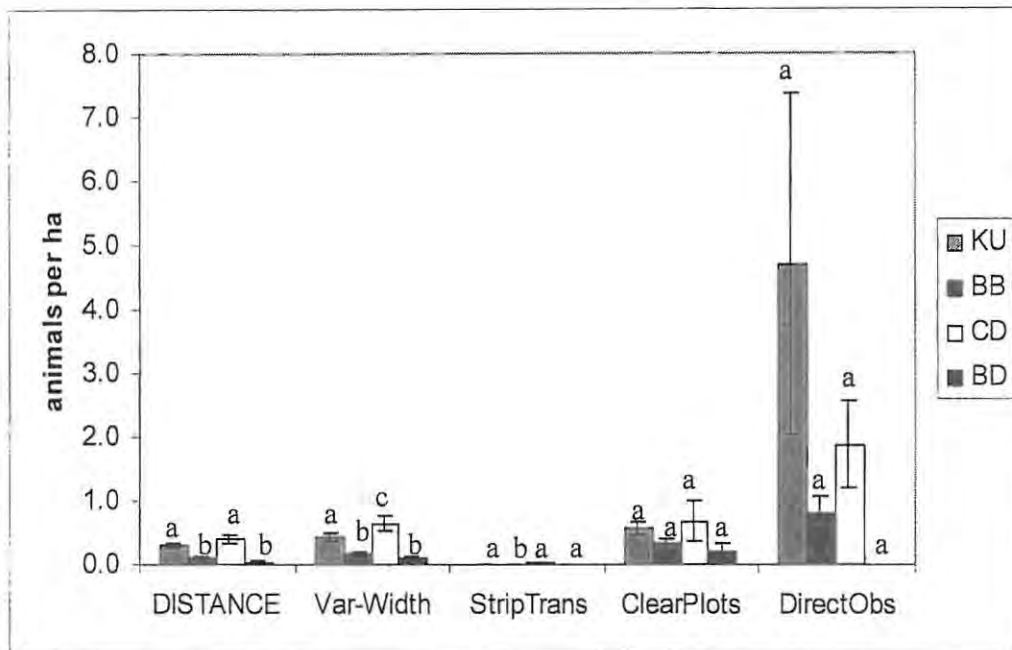


Figure 3.2. Mean ( $\pm$  s. e.) kudu (KU), bushbuck (BB), common duiker (CD), and blue duiker (BD) densities (animals per ha) estimated using DISTANCE, variable width, strip transect, clearance plots, and direct observation methods. Density estimates within each method with the same letter are not different at the  $\alpha \leq 0.05$  level. Means were compared using Tukey's test.

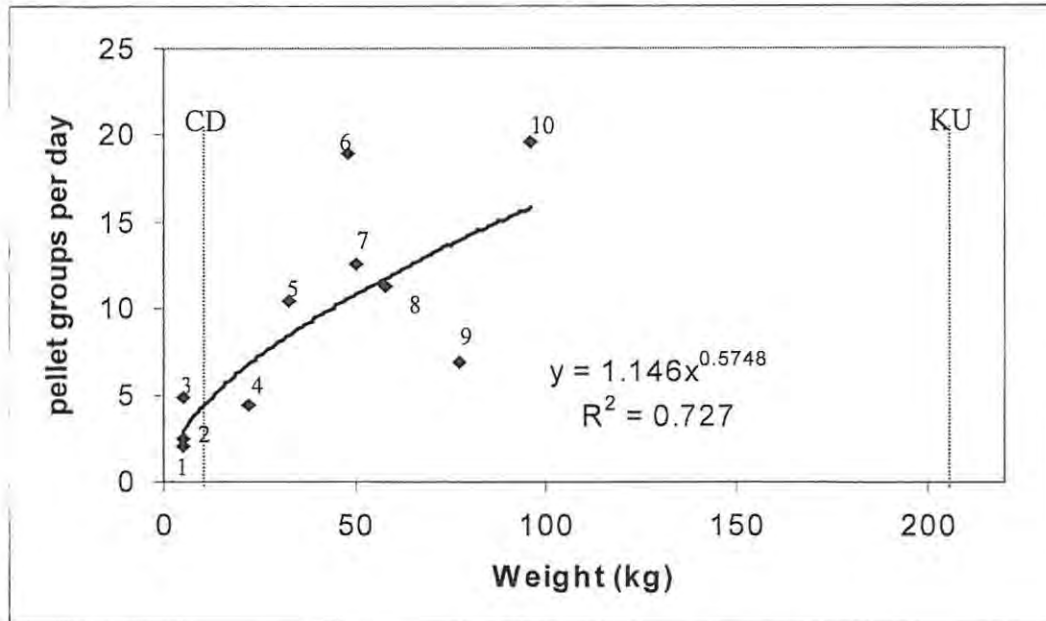


Figure 3.3. The power relationship for known ungulate defecation rates (pellet groups per day) and body weights (kg). The defecation rates are as follows: 1) blue duiker (Bowland and Perrin 1994); 2) blue duiker (von Gadow 1978); 3) blue duiker; 4) bay duiker; 5) blackbuck; 6) bushbuck; 7) axis deer; 8) fallow deer; 9) sika deer; 10) white-tailed deer. Defecation rates for numbers 3 to 10 were taken from a summary by Plumtre (2000). Dashed lines indicate where common duiker (CD) and kudu (KU) weights would fall on the line.

