LAND USE AND PREY DENSITY CHANGES IN THE NAKURU WILDLIFE CONSERVANCY, KENYA: IMPLICATIONS FOR CHEETAH CONSERVATION

By

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This thesis is dedicated to my parents.

Thank you for all of your love and support.

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Originally found throughout Africa outside of the Sahara and into Asia, the cheetah has disappeared from much of its former range and is under threat in those areas where it still exists. The current decline of cheetah populations has been attributed largely to habitat loss and a decline in prey densities. I attempt to explain the cause of the putative decline of the cheetah population, *Acinonyx jubatus,* in the Nakuru Wildlife Conservancy (NWC), Nakuru, Kenya. I examined prey density data for the NWC and analyzed land-use changes between 1986 and 2003 as possible correlates of the purported reduction in the cheetah population. To analyze and quantify landcover change, three Landsat satellite images from Path 169, Rows 60 and 61 were acquired representing the entire study area, and were classified separately using a combination of the supervised and unsupervised classification methods. Information on the density of prey species in different habitat types was collected using transects, and was analyzed with the program DISTANCE. Changes in prey density over time were determined by regressing the average density for the whole conservancy with time. Grassland landcovers in the conservancy were reduced by almost 16%, while bush increased almost 13%, and marginal areas overall increased almost 15%. The biggest changes were seen in the developed and baresoil classes, with increases of 348% and 290%, respectively. Preferred prey were found in higher densities in grassland areas as compared to bushland, although large and small prey showed no significant differences. Only preferred prey and Thompson's gazelle were shown to have declined significantly in density since 1996. Results indicate that recent changes (1986-2003) in landcover and prey availability within the Nakuru Wildlife Conservancy are insufficient to explain the marked decline of cheetahs in the area. Other factors, such as high human densities in NWC and proliferation of small scale agriculture in the surrounding areas, should be explored as possible explanations for the cheetah population decline.

CHAPTER 1
INTRODUCTION

Originally found throughout Africa outside of the Sahara and into Asia, the cheetah (*Acinonyx jubatus*) has disappeared from much of its former range, and is under threat in those areas where it still exists. Little more than half the countries in Africa that once contained cheetahs still retain populations. Of those, only 1/3 support viable populations. The largest population can currently be found in Namibia, with about 2,000-3,000 animals. Kenya has the second largest population, with between 1,000 and 2,000 animals. The populations in Asia have been lost completely, except for a relict population of about 200 in Iran (Marker-Kraus et al., 1996; Marker-Kraus and Kraus, 1993). Many explanations for this decline have been put forth, including loss of habitat, decline in prey abundance, genetic homozygosity, inter-specific competition, and persecution by people; but few have been demonstrated in field studies (Myers, 1975b; Eaton, 1974; Caro, 1994; Gros, 1998; Marker et al., 2003).

My objective was to evaluate the cause of the reported cheetah population decline in the Nakuru Wildlife Conservancy, Kenya by focusing on changes in prey densities and landcover patterns as factors that may have resulted in habitat loss for cheetahs and their prey. Once the cause is determined, management recommendations can be made to mitigate or even reverse this trend. An explanation for cheetah declines and management recommendations to address it could be applicable to other predator populations as well.

Background

All continents except for Antarctica host populations of endangered or threatened carnivores. The red wolf (*Canis rufus*), polar bear (*Ursus maritimus*), and some populations of the mountain lion (*Puma concolor*) are found in North America. In Africa, most of the large cats are considered at least threatened, while the African wild dog (*Lycaon pictus*) is endangered. Asia is home to the snow leopard (*Panthera uncia*), dhole (*Cuon alpinus*), all endangered tiger (*Panthera tigris*) populations, and several other carnivore species such as the panda (*Ailuropoda melanoleuca*) and Himalayan black bear (*Ursus thibetanus*). South America is home to the vulnerable spectacled bear (*Tremarctos ornatus*) and the jaguar (*Panthera onca*), and several species of small felids (IUCN, 1996).

Large carnivores face threats from many different directions including habitat loss, direct and indirect conflict with humans, disease, and loss of genetic diversity. These problems are exacerbated as human populations grow and expand into new areas, changing the landscape and pushing carnivores into smaller and smaller areas. Conflict is increased as predators move into neighborhoods, encounter domestic animals, and compete with humans for resources and space. A major cause of population declines in carnivores is direct persecution by people. Wolves (Mech, 1995) and African wild dogs (Frank and Woodroffe, 2001) were considered vermin, and were subjected to government policies to systematically remove them from their ranges, even from national parks. Carnivores are also shot for control purposes to reduce depredation on livestock or to protect people from possible attacks. Lions (*Panthera leo*) are regularly shot, and spotted hyena clans (*Crocuta crocuta*) are poisoned in the Laikipia District of Kenya to protect livestock (Frank, pers. comm.). Increased contact with humans and their pets have affected carnivores by possibly increasing the incidence of diseases such as rabies, distemper, and parvovirus, causing devastating losses in certain populations. The domestic dog population adjacent to the Serengeti and Masai Mara National Parks in East Africa was implicated in the canine distemper virus outbreak that killed 30% of the lion population (Roelke-Parker et al., 1996). Finally, the fracturing of populations into isolated groups because of habitat fragmentation and loss has potentially increased the level of genetic homozygosity in some species and populations, making them less adaptable and more vulnerable to changes in the environment.

Features of Susceptibility

Large carnivores are especially susceptible to population pressures because of their biology and behavior. Carnivores usually maintain exclusive territories and exist naturally at low population densities. They also have low reproductive output, with long inter-birth intervals resulting in low recruitment rates into a population. Many species of carnivores such as the Florida panther (*Puma concolor coryi*) have low genetic diversity, making them even more vulnerable to changes in the environment and unable to adapt (Roelke et al., 1993). Finally, carnivores often come into conflict with people over competition for resources such as prey, livestock, and space (Sillero-Zubiri and Laurenson, 2001). As humans affect all species, this conflict can have profound effects on carnivores, because their populations are often regulated by the quantity and quality of available food resources.

Effects of Prey on Carnivores

Carrying capacity has been defined by Goss-Custard and Durell (1990) and restated by Sutherland and Anderson (1993) as “those cases where the addition of a further individual will result in the death or emigration of another.” By removing prey resources from a system, the carrying capacity is reduced, and fewer carnivores can be supported. The quality and quantity of prey resources available in an ecosystem can determine the fitness of the carnivores that depend on them; and can regulate the carnivore's density, distribution, and home range size (Fuller and Sievert, 2001; Sunquist and Sunquist, 1989; Kruuk, 1986). A decrease in the quality or quantity of available food can have both direct and indirect demographic effects. A lack of food can result in compromised physical fitness, leading to an increase in adult mortality. For example, a period of hare scarcity in parts of Canada coincided with high levels of adult lynx mortality, due at least in part to starvation (Poole, 1994). Low food abundance can also have indirect effects, compromising reproductive ability and the capacity to successfully raise offspring to independence. In San Joaquin kit foxes (*Vulpes macrotis mutica*), a decrease in prey biomass resulted in a decrease in reproductive success and in the density of adult foxes the next year (White and Ralls, 1993). Low prey densities affected the nutritional status of wolves and consequently they produced smaller litters (Boertje and Stephenson, 1992). Lion and cheetah mothers are both known to abandon cubs in times of food scarcity or when they have difficulty in securing sufficient prey (Hanby et al., 1995; Caro, 1994).