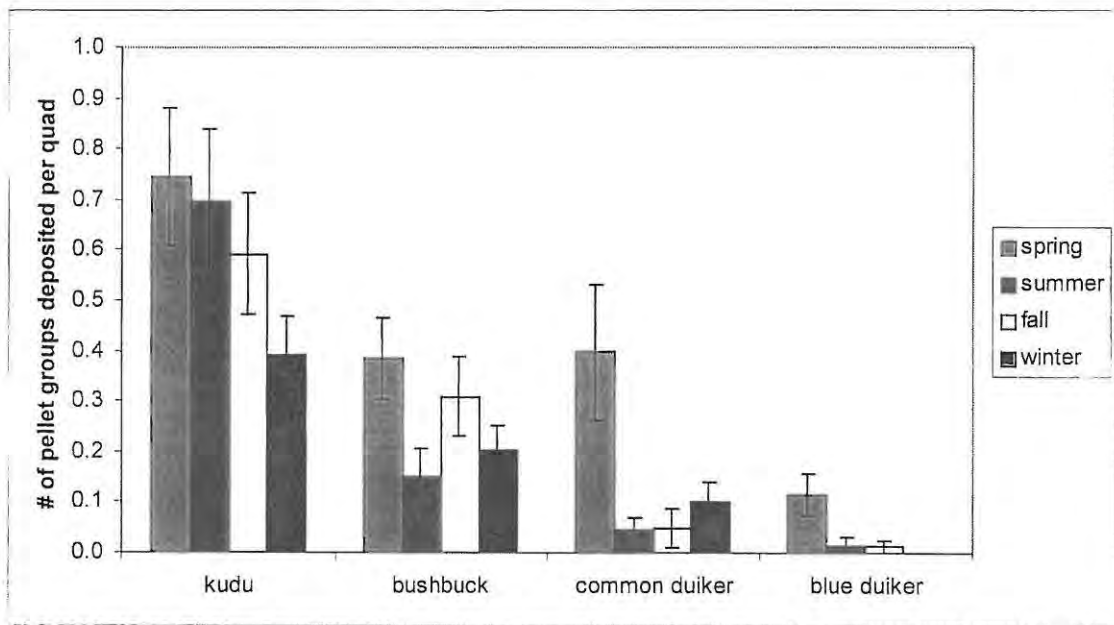


Figure 3.4. Mean ( $\pm$  s. e.) number of pellet groups deposited between visits to clearance plots for each species during each season.

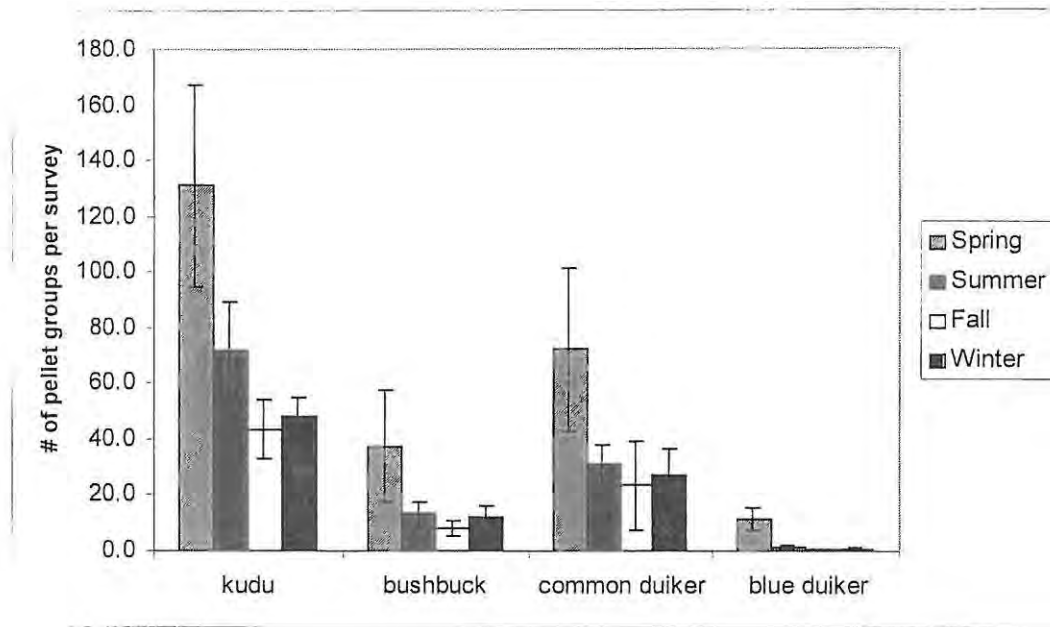
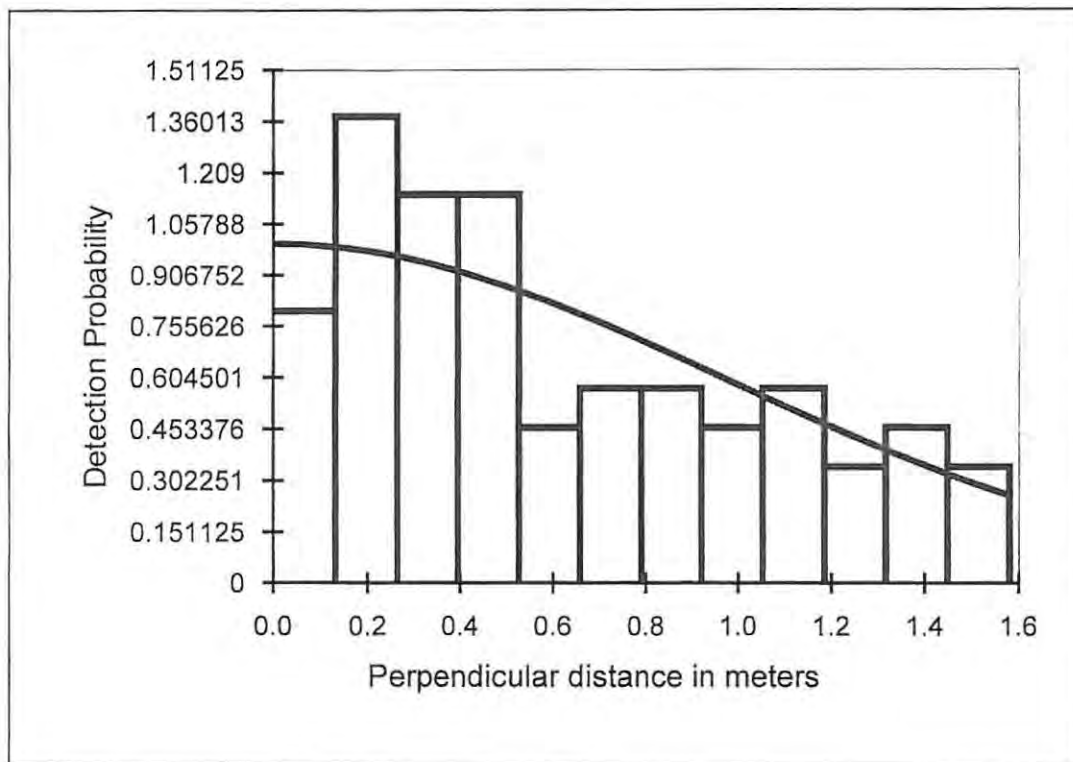


Figure 3.5. Mean ( $\pm$  s. e.) number of pellet groups counted during a line transect survey (250 m straight-line length) for each species during each season.  $n = 5$  line transect surveys for all values.



**Figure 3.6.** Example graph of the detection function (line) fitted to the observations recorded (bars). As the perpendicular distance from the line increases, the detection probability decreases.

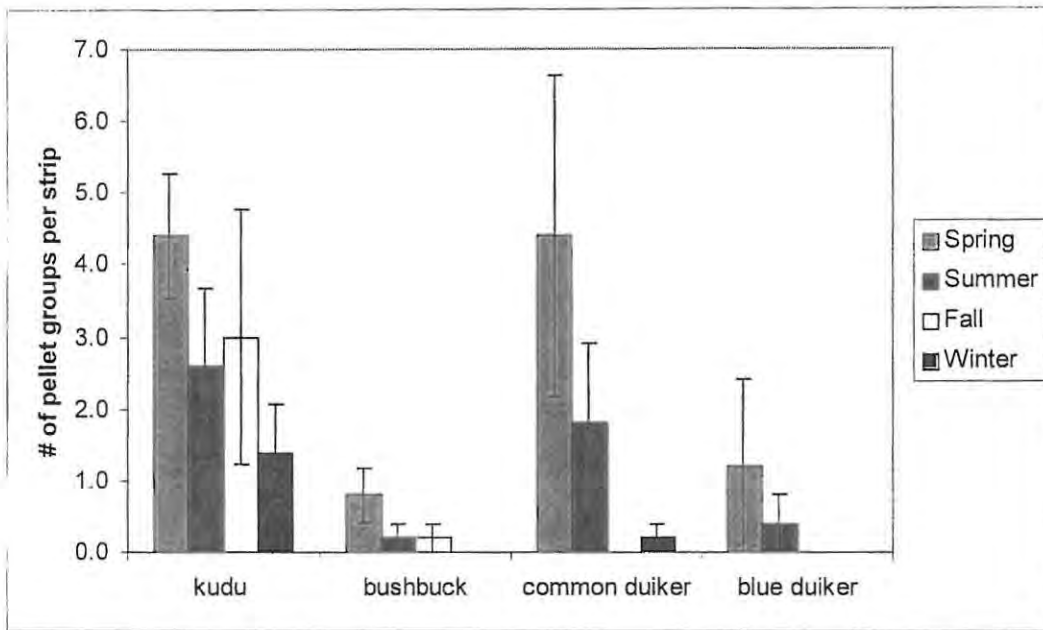


Figure 3.7. Mean ( $\pm$  s. e.) number of pellet groups counted during a strip transect survey for each species during each season.  $n = 5$  strip transect surveys for all values.

## CHAPTER 4: DISCUSSION

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Reliable game counts are an essential part of an effective game management program (Bothma 2001). When selecting a population estimation technique, it is important to identify the specific objectives of the investigation, whether monitoring population changes, calculating harvest levels, or determining minimum viable populations (Bowland and Perrin 1994). The choice also must consider whether an index or an accurate population assessment is required, habitat type and terrain of the study area, seasonal and daily behavior patterns of the species in question, resources available in terms of cash, labor, and expertise, and the timescale in which the information is required (Mayle et al. 1999). Taking all of this into consideration, a practical approach must be taken in evaluating and choosing a method (Bowland and Perrin 1994).

The managers of Shamwari Game Reserve required information specifically on the numbers of kudu, bushbuck, common duiker, and blue duiker because of concerns about the impact of re-introduced lions which were killing these species. Since the reserve's management wanted a method that would generate an estimate of abundance, a method that generated an index of abundance was not suitable. Furthermore, the reserve's management did not require information on sex or age structure although such information would be necessary for modeling purposes. In this study, low-cost methods were evaluated to determine their effectiveness in estimating the density and number of forest ungulates within subtropical thicket habitat. The coefficient of variation was used as a measure of precision of the methods (Marques et al. 2001), while the man-hours required for each method were used to determine labor and cost requirements of the methods. This comparison of methods showed that some are more suited to estimating densities within thick bush habitat than others, while all methods had their own advantages and disadvantages (Table 4.1).

## Direct Sampling Methods

### *Direct Count Observations*

The advantages of direct observations were that actual animals were counted and no indirect variables, such as decay and defecation rates, were required. Decay and defecation rates vary seasonally; therefore, they carry their own variability with them, which in turn, will add to the variability of the density estimates (Rogers 1987, Aulak and Babińska-werka 1990). Direct observations also would provide information on the sex and age structure of a population which is not available using indirect methods.

Unfortunately, direct observations did not perform well in this study and the estimated densities for each species were very high. For the test of methods on the Breeding Center, direct observations yielded an estimate 26 times higher than the actual kudu number. This might be due to the assumption made that animals counted crossing the cut-line, represented the density of animals across all subtropical thicket habitat. It also suggests that it might be possible to achieve a more accurate estimate of density by modifying the equation that was used to calculate density from observations. However, the coefficient of variation was high throughout the study for all species. As a consequence of the high variation, although estimates of kudu density were 2.5 times greater than common duiker and almost 6 times higher than bushbuck, the differences between density estimates were not significant. This would make the method unsuitable for use even as an index. Since the variation was too high to allow detection of differences between species, it likely will not detect yearly changes. Also, no blue duiker was counted during observations, which suggests that the direct count technique is unsuitable because of the secretive behavior of this species (Stuart and Stuart 1988).

There was no significant difference between the number of animals or the species counted during morning and evening observation times. From the species descriptions given earlier, one would expect this to be the case since all species in question are active in the early morning and late evening. The only significant seasonal difference detected was for common duiker, which yielded higher counts in summer than in fall. Since this pattern was not significant for all species, it is difficult to speculate as to the reason for the difference. Since there were no overall seasonal or time differences, direct observations could be applied during either morning or evening and during any season in order to get a

density estimate for the year. However, seasonal observations would allow researchers to monitor the effects of unpredictable events, such as drought or fire, and would increase the sample size which, in turn, might increase the accuracy of the estimate.

Using direct observations required several volunteers in order to cover all sites simultaneously. Differences in how individuals conducted observations could affect the number of animals counted, by, for example, disturbing animals with excessive noise or movement. It is important to use the same observers throughout observations and to inform them how properly to observe their area to minimize disturbance and to reduce observer bias. Also, the man-hours required to conduct direct observations at one site only (6 man-hours) was higher than any other method. Due to the nature of direct observations, it is necessary to conduct observation simultaneously at multiple sites, which will only increase the man-hours required.