Prey densities also affect the space-use pattern of carnivores, by affecting home range configuration and territory size. Lions found in the Ngorongoro Crater of Tanzania, where prey resources are abundant year round, live at higher densities and have smaller ranges than their conspecifics on the Serengeti plains, where prey densities remain low except during the migration season (Hanby et al., 1995). Coyotes (*Canis latrans*) in Utah were shown to have larger territories and home-range sizes during periods of low prey abundance (Mills and Knowlton, 1991). When home ranges expand in response to a decrease in food or other resources, the density of carnivores found in any given area is consequently reduced.

Human-Predator Conflicts

One of the major causes of declines in carnivore populations is conflict with humans, resulting in both direct and indirect mortality due to exploitation, competition for resources, and the control of problem animals. The exploitation of carnivores for products and parts to sell on a commercial market and sport hunting has reduced some populations to alarmingly low numbers. Spotted cats have been exploited for their pelts while tigers and bears are killed for their bones and gall bladders, respectively, for use in Asian medicines (Sillero-Zubiri and Laurenson, 2001). Carnivores also face competition with humans for resources such as prey and space. In the past, humans have considered large carnivores such as wolves and pumas as competitors for game species, and have consequently removed them to increase game populations. For example, wolves are controlled through harvesting in interior Alaska to increase ungulate biomass (Boertje and Stephenson, 1992).

Space is also an issue, as large carnivores generally have large spatial requirements. Human population expansion is inevitably eroding the land available to carnivores, leading to the formation of small, isolated populations with reduced opportunities for gene flow. The conversion of natural areas to human-dominated landscapes characterized by agriculture, housing developments, livestock ranching, and other hostile uses of land further constrain movement and foraging. Carnivores and other wildlife species are often actively discouraged from using land under cultivation or around human settlement for fear of losing life, limb, or a source of income. Roads often intersect carnivore territories, resulting in barriers to dispersal and movement, fragmentation of habitat and mortality caused by collisions with vehicles (Smith, 1999; Sunquist and Sunquist, 2001). As humans and their domestic animals move into carnivore territories, increased levels of depredation can occur, resulting in the loss of carnivores killed for control purposes. In Nepal and Kenya, snow leopard (Oli, 1994) and lion (Frank, pers. comm.) populations are threatened due to their depredation on local livestock.

Factors Affecting Cheetah Declines

Cheetahs are as vulnerable to population decline as any other carnivore, perhaps even more so, because of the low density at which they are normally found. In one area of Namibia, home ranges varied from 800 km^2 for males to 1,500 km^2 for females (Morsbach, 1987). In the Serengeti, lions occur at a density 3-5 times greater than cheetahs while spotted hyenas live at densities 5-10 times greater (Laurenson et al., 1992). Interspecific competition has been implicated in the low cheetah densities found throughout their range. Because of this competition, cheetahs avoid areas where competitors are found, both temporally and spatially (Durant, 1998 and 2000). Cheetahs lose their kills to lions, hyenas and other competitors and are also killed directly by them (Myers, 1975a; Caro, 1994). In the Serengeti, 73% of the cheetahs that die before adulthood are killed by other carnivores, making predation the largest source of mortality for cheetahs in this area (Laurenson, 1994). Therefore, it has been suggested that the cheetahs' best chance for survival will be through conservation in areas outside of national parks as national parks are often refuges for the other large carnivores (Caro, 1994; Gros, 1998). Rangelands become the next best option as long as ranchers and other property owners can be convinced of the desirability of allowing these creatures on their land.

Another factor adding to the cheetahs' vulnerability is their genetics. O'Brien et al. (1986) report that of the 250 species that had been studied, "the cheetah has the least amount of genetic variety". The lack of genetic diversity makes the cheetah susceptible to stochasticity in the environment. While loss of genetic diversity has not been shown to cause declines in populations on its own (Caro and Laurenson, 1994), it can be a contributing factor if it keeps a population from adapting to a changing environment (O'Brien et al., 1985).

The current decline of cheetah populations has been attributed largely to habitat loss and a decline in prey densities (Caro, 1994; Marker-Kraus and Kraus, 1993; Myers, 1975b). While there have been many studies of cheetahs, few have looked at them outside national parks. The works of Caro (1994), Durant (1998, 2000), and Kelly, Laurenson and Fitzgibbon (1998) were done in the Serengeti. Eaton (1974) studied them in Nairobi National Park. Other studies concentrated on captive populations or populations under direct persecution by humans. Yet it has been stated that the cheetah's best hope for survival lies in their conservation outside of protected areas.

Cheetahs in Kenya face the same pressures as cheetahs in other parts of their range. Gros (1998) concluded that the population of cheetahs in Kenya has remained stable between 1970 and 1990, but these figures are based on comparisons of densities in two national parks. She also goes on to say that the majority of cheetahs in Kenya live outside of parks, so the conclusion she reached of a stable population may not be applicable to the majority of the population or the land they inhabit. The land inside national parks is unlikely to have changed extensively due to its protected status, whereas land outside of parks will more likely face pressures from a growing human population for conversion to human uses. The Nakuru area has experienced extensive growth in the last 17 years due to the growth of the flower industry and human population growth in general (Wykstra, pers. comm.). Most likely, a variety of factors are contributing to the decline in the cheetah population of Nakuru, but habitat loss affecting prey densities and the cheetah directly are probably the most significant contributors. As these issues have the potential to affect carnivores everywhere, any insight into their impacts would be beneficial for the development of management schemes addressing habitat loss and its effects.

Description of Problem

In 2000, members of the Nakuru Wildlife Forum (NWF), a group comprised of private and public land owners and managers who work together to make landscape level management decisions for the benefit of the Nakuru Wildlife Conservancy (NWC), contacted the Cheetah Conservation Fund in Namibia to express their concern about cheetahs in the NWC area. They had noticed a decline in the cheetah population and in wildlife numbers in general since the early 1990s, and were wondering what the cause of the decline could be. The Cheetah Conservation Fund (CCF) set up a satellite program in the Nakuru area of Kenya with the primary purpose of estimating the current cheetah population size and the cause of a decline, if it did in fact exist. The Nakuru-Naivasha area encompassed by the conservancy has experienced phenomenal growth in the human population with the growth of the commercial flower farm industry along Lake Naivasha. It has also experienced a large amount of growth in developed areas due to the infrastructure necessary to support the flower industry and the workers employed there. The large growth in the human population combined with the growth in developed areas are most likely having a negative impact on the wildlife found in the Nakuru Wildlife Conservancy area.

Purpose of Study

The purpose of this study is to evaluate the two leading hypotheses for the cause of the putative decline of the cheetah population in the Nakuru Wildlife Conservancy, Nakuru, Kenya. Factors most likely affecting the Nakuru population include changes in availability of their preferred prey species, and habitat loss or degradation, though other possibilities exist. I examined prey density data for the NWC and analyzed land use changes over the last 17 years as possible correlates of the purported reduction in the cheetah population. With this information, steps can be taken to stop or reverse the cheetah population decline, thus conserving them in the Nakuru area.

CHAPTER 2
STUDY DESIGN

Study site

This study was conducted throughout and immediately surrounding the Nakuru Wildlife Conservancy, a 350,000 acre area managed by the Nakuru Wildlife Forum and located in the Nakuru District of Kenya, NW of Nairobi (-0º 27' 54" latitude and 36º 12' 4" longitude) (Figure 1). A variety of land uses are found in the NWC, including cattle ranching, subsistence and commercial agriculture, flower farming for export, government holdings and three national parks. The third largest city in Kenya, Nakuru, is found just north of the northern end of the conservancy. Two other important towns in the area are Gilgil and Naivasha.

The area is mostly semi-arid savanna with grassland and leleshwa (*Tarchonanthus camphoratus*) and acacia (*Acacia* sp.) bushland. Forests of yellow fever acacia (*Acacia xanthophloea*) are found along the three lakes and rivers. There are two rainy seasons, the short rains fall in October and November while the long rains fall from March through June. NWC sustains a diverse wildlife community, though many of the large and destructive mammals have been killed or driven out of the area, including elephants and lions. Spotted hyenas are persecuted but they have managed to maintain a small but steady population.

The local people who make up the NWC suspected a decline in the population of cheetah and other wildlife in the last 15 years (1985-2000) and approached the Cheetah Conservation Fund (CCF) to determine the cause. An increase in the human density has occurred in the same time that the wildlife densities had decreased (Wykstra-Ross and Marker, pers. comm.). A survey conducted by Gros in 1990 (Gros, 1998) supports the idea that the cheetah population in Nakuru is declining. Currently, very little is known about the populations of cheetahs, their prey or of competitor species in the Nakuru area.

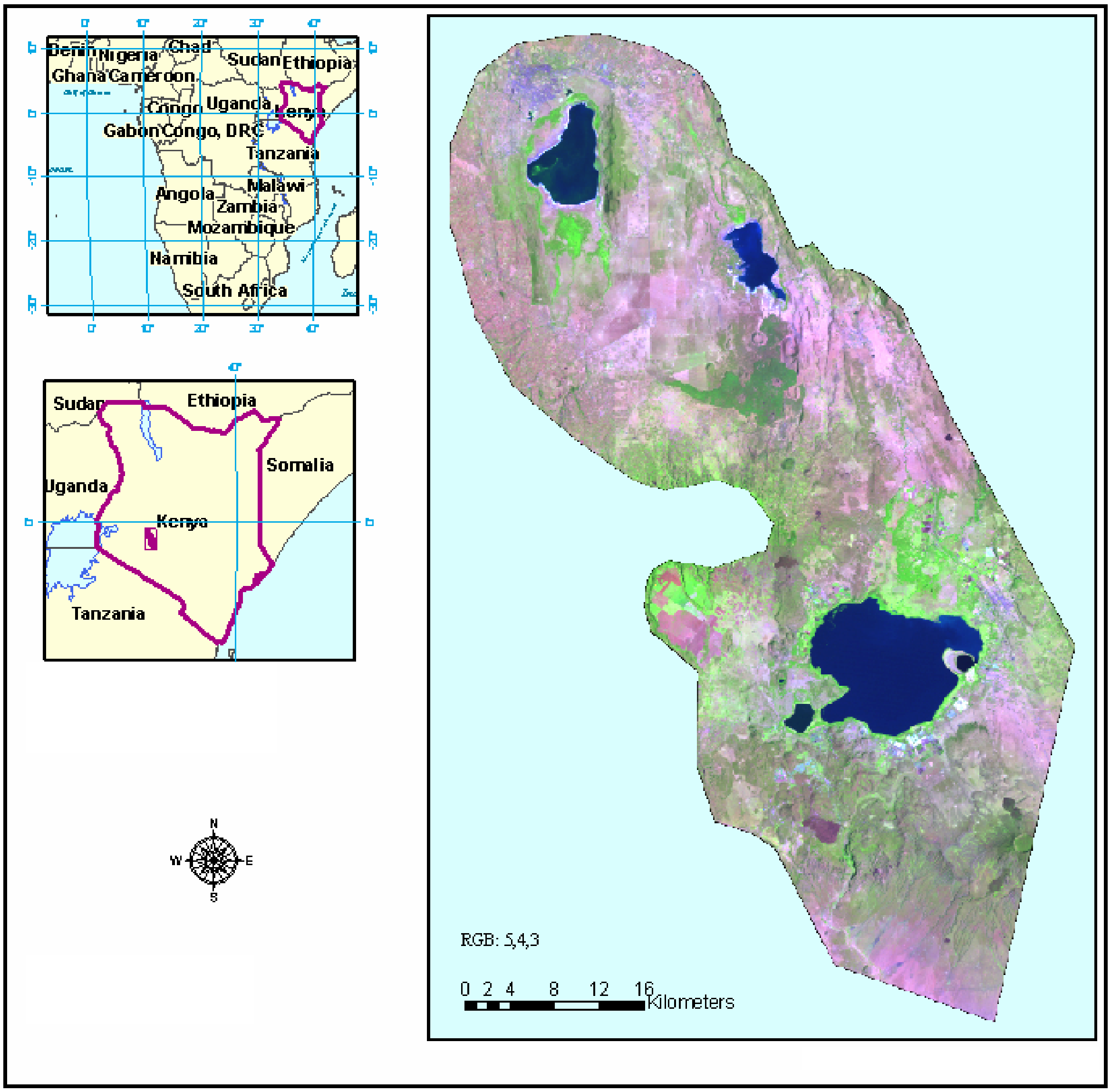


Figure 1. Map of the Nakuru Wildlife Conservancy, Kenya

Image Processing

To analyze and quantify landcover change, three Landsat satellite images from Path 169, Rows 60 and 61 were acquired representing the entire study area. The dates used for the analysis were 28 January 1986, 06 February 1995 and 04 February 2003. Care was taken to choose images with anniversary dates as close together as possible to minimize differences in spectral signatures of vegetation and other landcovers due to seasonal variation. While these dates did not fall within the time frame of field work, they were chosen due to their ease of acquisition and availability. Landsat images have a pixel size of 28.5 m x 28.5 m giving them a spatial resolution fine enough to distinguish details in the landscape that would be seen by cheetahs and their prey. All image processing was done in Leica Systems Erdas Imagine 8.6 unless otherwise indicated.