It would be difficult to improve the method for use in subtropical thicket habitat. Direct observations would be more suitable in open habitats, with observations made from vantage points over a larger area. Dinerstein (1980) successfully used sample-area direct counts from observation platforms for counts of relatively sedentary ungulate populations in open habitat conditions. But, as with my study, Bowland and Perrin (1994), using similar cut-line counts to count blue duiker and red duiker (*Cephalophus natalensis*), found that although the cut-line was suitable for sampling, it was avoided by the duiker species. They concluded that the sampling line must accommodate the behavior of the animal. Due to the density and structure of the subtropical thicket, it would not be possible to achieve complete and accurate counts within the thicket due to low visibility. MacLeod et al. (1996) found that while observational data are useful for estimating habitat use of non-secretive animals in open areas, direct observations underestimated the utilization of denser habitats due to reduced visibility and behavioral avoidance by bushbuck. Therefore, this method is not recommended for use as an index or density estimation method.

### **Indirect Sampling Methods**

Indirect sampling methods involving pellet group counts have been shown to be a valid means of estimating vertebrate populations (Barnes 2001). They have been tested against known populations and reasonable and acceptable accuracy of estimates has been

obtained in many cases (Neff 1968). Pellet group counts have potential as population indices and for estimating densities (Koster and Hart 1988). However, they are not appropriate for broad-scale survey work and are best used for monitoring individual species or a small number of target species (Wemmer et al. 1996). The use of these methods requires a determination of daily defecation rates during individual seasons of the year and an assessment of the weathering rate and decomposition of pellet groups under various habitat conditions (Dzięciołowski 1976).

The most difficult of the parameters to estimate is the defecation rate of a free-living population (Batcheler 1975). The quantity, size, shape, and consistency of pellet groups largely depend on diet, which often shows seasonal changes (Wemmer et al. 1996). Defecation rates have been found to vary seasonally, with the highest rates in spring and fall, but seasonal variation may be less pronounced in areas where winters are less severe and food quality does not decrease (Rogers 1987). Defecation rates can be affected by artificial diets, abnormal behavior, and stress; therefore, in order to improve estimates, observations should be conducted on free-ranging animals over all seasons (Rollins et al. 1984). In my study, due to time constraints, it was not possible to calculate site, season, and species specific defecation rates and I have used previously published rates for bushbuck and blue duiker and calculated rates for kudu and common duiker.

An accurate decay rate is essential for interpretation of pellet group counts (Harestad and Bunnell 1987). Decay rates have been shown to vary widely with substrate, season, and climatic conditions; therefore, it is important to determine site specific decay rates (Wemmer et al. 1996). Groups deposited under dry conditions may harden and persist for long periods, with some remaining unchanged for over three years (Eberhardt and Van Etten 1956). Pellet group persistence is least in moist, vegetated forest habitats and greatest in dry, bare habitats (Harestad and Bunnell 1987). Rate of decay has also been found to depend largely on weather conditions experienced soon after defecation (Plumptre and Harris 1995). Rainfall (monthly precipitation and number of days per month with precipitation) and invertebrate activity have a significant impact on the rate of pellet group decay (Wallmo et al. 1962, Downing et al. 1965, Wigley and Johnson 1981).

Since this was only a one-year long study, it did not explore variation in decay rates among seasons, and this may reduce the accuracy of the density estimate (Focardi et

al. 2002). Also, this study did not find any species differences in decay rates which could be due to the low sample sizes and the high degree of variation within each species. In this study, it was difficult to locate fresh pellet groups because most visits to the sites were made in the afternoon, by which time the sun had already hardened pellet groups deposited the night before and that morning. It is recommended that pellet groups are located early in the morning to ensure that groups are fresh. In order to improve decay rate estimates, it would be necessary to mark more pellet groups for all species within subtropical thicket habitat during all seasons and to trace decay over several years.

### *Clearance Plots*

The clearance plot method did not perform well in this study. The coefficient of variation was high in comparison to some of the other methods and it yielded the highest density estimates of all indirect methods. Due to its high variance, differences between estimates of species densities were not detected even though, for example, common duiker density was 3 times higher than blue duiker density. Spring yielded the highest overall mean density and the significance of this will be discussed later. The clearance plot method density estimates on the Breeding Center were almost 3 times lower than the actual kudu number, but on the reserve the estimates were about 1.3 times higher than the DISTANCE kudu estimate. This may be due to the limited number of visits made to quads or the smaller number of quads on the Breeding Center.

When analyzing the mean number of pellet groups deposited between visits to the quads by season and species, both effects were found to be significant. During spring, the highest number of pellet groups, almost double any other season, were deposited. This could be a reflection of the higher defecation rate in spring due to a diet with higher moisture content from new plant growth (Rogers 1987). Of the species, kudu had the highest pellet group deposition rate, while bushbuck was higher than blue duiker. The high deposition rate for kudu, again, could be a reflection of its defecation rate, which was higher than all other species, and its abundance.

One advantage of the clearance plot method is that it does not require an estimated decay rate since the time period for deposition is known and is far too short for decay to be relevant. In order to improve density estimates based on clearance plots, it would be

necessary to install more sample plots. The 5 m by 5 m plot size used in this study worked well in the thick bush habitat. Also, smaller plots (approximately 4 m<sup>2</sup>) have been found to be more efficient than larger ones (approximately 80 m<sup>2</sup>) since the error of missed groups is influenced by plot size and shape, type and density of understory vegetation, and observer fatigue and inherent visual acuity (Neff 1968, Smith 1968). In general, there is less chance of overlooking pellet groups on smaller plots (Neff 1968). The design of a pellet group survey must consider the distribution of pellet groups over the sample area, cost to install the survey design, pellet group density, and the shape of the sample area (Smith 1968).

Using the coefficient of variation from this study, it is possible to estimate the number of quads needed to reduce the coefficient of variation. Using a formula from Cochran (1977), the number of quads needed to reduce the overall coefficient of variation for kudu density from approximately 103% to 20% would require sampling 538 quads. Kudu had the lowest coefficient of variation, so sampling would be even greater to improve estimates for bushbuck (788 quads), common duiker (924 quads), and blue duiker (1287). For this study, 1.5 man-hours were required to visit 3 quads 6 times during a season. To visit 538 quads 6 times during a season would require 269 man-hours, not counting the amount of time and effort required to initially set-up quads. This would require a tremendous amount of work, man-power, and time and is therefore impractical. Schmidt (1983) experienced similar problems using 2.7 m by 2.7 m quads to estimate the density of common duiker and bushbuck and abandoned the clearance plot method due to high man-hour and cost requirements.

### *Line Transects*

For the objectives laid out in this study, the use of line transect methodology is likely to provide a cost-effective alternative to clearance plot methods because line transect surveys are not repeated as often as quads are cleared and thus the man-hour requirements are less (Marques et al. 2001). The line transect method required only 2 man-hours per site each season and the equipment requirements were minimal, a 50 m tape measure and 9 m steel tape measure.

When analyzing the effects of season and species on the number of pellet groups counted for each line transect survey of 250 m straight-line length, both were found to be significant. The mean number of pellet groups counted during spring was greater than all other seasons. As before, this probably reflects higher defecation rates in spring. The number of pellet groups counted for kudu was greater than all other species, while common duiker was greater than blue duiker. As before, this is probably due to kudu's higher defecation rate, while common duiker could be more abundant than blue duiker since they have similar defecation rates.

The method used in this study met all of the assumptions of line transect sampling given by Anderson et al. (1979). Observers made certain that all pellet groups on the line were detected and counted. Since it was a survey of pellet groups, there was no possibility of the objects moving from the initial sighting position and no pellet groups were counted twice. The use of a steel measuring tape ensured that measurements were accurate to the nearest cm. In order to accommodate the thick bush vegetation, line transects were a series of straight-line segments.

#### *Variable Width*

The variable width method performed reasonably well throughout the study, but did have a higher coefficient of variation than the DISTANCE method. The advantage of variable width sampling is that it does not require additional computer analysis and an estimate could be achieved no matter how few pellet groups were counted. On the Breeding Center, the method overestimated the true population by 1.5 times. On the reserve, the variable width density estimate also was 1.5 times the DISTANCE estimate. The difference between the two methods is that the variable width method rests on the assumption that detection probability equals 1 for all distances, but DISTANCE method makes the assumption that detection probability only equals 1 when the distance equals zero or the pellet group is on the line (Burnham and Anderson 1984).

The variable width method estimated common duiker to be more abundant than kudu, while both were more abundant than bushbuck and blue duiker. Again, the overall average density of animals estimated in spring was greater than all other seasons and will be discussed later. Bowland and Perrin (1994) found the variable-width method suitable

for estimating forest duiker population densities, but counted actual animals instead of pellet groups. In order to improve the variable width method to work with pellet group counts, it may be possible to use a correction factor, such as reducing its estimate by 70%, to achieve a more reliable estimate. To do this, the method must be tested against a known population several times. Also, differences between the variable-width and DISTANCE method estimates could be due to the lack of truncation in the variable-width method. Truncating the pellet group observations to remove outliers could possibly improve density estimates.

### *DISTANCE*

For estimating the density and number of forest ungulates within subtropical thicket habitat on Shamwari Game Reserve, the DISTANCE method performed the best overall. This method exhibited the lowest coefficient of variation and provided the most accurate results for the test of methods on the Breeding Center. When the results for the DISTANCE method are compared to the helicopter-generated game counts on Shamwari Game Reserve, the DISTANCE estimates were 2 to 3 times greater for all species except bushbuck (Table 4.2). In the case of bushbuck, the two estimates were similar which could be a result of missed bushbuck pellet groups, which is discussed later, or that the estimates for bushbuck defecation and decay rates were better than those used for the other species. The DISTANCE method estimated common duiker and kudu to be more abundant than bushbuck and blue duiker. There were no seasonal differences in estimates. This suggests that the method could be applied once a year and achieve similar results and that this method is repeatable providing precise results.

The comparison of the DISTANCE method to helicopter counts of kudu on Kwandwe Game Reserve yielded higher density estimates by the DISTANCE method. However, the DISTANCE method was able to recognize the high- and low-density areas. The over-estimations were similar in both areas, being 2.3 times higher than the helicopter counts in the high-density area and 3 times higher in the low-density area. The ratios (low-density area : high-density area) were similar for both methods, with helicopter counts being slightly higher (1 : 5.6) than the DISTANCE method (1: 4.2). The difference between the results for the 2 methods could be due to the decay rate used to calculate kudu density from the DISTANCE pellet group count. The decay rate had been calculated

specifically for Shamwari, where rainfall was greater. Also, as discussed above, the decay rate on bare ground is slower than that in vegetated areas. Although not quantified, there appeared to be more bare ground present at Kwandwe than Shamwari. It is thus necessary to establish decay rates for Kwandwe in order to achieve more accurate animal density estimates from the use of the DISTANCE method.

In both cases (on Shamwari and Kwandwe Game Reserves) where the DISTANCE method was compared to helicopter counts, DISTANCE estimates were about 2 to 3 times greater than the estimates of the helicopter counts. But, on the Breeding Center, the DISTANCE method estimated the kudu population that was exactly within the actual range. The difference could be due to the percentage of the total area covered by the line transect surveys. The Breeding Center was composed of approximately 142 ha of thicket habitat (*Acacia* and subtropical thicket). If it is assumed that at least 2 m were surveyed on each side of the line, then approximately 1000 m<sup>2</sup> (0.1 ha) were covered by each line transect survey of 250 m. Therefore, for the Breeding Center approximately 0.07% of the total thicket area was surveyed. In comparison, only 0.007% of the total 6575 ha of subtropical thicket was surveyed on Shamwari Game Reserve and 0.006% of the 6400 ha on Kwandwe Game Reserve. Therefore, in order to improve the DISTANCE estimates of density, it may be necessary to increase sampling effort to that used in the Breeding Center. On Shamwari Game Reserve this would be achieved by conducting 46 line transect surveys of 250 m of total straight-line length throughout the 6575 ha of subtropical thicket habitat.

In order to better understand the relationship between helicopter counts and the DISTANCE method, it would be necessary to test both methods against a known population. It would be important to conduct this in an area of subtropical thicket and to attempt to count the kudu, bushbuck, common duiker, and blue duiker specifically. Aerial surveys work well for game on open planes but not for more camouflaged game in woodland areas (Hirst 1969), which would be the case for the subtropical thicket ungulates. When helicopter counts are used to count an entire population, the results will be an underestimation of the true number but the degree of undercounting varies and depends upon the species and habitats involved (Eltringham 1979). Bothma et al. (1990) tested various methods of counting game in an open bushveld area and found helicopter

count estimates of kudu to be only 56% of assumed true population estimates derived from a drive count. If this was the case for Shamwari and Kwandwe Game Reserves, then the DISTANCE method estimates would be closer to the true population. But if the helicopter counts are more accurate, then a correction factor or better decay and defecation rates could be established to adjust the DISTANCE method estimates. The question of which method is more accurate can only be answered by testing the methods against a known population.