Image Acquisition and Pre-Processing

2003: The 2003 image is an Enhanced Thematic Mapper (1G) image (ETM+) from Landsat 7. The 1G designation indicates that the image has been radiometrically and geometrically corrected by USGS. The study site crosses two images but the image acquired from USGS had the two scenes mosaicked together. The image was reprojected into UTM WGS84 37S, to match the coordinate system of the points collected in the field. No further image pre-processing was done to the 2003 image and the final result was a 6 band image made up of three visible bands, one near infrared band and two mid-infrared bands. The band widths can be found in Table 1. The thermal and panchromatic bands were not included because I did not think they would add enough useful information. The 2003 image was used as the reference scene for geometrically and radiometrically correcting the 1986 and 1995 images.

Table 1. Bandwidths for Landsat 7 ETM+ and Landsat 5 TM satellite imagery

Band	ETM+	TM
1 (blue)	0.45-0.52	0.45-0.52
2 (green)	0.53-0.61	0.52-0.60
3 (red)	0.63-0.69	0.63-0.69
4 (NIR)	0.78-0.90	0.76-0.90
5 (MIR1)	1.55-1.75	1.55-1.75
7 (MIR2)	2.09-2.35	2.08-2.35

1986 and 1995: The 1986 and 1995 images are Thematic Mapper images from Landsat 5 downloaded from the University of Maryland Global Land Cover Facility. The two scenes that make up the study site were downloaded separately and mosaicked together using a feathering process to blend the areas of overlap. The images were geometrically corrected to the 2003 image using 50 to 60 points with a final RMS value of less than 0.25 pixel and reprojected to the same coordinate system as the 2003 scene. The histograms for all six bands of the 1986 and 1995 images were matched to the 2003 image and radiometric corrections were performed on both images using the method described in Jensen (1996) as multiple-date empirical radiometric normalization using regression to reduce differences between them and the 2003 image caused by atmospheric attenuation. Nineteen radiometric control points were chosen so that they fell on areas that did not change spectrally over time, generally permanent lakes, patches of bare soil, rock and roads. Digital numbers were recorded for bands 1-5 and 7 and a linear regression analysis performed on each. R^2 values were all greater than 0.9. Final equations and R^2 values are given in Table 2. The resulting equations were applied as the correction to the image.

Both images were subset to an area slightly greater than the boundaries of the Nakuru Wildlife Conservancy. I was unable to follow the exact boundaries of the NWC because I was not able to acquire information that would allow me to find them accurately enough on the image.

Table 2. Regression equations used to radiometrically correct the 1986 image to the 2003 image.

Band	Correction equation	R^2 value
1	y=0.943751x-30.2539	0.9240
2	y=1.529852x-16.0622	0.9298
3	y=1.212533x-11.2657	0.9061
4	y=1.030524x+2.8338	0.9506
5	y=0.582207x+5.1756	0.9685
7	y=0.778132x+6.0936	0.9400

Image Classification

All three scenes were classified separately using a combination of the supervised and unsupervised classification methods (Jensen, 1996). In principle, each landcover has a unique spectral reflectance in the bands that make up the image. These differences in spectral reflectance can be used to classify an image by selecting and grouping together those pixels with similar signatures. When doing a supervised classification, the user creates training signatures by defining training sites on the image which delineate known, homogeneous ground covers. Training sites are selected based on ground truthing data, shapes associated with specific ground covers and *in situ* knowledge of the area. Ground truthing data were collected in the field by recording the coordinates of landcover patches with a minimum size of 100 m x 100 m using a Garmin 76 GPS receiver. Other information collected included dominant vegetation type, ground cover type, open or closed canopy, and landuse where applicable. When a coordinate could not be taken from the center of the patch, distance and direction to the center of the patch were recorded.

In an unsupervised classification, the computer program divides the pixels into the specified number of classes based on spectral similarities without reference to outside sources of information. The steps outlined below describe the classification process for each of the three images. There were slight differences in the number of steps necessary for complete image classification between years.

- A normalized difference vegetation index (NDVI) was created from bands 3 and 4 to show differences in vegetation biomass. This calculation (B4-B3/B4+B3) has been shown to be useful in distinguishing land cover types with varying amounts of vegetation (Jenson, 1996).

- A tasseled cap analysis (TCA) was created to bring out land cover differences in brightness (layer one), greenness (layer two) and wetness (layer three). I discarded the other layers created by a TCA because they do not yield enough useful information.

- The NDVI and the first three layers of the TCA were stacked onto the original six-layer image resulting in a 10-layer image used in all subsequent analyses.

- A principal components analysis (PCA) was performed on the 10-layer image. The major components of the first principal component were band 5, the NDVI and the brightness layer of the TCA and accounted for over 95% of the variation in the images. A 3-class ISODATA unsupervised classification was performed on the PCA, set to 20 iterations and a convergence value of 95%. The resulting classes included water; areas of heavy, healthy vegetation (forest); and areas of low green biomass and high soil or senescent vegetation (savanna). The three classes were used to create masks to break the 10-layer image into two images to be further classified separately. Forest was left on its own while the water and savanna classes made up the second section.

- A 15 class ISODATA unsupervised classification was performed on the forest section following the parameters outlined above. Each of the resulting classes was inspected and placed into one of three categories: badland, bush or forest, based on their spectral signatures and knowledge of the area. Each category was recoded to 1, 2 or 3 and used to create masks to further break the forest image into 3 images to be further classified separately.

- Similar steps were followed for the savanna section of the original image except that a 20 class unsupervised classification was performed and the resulting classes placed into one of six categories: water, urban, bush, grass, baresoil and mud.

- At this point, some of the individual pieces were left as they were because they represented only one landcover type. The remaining pieces were either further subdivided by the method already outlined, or classified using a supervised classification scheme. Whether a supervised or unsupervised classification scheme was applied next depended on how many landcover types were represented in the piece.