As with the variable-width method, the DISTANCE method has been used successfully with direct animal counts (Focardi et al. 2002, Lannoy et al. 2003). Focardi et al. (2002) obtained coefficient of variation values of 15 to 20% with 40 to 50 observations. The method proved useful within dense Mediterranean forest for both research and management of forest ungulates (Focardi et al. 2002). Lannoy et al. (2003) also successfully used DISTANCE to estimate the biomass of duiker species within a dense, evergreen rain forest. As with my study, Plumptre (2000) used the line transect method with the DISTANCE analysis to estimate ungulate numbers from pellet counts, but also recommended that a multi-method approach, incorporating both pellet counts and direct observations, should be taken to give a clearer picture of changes in animal abundance.

### *Strip Transect*

The strip transect method did not perform well in our study. Its estimates were low compared to other methods and to the true population on the Breeding Center. Since there was only one strip transect at each site, it was not possible to calculate a site coefficient of variation for the method. When analyzing the effect of season and species on the number of pellet groups counted in a strip transect, both effects were found to be significant. The number of pellet groups counted in spring was greater than fall and winter, which followed a similar trend to the other indirect methods. Also, the number of pellet groups counted for kudu was greater than bushbuck and blue duiker. Again, this is a similar trend exhibited by all other indirect methods tested in this study.

The strip transect method only detected that estimates of kudu, common duiker, and blue duiker densities were greater than bushbuck density. There also were seasonal differences with spring density being greater than fall and winter.

Strip transects were located on the cut-line at each site, which was an open, exposed access road. The decay rate on the cut-line would be faster than that within the thicket since trees do not protect it and vehicles could drive through the area. Also, it has been found that strip counts often result in incomplete counts with undetected objects, and some ancillary information is needed to adjust for this bias (Burnham and Anderson 1984). For various reasons it would be difficult to apply the strip transect method within the bush thicket. To begin with, marking the area would be difficult, but locating pellet groups within the area would be even more difficult and ensuring that all pellet groups were counted would be impossible. Therefore, in order to improve the method, it would be necessary to estimate decay rates for the open cut-lines. Although the method required only 0.5 man-hour and a 50 m tape measure, it is not recommended for use as a population estimation method for subtropical thicket habitat.

### Summary

Overall, for this study the indirect methods using pellet group counts performed better than the direct counts (Table 4.1). An advantage of pellet group counts over direct counts is that pellet groups provide a persisting record of the presence of an animal, while direct counts depend on current activity and may be affected by the presence of the observer and weather conditions (Eberhardt and Van Etten 1956). Pellet count methods have been widely adopted in forest studies because fecal remains are less elusive than the animals themselves (Wallmo et al. 1962). Pellet count transects also have been found to provide more reliable results than direct observations (MacLeod et al. 1996). More specifically, pellet counts have been a useful tool for estimating the numbers of bushbuck and blue duiker in dense forest and hold promise as a practical and economical instrument (von Gadow 1978). In an evergreen forest in Zaire, line transect surveys of pellet groups for several duiker species yielded similar density estimates as drive counts and were declared as useful for estimating densities (Koster and Hart 1988). Also, Plumptre and Harris (1995) used pellet counts to estimate black-fronted duiker (*Cephalophus nigrifrons*) and bushbuck densities in tropical montane forest and found estimates consistent with the number of animals that could be recognized in the area. In contrast, Bowland and Perrin (1994) obtained unsatisfactory results from pellet group counts of blue duiker and red duiker and found density estimates double those of drive counts and direct observations.

It must be stressed though that population estimates based on pellet group counts are only as strong as the estimates for species, site, and season specific decay and defecation rates. Fuller (1991) found the usefulness of pellet group counts to be limited due to the number of factors that might affect pellet group deposition. Dzieciolowski (1976) had similar problems and declared pellet counts as an unpromising method but stressed that adaptation was possible by determination of defecation rates during individual seasons, decay rates under various habitat conditions, and repeated field tests on known populations. The review of the pellet count method by Eberhardt and Van Etten (1956) summarized studies up to that time in which pellet counts were compared to known populations and, overall, the accuracy was not good due to serious errors from either natural causes or observer error or both. Eberhardt and Van Etten (1956) believed that the errors could be controlled sufficiently to permit use of pellet counts as a reliable means of estimating populations.

The clearance plot, variable width, and strip transect methods had significantly higher overall density estimates in spring which could reflect a movement of animals into the thickets in spring or an increase in defecation rates at this time. Also, spring was the first sampling season and it may reflect field workers learning how to apply the methods and identify pellet groups. In order to determine if this is a seasonal trend, the study will need to continue for several more years.

The animal densities that resulted from the various indirect methods in subtropical thicket habitat were greater than those for the riverine habitat type. However, caution must be used when interpreting these results because there are several possible sources of inaccuracy when using pellet group counts as indicators of habitat use. Defecation by an animal may not be regular throughout the day with animals having a preferred time, area, or vegetation type in which to defecate (Bailey and Putman 1981). Animals of different sex or age may have different defecation rates and recovery of pellet groups may not be equally efficient in all habitat types (Bailey and Putman 1981). Also, problems may arise from differential rates of decay of pellet groups in different habitat types (Bailey and Putman 1981). Direct observations in the two habitats yielded similar results, except for common duiker density, and supported the pellet count methods used. My study sampled only one area of riverine bush; therefore, sampling intensity within riverine bush habitat

would need to be increased to that of the subtropical thicket in order to make a valid comparison. My results do suggest that it is likely that the abundance of ungulates is higher in the subtropical thicket than the riverine bush. The subtropical thicket provides a higher variety of tree species for browse and better cover with denser bush, both of which are important to all species in question.

All indirect methods tested do have the potential of providing an index of abundance. A good index should increase directly when the population increases in size and decrease when the population decreases (Conroy 1996). It would be necessary to validate these trends against a known population. An index may be desirable when only a measure of relative abundance or change in abundance is the goal of an investigation (Conroy 1996). But, an index will not allow comparison between species, since defecation rates vary by species. All indirect methods in this study found more kudu pellet groups than the other species, but when pellet group counts were converted to estimated density, common duiker had the highest estimated density. Therefore, pellet counts as an index would only be of use if the goal of a study was to compare a single species' abundance among different areas or to monitor population changes over time.

The DISTANCE method performed best for estimating the density of animals within subtropical thicket habitat. The method was easy to apply and required only 2 man-hours per site. The equipment requirement was minimal, a 50 m tape measure and 9 m steel tape measure, and the DISTANCE software which was available for free download from the internet. Distance sampling methodology is designed to produce estimates that are less biased than those produced by assuming perfect detectability, such as the variable width or strip transect methods (Barry and Welsh 2001). The method is independent of plot size; therefore, search time depends upon pellet group density and will be lower at high densities (Quayle 1998). Also, line transect surveys can be conducted under a variety of budgetary, personnel, topographic, and vegetation conditions (Rudran et al. 1996).