- For the supervised classifications, training sites were taken from ground truthing data and familiarity with the area. They were created by outlining the edges of the training area or by using the area of interest (aoi) seed tool set to a spectral euclidian distance of 10. The aoi seed tool is used to collect neighboring pixels with similar spectral characteristics to create a training area. When the seed pixel is chosen, the program inspects each neighboring pixel to see if it is spectrally similar based on parameters set by the user. If a pixel is similar, the program then inspects the neighbors next to it. This continues in a stepwise process until all similar, neighboring pixels are selected or until the maximum number of pixels is reached.
- Once each piece was classified, they were recoded to one of 9 landcover types: developed, agriculture, bush, badland, open forest, closed forest, baresoil, grassland and water. Descriptions of types are given below.
- Finally, the pieces were mosaicked together using the maximum overlay function to produce the final, complete classified image.

A second set of classified images was created by collapsing the nine classes already created into three based on the ability of cheetahs to exploit them. These classes are as follows: suitable (grassland), marginal (bush, open forest and baresoil) and unsuitable (badland, closed forest, developed, agriculture and water). Further descriptions are given below.

The classified images were further processed to remove isolated pixels that were most likely misclassified and within a matrix of dissimilar pixels. An accuracy assessment of the 2003 image showed that this process did not improve overall accuracy but rather made it worse by about 3%. However, the 1986 and 1995 images had greater problems with isolated pixels and I believed that while removing them did not improve the 2003 image, it would improve the other classification. For this reason, I decided to reassign the class of all clumps less than 3 pixels in size to the value of the majority of surrounding pixels. The 2003 image needed to be processed in the same way to make comparisons between years possible.

The accuracy of the 2003 image was assessed by randomly selecting 256 points and determining their actual landcover based on field work and knowledge of the area. This was then compared to the classified image using the accuracy assessment function in Erdas Imagine 8.6.

The resulting four classified images were each analyzed separately using FRAGSTATS 3.3 to examine differences in classes between and within years. The following indices were used: (1) total area (ha); (2) number of patches; and (3) mean patch size (ha). Edge metrics were not considered because cheetahs are landscape species and are not confined to a single habitat type. They readily move between landcovers and exploit multiple habitat types.

Habitat Types

Representative signature histograms for eight of the nine landcover classes are shown in Figure 2. Agriculture was not included. Each crop will have a unique signature so graphing them would be difficult and uninformative. Figure 3 shows pictures of the different landcovers.

Closed forest: This landcover type is dominated by yellow fever acacia (YFA), *Acacia xanthophloea*, in the NWC area. It grows to 25 m in height and is most commonly found around lakes, rivers and in areas with high ground water and black cotton soil. YFA generally grows in single species stands. Other tree types that may be found in this landcover category include blue gum (*Eucalyptus globulus*), pine (*Pinus sp.*), euphorbia (*Euphorbia bussei, E. candelabrum* and other sp.), and deciduous mixed hardwoods, though YFA are by far the most common. The hardwoods are confined to hills and other areas that have not yet been exploited for agricultural or settlement purposes. Closed forests have an understory that is difficult to penetrate and which hinders movement. It is dominated by the shrub *Pluchea bequaertii*, a symbiotic species.

Open forest: Open forests are made up almost exclusively of YFA. It differs from the closed forest category in that the understory is dominated by grasses, forming an open, parkland landscape. Like the closed forest category, open forest is usually found near lakes, rivers and other waterways.

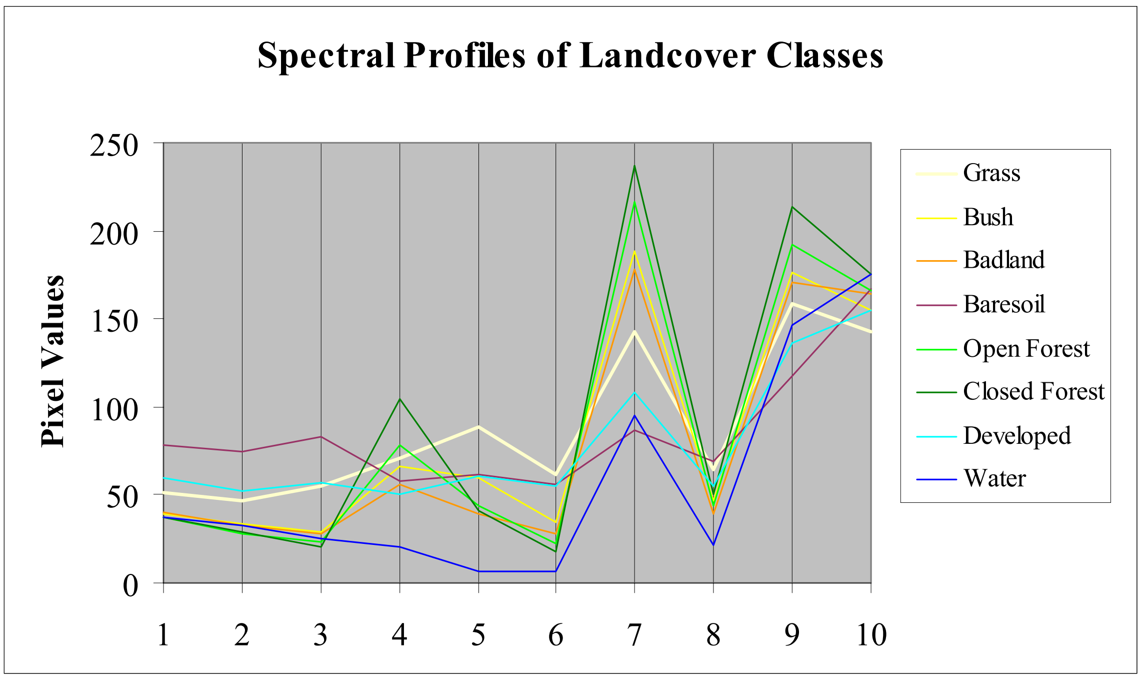


Figure 2. Spectral profiles of eight landcover classes

Grassland: Grassland areas are dominated by grass species with some low-lying herbaceous plants present. Much of this landcover type consists of dead biomass and patches of bare soil though green grass can be found around Lake Naivasha.

Bushland: Bushland areas are dominated by shrubs, bushes and low-lying trees interspersed with grasses and patches of bare soil. Bushland and grassland areas are continuous with varying proportions of bush to grass. The most common type of bushland found in the conservancy is mixed stands of leleshwa and acacia sp. with proportions varying in different areas. Other types of bushland include croton, grewia and rhus.

Agriculture: Agriculture is areas of landscape modified for the purpose of growing crops, either at the subsistence level or for commercial purposes. Agriculture areas may also contain some structures such as single-family homes, storage sheds or buildings used to support the industry.

Developed: Developed areas are landscapes consisting of extensive human modifications dominated by built structures where the landscape is unrecognizable from its original form. Examples include urban areas, villages, flower farms (greenhouses), roads, buildings and other similar structures.

Water: Lakes, rivers and streams.