In order to improve the DISTANCE method, it is necessary to adjust the total straight-line length for each species in question. Anderson et al. (1979) recommended that studies be designed to detect at least 40 objects, while Buckland et al. (1993) suggested a sample size of at least 60-80 objects for an adequate estimation of density. Further, Plumptre et al. (2000) recommended that at least 100 objects should be detected in order to

monitor the population changes in the future. One objective of the study was to develop a method that will detect changes (increases or decreases) in the population numbers. Using the encounter rates from this study, in order to reach 100 pellet groups, the line transect survey must cover 380 m for kudu, 1515 m for bushbuck, 877 m for common duiker, and 9091 m for blue duiker. These lengths should be distributed across the area in 10 – 20 separate transect lines since many short transect lines ( $\leq 50$  m) will provide better spatial coverage and more reliable estimates of precision than fewer, longer lines (Marques et al. 2001).

### **Management Implications**

In arriving at a decision as to which method is the most applicable, one must consider economics, availability of trained personnel and time, and the use to which the data will be put (Rogers et al. 1958). Also, knowledge of the habitat preferences and other ecological requirements of the animals in question is basic to any management program (Dekker et al. 1996). Animals are usually not evenly distributed, but rather tend to congregate in patches in preferred sections of the habitat; therefore, the area should be divided on the basis of the habitat preferences of the animals for game counts (Bothma 2001). Also, if the animals in question are sparse or grouped, it is necessary to make more sample counts to give reliable estimates (Bothma 2001). The manager of an area should be familiar with the general species distribution and abundance and should plan a survey accordingly. If not, then a pilot survey, such as my study, is recommended to determine the amount of survey effort required (Marques et al. 2001). Also, a flow-chart based on Mayle et al. (1999) is provided to aid in decision making (Figure 4.1). This chart does not take into account the cost of a method, so some methods, such as thermal imaging, may not be an option when budgets are limited.

Four important variables to consider when planning a line transect survey are density and distribution of pellet groups, distribution and length of sampling lines, size of area to be sampled, and sampling accuracy desired (Rogers et al. 1958). The line transect survey design should provide equal coverage probability throughout an area to reduce any bias that could result from coverage of areas that present either very high or very low ungulate densities (Marques et al. 2001).

In order to apply the DISTANCE method, the manager and field workers should be able to confidently identify pellet groups, accurately measure distances, and perform the DISTANCE analysis using a computer and software. The number of persons involved in conducting the line transect surveys should be kept to a minimum to reduce inter-observer bias (Wemmer et al. 1996). The best results are achieved with one observer surveying all sites. The DISTANCE method is outlined step by step in Appendix 1, which is how the method was performed in this study. It may be desirable, and managers are encouraged, to make changes to accommodate study differences. From this study's results, it is recommended to conduct the survey once a year in fall or winter since ground cover will be sparse and pellet detection will be easier and to use the recommendations made earlier on the total straight-line lengths necessary to detect changes in each species' population.

### **Future Research**

Further studies should be conducted on the use of all methods. The methods should be tested against known populations of kudu, bushbuck, common duiker, and blue duiker. The test of methods in this study only involved kudu, but the methods may behave differently when applied to other species. It has been found that objects of different sizes have different sighting probabilities (Otto and Pollock 1990). It is easier to detect kudu pellet groups than, for instance, bushbuck pellet groups. This was reflected in the effective strip widths for the variable width and DISTANCE methods. Common duiker and blue duiker had the highest effective strip width, which would reflect the fact that pellet groups commonly occurred in middens that were easily detected from the line transect. Kudu, which had the next highest effective strip width, has relatively large pellets within large groups that are easy to spot during surveys. Bushbuck had the lowest effective strip width. Bushbuck pellet groups are small in comparison to kudu and common duiker and are more easily overlooked during a line transect survey. These differences may be important in how well a method performs.

Blue duiker and common duiker pellet groups, and to a lesser extent, those of bushbuck, have been found to display a clustered distribution (von Gadow 1978). The effect of clustering on common and blue duiker density estimates should be explored. The perpendicular distance to the center of the cluster should be measured, and the number of pellet groups within the cluster should be counted (Rudran et al. 1996). The DISTANCE

analysis can take into account clustering, but this was not explored in this study due to lack of necessary information and measurements, such as the number of pellet groups within a cluster.

The methods evaluated in this study worked well to detect all species except blue duiker. This could be a reflection of the lower density of blue duiker or the species' more secretive behavior (Stuart and Stuart 1988). In order to obtain better estimates for blue duiker, it is necessary to increase sampling effort. Also, more intense methods, such as radio telemetry may be successful. Komers and Brotherton (1997) successfully used a modified form of pellet counts to estimate the abundance of dik-dik (*Madoqua kirkii*) by developing a pellet-matching method using variation in pellet characteristics between individuals. The dik-dik shows similar behavior to blue duiker and prefers dense woodland (Stuart and Stuart 1988). For blue duiker specifically, Bowland and Perrin (1994) found variable-width transects using direct counts to be a suitable method for estimating forest duiker populations. Koster and Hart (1988) employed a similar transect method as Bowland and Perrin (1994) but found that animals were difficult to detect because they moved away from the observer. No matter what method is chosen for blue duiker population estimation, intensive sampling and surveying will be necessary.

Improvements can also be made to defecation and decay rates. The accuracy of any indirect method using pellet counts will depend upon the accuracy of these variables. As suggested before, direct observations on free-roaming animals should be conducted over several seasons to determine defecation rates. Decay rates within subtropical thicket habitat should be recorded for several years for all species. Improvements in the estimates for these variables would, in turn, improve density estimates.

Although the DISTANCE method performed best, correction factors may be developed to improve density estimates from the other methods. The ratios of the estimates from the methods were fairly consistent throughout the study. If the methods were tested several times against a known population, it would be possible to calculate a correction factor that can be used to make density estimates more precise. The ratios from this study suggest that these correction factors may need to be species specific; therefore, tests must be done against known populations for the species under questions.

**Conclusions**

As hypothesized in this study, the indirect methods performed better than direct methods in subtropical thicket habitat within Shamwari Game Reserve. Within indirect methods, the line transect survey method using the DISTANCE software to calculate density performed best overall. The method had the lowest coefficient of variation and yielded the most accurate estimate on the Breeding Center. The main advantage of the DISTANCE method was its simplicity and low economic requirements. The method suited the objectives in that it was easy to apply, yielded the most accurate results, and worked reasonably well for all species in question.

**Table 4.1. An assessment of methods tested in this study including the man-hours required to perform the method at each site for a season, whether the density estimates overall were high or low in comparison to the DISTANCE method, and the advantages and disadvantages of each method.**

Method	Man-hours	Overall Density Estimates	Advantages of Method	Disadvantages of Method
Direct Count Observations	6	High	<ul style="list-style-type: none"> <li>• Did not require decay and defecation rates to calculate animal density</li> <li>• Allowed viewing of animals and collection of addition information, such as, age and sex</li> </ul>	<ul style="list-style-type: none"> <li>• High man-hour requirements</li> <li>• Observer bias since multiple observers are required</li> <li>• Produced unrealistic estimates in this study</li> <li>• High coefficient of variation</li> </ul>
Clearance Plots	1.5	High	<ul style="list-style-type: none"> <li>• Did not require decay rate to calculate animal density</li> </ul>	<ul style="list-style-type: none"> <li>• Great amount of time needed to establish quads</li> <li>• Multiple visits to quads</li> <li>• High coefficient of variation</li> <li>• Required defecation rate</li> </ul>

Method	Man-hours	Overall Density Estimates	Advantages of Method	Disadvantages of Method
Variable Width	2	High	<ul style="list-style-type: none"> <li>• Easy to apply</li> <li>• Required only one visit to an area</li> <li>• Simple calculation of animal density</li> </ul>	<ul style="list-style-type: none"> <li>• High coefficient of variation</li> <li>• Required decay and defecation rate</li> </ul>
DISTANCE	2	-	<ul style="list-style-type: none"> <li>• Easy to apply</li> <li>• Required only one visit to an area</li> <li>• Performed best during validation of methods for kudu</li> </ul>	<ul style="list-style-type: none"> <li>• Required the use of a computer program for analysis</li> <li>• Required decay and defecation rate</li> </ul>
Strip Transect	0.5	Low	<ul style="list-style-type: none"> <li>• Easy to apply</li> <li>• Low man-hour requirements</li> </ul>	<ul style="list-style-type: none"> <li>• Animal density estimates were low</li> <li>• Needs decay rate determined specifically for the strip</li> <li>• Required decay and defecation rate</li> </ul>

**Table 4.2. The number of animals present on Shamwari Game Reserve as determined by the DISTANCE method and helicopter counts.**

Method	Species			
	Kudu	Bushbuck	Common Duiker	Blue Duiker
DISTANCE	1973	710	2545	184
Shamwari's 2003 Census	900	950	850	80
Amount of overestimation by DISTANCE	2.2 ×	0.75 ×	3.0 ×	2.3 ×

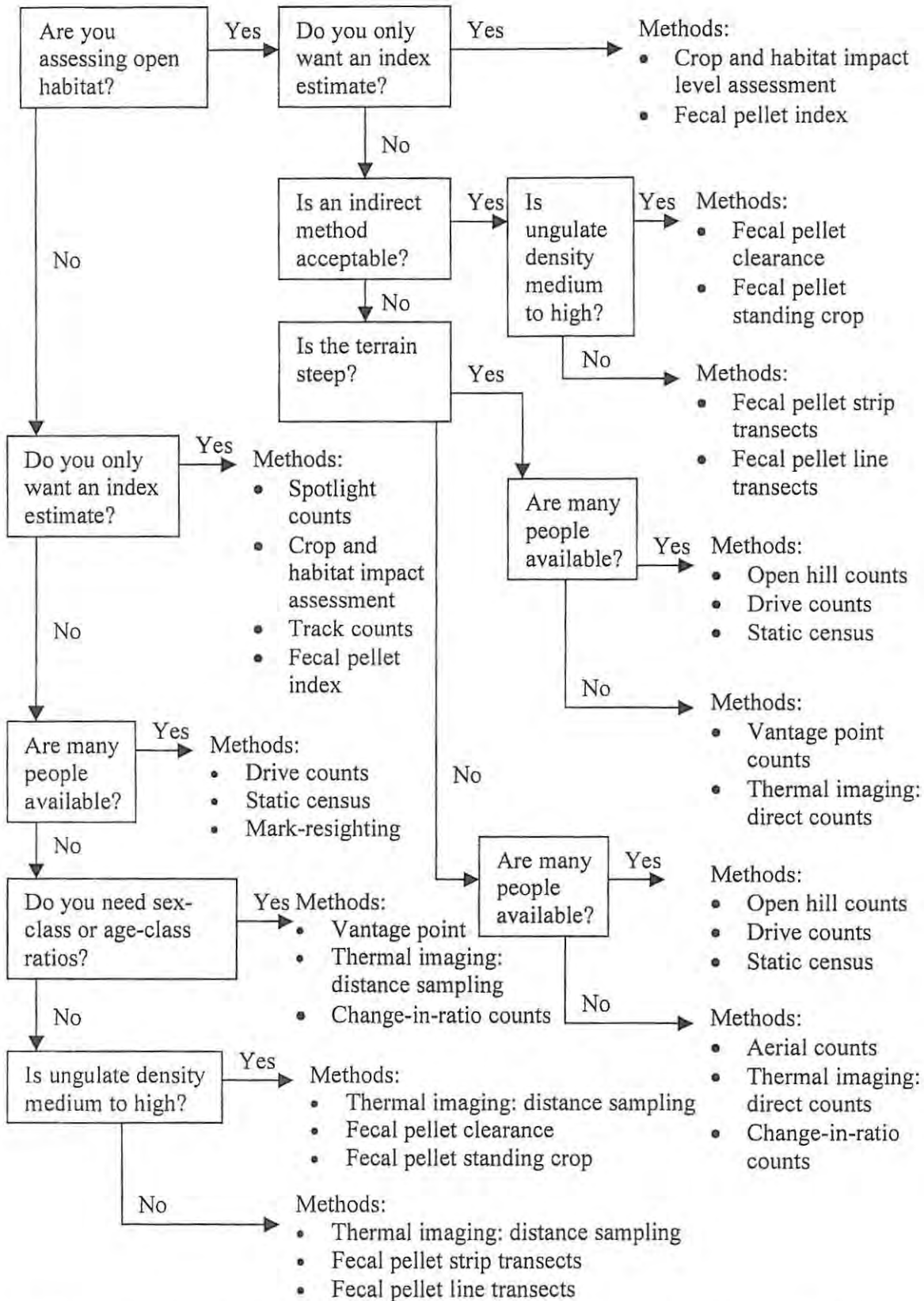


Figure 4.1. Flowchart for selecting appropriate census method modified from Mayle et al. (1999).

## CHAPTER 5: REFERENCES

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