Badlands: Badlands are areas of thick bush found specifically on old lava flows and other types of rocky outcrops. There are many species of bushes and herbaceous species that occur in this landcover type including *Aloe* sp., *Croton* sp., *Euphorbia* sp., *Acacia* sp., *Grewia* sp., *Rhus* sp. and others. Grasses in this type of landcover are sparse. Areas of badland are very difficult to penetrate due to the thickness of the bush and the spines and thorns associated with them.

Bare soil: Areas of bare soil include mudflats found around the lakes, degraded lands and cleared patches around urban areas.

The landcover types already described were further refined to give three land-use types relevant to cheetahs. The landcovers were placed in one of three categories: suitable, marginal or unsuitable.

Suitable: This category includes those areas where cheetahs are most likely to set up residence for an extended period of time. Cheetahs are creatures of the open plain. They are more particular about the areas they choose to live than other large African felids and require habitats that meet their unique needs. Two features high on the list of priorities are open space to see their prey and the room to run to attain the high speeds necessary for capturing prey. Grassland is the only classification that meets these two requirements. They are also the areas where game is most abundant. Grassland is the only landcover type that would be considered suitable for cheetahs.

Marginal: Marginal areas are those where cheetahs are known to be found but they support a lower density of preferred prey species, making them unable to support as large a cheetah population as found in grassland areas. Marginal areas can also be used by cheetahs as movement corridors. Land cover types that make up this category include bushland, badland, bare soil and open forest.

Unsuitable: These landcover types would be avoided by cheetahs and include developed, closed forest and agricultural areas. Cheetahs are shy creatures and avoid areas with high human presence as found in agricultural and developed areas. Closed forests and badlands would also be avoided as they would be too thick for a cheetah to easily pass through.

Prey Density Estimates

Data Collection

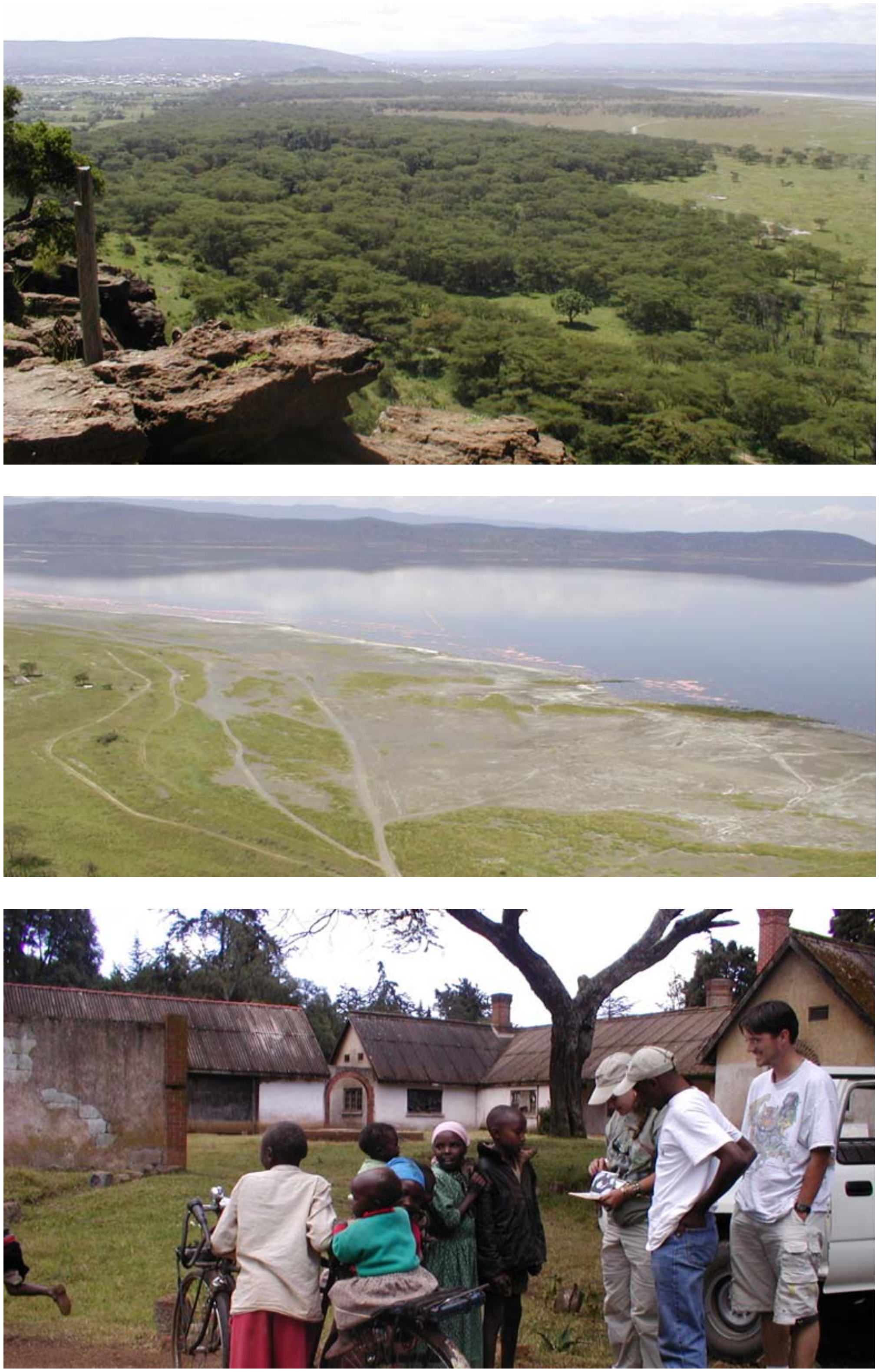
Information on the density of prey within different habitat types was collected using line transects. It was necessary to determine the density of potential prey species in the NWC to see if a decline in prey availability could account for the loss of cheetahs and to determine suitability of different land cover classes for supporting cheetahs. For this

A

B

C

Figure 3. Representative images of seven landcover classes. A) Grassland. B) Bushland. C) Open forest. D) Closed forest. E) Bare soil and water. F) Developed. All pictures taken by M. Evans



D

E

F

Figure 3. Continued

analysis, I began by conducting a series of transects using the protocols as described by Buckland et al. (2001) for use in the program DISTANCE 4.1 (Thomas et al., 2003), a computer program that analyzes transect data to determine animal densities. For DISTANCE to give accurate results, three fundamental assumptions must be met when designing and conducting the survey: (1) "Objects on the . . . line are always detected"; (2) "Objects are detected at their initial location, prior to any movement in response to the observer"; (3) "Distances (and angles where relevant) are measured accurately . . . or objects are correctly counted in the proper distance interval" (Buckland et al., 2001; pg 18).

I began by randomly choosing one thousand sets of geographic coordinates within and immediately surrounding the study area using the program ArcView 3.2 to meet another assumption of DISTANCE, that transects are laid out randomly. The points served the dual purpose of use as testing sites for the satellite image classification. I chose the large number because I knew not all points would be accessible or usable. I also did not have exact coordinates for the study site and knew some of the points would fall outside of the NWC. One thousand compass points were then randomly chosen by the program Microsoft Excel and paired with the geographic coordinates. Three habitat types were censused with transects including grass, bush and open yellow fever acacia forests. These habitat types were most likely to be used by cheetahs based on their vegetative structure and potential prey populations. Other habitat types available in the area were either too developed or too thick to be included in the census. I decided that the likelihood of a cheetah using a developed or agricultural area regularly was low enough that I could safely classify those areas as unsuitable without doing prey transects in them. It was also very clear that developed areas had high human densities and generally low wildlife densities. Natural areas that were not censused included badlands and forests with thick undergrowth where it would be impossible to ensure that assumptions one and two were not violated, and where safety from buffalo was a concern. These are also areas cheetahs are not known to inhabitat.

Transects were conducted in suitably large patches of individual habitat that could possibly be used by cheetahs, with the starting point determined by the random point closest to an edge of the habitat. Walking direction was determined by the compass direction associated with the starting point. On at least one occasion, the perpendicular direction was used due to ease of walking. At least two observers were used at all times. When an animal of interest was sighted, information on species, number (cluster size), sex, age, UTM position of observer, distance from observer (transect line), and angle from north was recorded. Distance and angle were recorded to where the animals were first sited. Angles from north were later converted to angle from the line. Transects were walked at a speed of 1-2 km per hour from one end of the habitat type to the other, at which point a parallel line was walked in the opposite direction, offset from the first by 200-500 meters, depending on line of sight distance.

This process was repeated until the entire habitat area was covered, or until it became too dark to continue. Care was taken to avoid double counting animals on different transect legs. It was noted whether or not groups moved in the direction of the next transect leg. If so, then any group with a similar size and composition found on the next leg was not counted. This was rarely an issue.

Thirteen transects were walked for a total of 19.4 km in grassland habitats and 35.9 km in bush/ open forest habitats. Transects were walked in the early morning hours starting at about 6:30 hour or in the afternoon starting at about 16:30 hour. These are the times when wildlife is most active and therefore most likely to be seen. It is also when cheetahs most actively hunt. Transect data were analyzed using the program DISTANCE.

The species censused were those found in the area and known to be preyed upon by cheetahs. They included zebra (*Equus burchelli*), eland (*Tragelaphus oryx*), waterbuck (*Kobus ellipsiprymnus*), kongoni (*Alcelaphus buselaphus*), thompson's gazelle (*Gazella thomsoni*), grant's gazelle (*Gazella granti*), impalas (*Aepyceros melampus*), warthogs (*Phacochoerus aethiopicus*), hares (*Lepus capensis*), guinea fowl (*Numida meleagris*), steenbok (*Raphicerus campestris*) and dik dik (*Madoqua kirkii*) (Graham, 1966; McLaughlin, 1970; Eaton, 1974; Burney, 1980, Frame, 1986; Caro, 1994). Thompson's gazelle, grant's gazelle and impalas are considered primary prey species for this study as they represent between 62% and 75% of cheetahs' diet in studies conducted in Kenya (McLaughlin, 1970; Eaton, 1974; Burney, 1980).

DISTANCE Analyses

Data required for DISTANCE to do the analyses include transect number, cluster size, radial angle from line (this was calculated based on angle of the line from north), distance from line and total length of transect. Total length of transect was calculated by adding up the lengths of the individual legs of each transect. All analyses were based on cluster size as most of the species recorded occurred in groups rather than as individuals. Counts in open YFA and bush were pooled together as there were not enough sightings in either habitat type to give good results. Also, the habitats had similar characteristics.

The sightings were divided into different groups based on body size and habitat. Groups analyzed included: large herbivores (>40 kg) in grass, large herbivores in bush, thompson's gazelle in grass and bush, impala and grant's gazelle in grass and bush, small herbivores (<12 kg) in grass and bush and preferred prey in grass and bush. Large herbivores included zebra, eland, waterbuck and hartebeest. Small herbivores included hares, dik dik, steinbok and guinea fowl. Warthogs were censused but not included in the analyses as they did not fit easily into any of the categories and there were not enough of them to analyze separately. DISTANCE assumes that the animals being counted have the same probability of detection if they are being analyzed together. I believe that this assumption is not violated with the groupings I have made as the species in each group are "of similar size and provide similar visual cues" (Buckland et al., 2001: pg 302).

For the analyses, a natural log transformation was applied in DISTANCE to the cluster size for all groupings because of the large variation seen in cluster size between groups. The transformation reduces the influence of a few large cluster sizes on the estimation of density. For those analyses done on groupings in the bush, perpendicular distance from the line, yi, was replaced with g(yi) in the regression. "G(yi) is the estimated detection function from the fit of the selected model to the distances from the line or point to detected clusters." (Buckland et al., 2001). This corrects for the problem of a shoulder in the detection function where "mean cluster size does not increase with distance until detection distance exceeds the width of the shoulder." (Buckland et al., 2001). The same correction was not applied to the groupings in grass habitats because detection did not vary with distance due to the nature of the terrain. Only the small bush group was truncated 5% at the right tail due to some distant outliers that made modelling the regression line problematic.

Five models were run for each of the groupings and Akaike's information criterion (AIC) values compared to choose which model gave the most robust results. In those instances where AIC values differed by less than two, model choice was also based on goodness of fit tests provided by DISTANCE. Those models in each of the groups with the lowest AIC values and the best fit were chosen to report results (Table 3) (Buckland et al., 2001).

Table 3. DISTANCE models used in analyses

Key function	Series expansion
Uniform	Cosine
Uniform	Simple polynomial
Half-normal	Cosine
Half-normal	Hermite polynomial
Hazard-rate	Cosine
Hazard-rate	Simple polynomial

Differences in densities between bush and grassland habitats for each group were tested using a T-test as described in Buckland et al. (2001). The biomass of preferred prey species in each habitat type was calculated from the density. The total biomass for the group was calculated by multiplying the density estimate for the group by the average body mass of the group. Average body mass was calculated by multiplying the number of times a species was seen in a habitat by that specie's average body mass as reported by Schaller (1972) and Caro (1994), adding up the body masses for all individuals and dividing the total by the total number of animals from that group.

Potential Cheetah Population Size

The potential number of cheetahs the NWC could support was calculated using two methods. I used the regression equation of Gros et al. (1996) to predict cheetah biomass per unit area based on prey biomass (y = 0.002x + 0.21) in the Nakuru area. I also followed Emmons (1987) by assuming that 70% of a prey individual was edible and that cheetahs could take 10% of the prey population per year. I divided the resulting available biomass by a cheetah's average yearly food requirement (calculated from the average daily requirement of 4 kg/day (Schaller, 1972)) to again determine the potential cheetah population size for the NWC.

NWF and LNNP Counts

The Nakuru Wildlife Forum has conducted biannual game counts since October of 1996 throughout the conservancy area, with the exception of 2001. Counts on all properties are conducted on the same day at the same time to reduce the possibility of double counting animals. The different properties are divided into blocks based on configuration of roads, vegetation and area to be covered. Teams of counters consisting of at least one driver, one spotter and one recorder drive through each block and get total counts of all mammal species encountered. Except for some Lake Nakuru National Park (LNNP) counts, information about sex or age of animal, and vegetation type is not recorded. The block counts are later compiled into total counts for each property and for the total conservancy to track changes in game counts over time. Only the fall counts were used for this study. There was some evidence of biannual fluctuations in animal numbers so only those counts that coincided with the timing of the density counts were used. Because the number of properties participating in the counts, and thus the total area surveyed, varied over time, total counts of wildlife numbers could not be used for comparison purposes. Instead, yearly average density was calculated by dividing the total number of animals counted throughout the survey by the total area surveyed. In order to detect statistically significant changes in density, average density was regressed against year using Microsoft Excel. Individual species were tested as well as preferred prey as a group and large prey as a group. Small prey were not tested. Not all of the species included in the DISTANCE analyses were counted as part of the forum counts. Also, forum counts are usually conducted from a vehicle rather than on foot, reducing the likelihood of accurately counting small mammals.

CHAPTER 3
RESULTS

Classification

The final classifications for the 1986 and 2003 scenes can be seen in Figures 4 through 7. The 1995 classification was not included because the results of the classification did not make sense, which I think is related to problems with the classification itself rather than actual landcover changes. The overall accuracy for the nine class 2003 classification was 70.3%. Kappa statistics and producers and users accuracy are summarized in Tables 4 and 5. The errors associated with the classification occurred between grass and bush, grass and agriculture, closed forest and open forest, urban and baresoil, and bush and open forest. Forty of 76 misclassified points occurred between grass and bush. These are continuous habitat types and defining where the cutoff between grass and bush occurs spectrally was difficult. I'm sure that those areas of pure bush or pure grass were correctly classified, but areas with sparse bush or thick grass are the areas most likely to have been classified incorrectly. Six of the misclassifications occurred between grass and agriculture. A common crop grown in the NWC is wheat, making grass and agriculture easy to separate when creating training sites based on shape of agricultural plots, but difficult to separate spectrally. Their signatures were quite similar and therefore often confused in the final classification. Bare soil in the NWC is often very lightly colored, and local soils can be used as building materials, making the spectral signatures for these classes similar. It was impossible to sufficiently separate developed from baresoil areas despite repeated attempts, especially along lake shores.

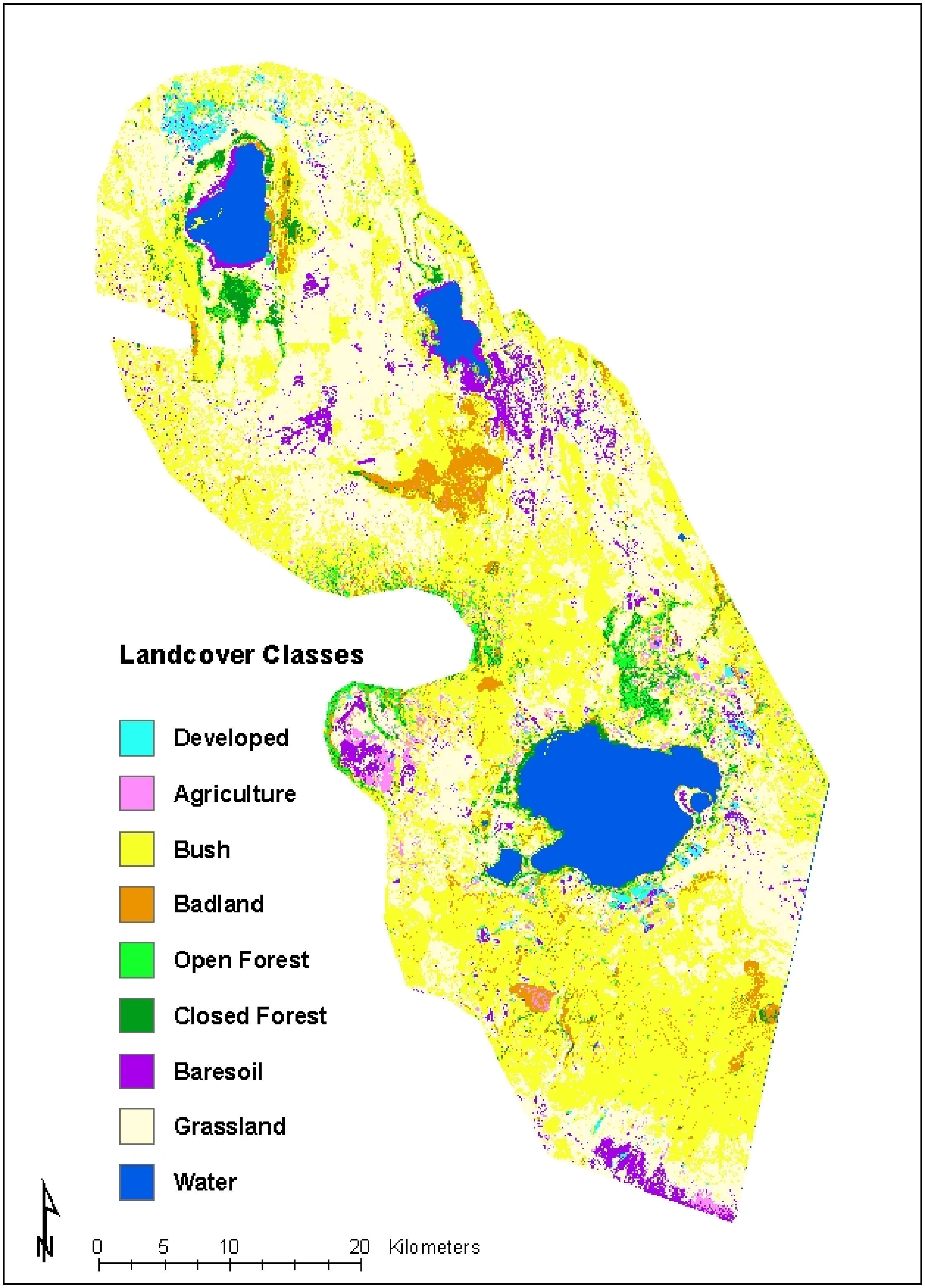


Figure 4. 2003 landcover classification. Enhanced Thematic Mapper image of Nakuru Wildlife Conservancy, Kenya, 04 February 2003.

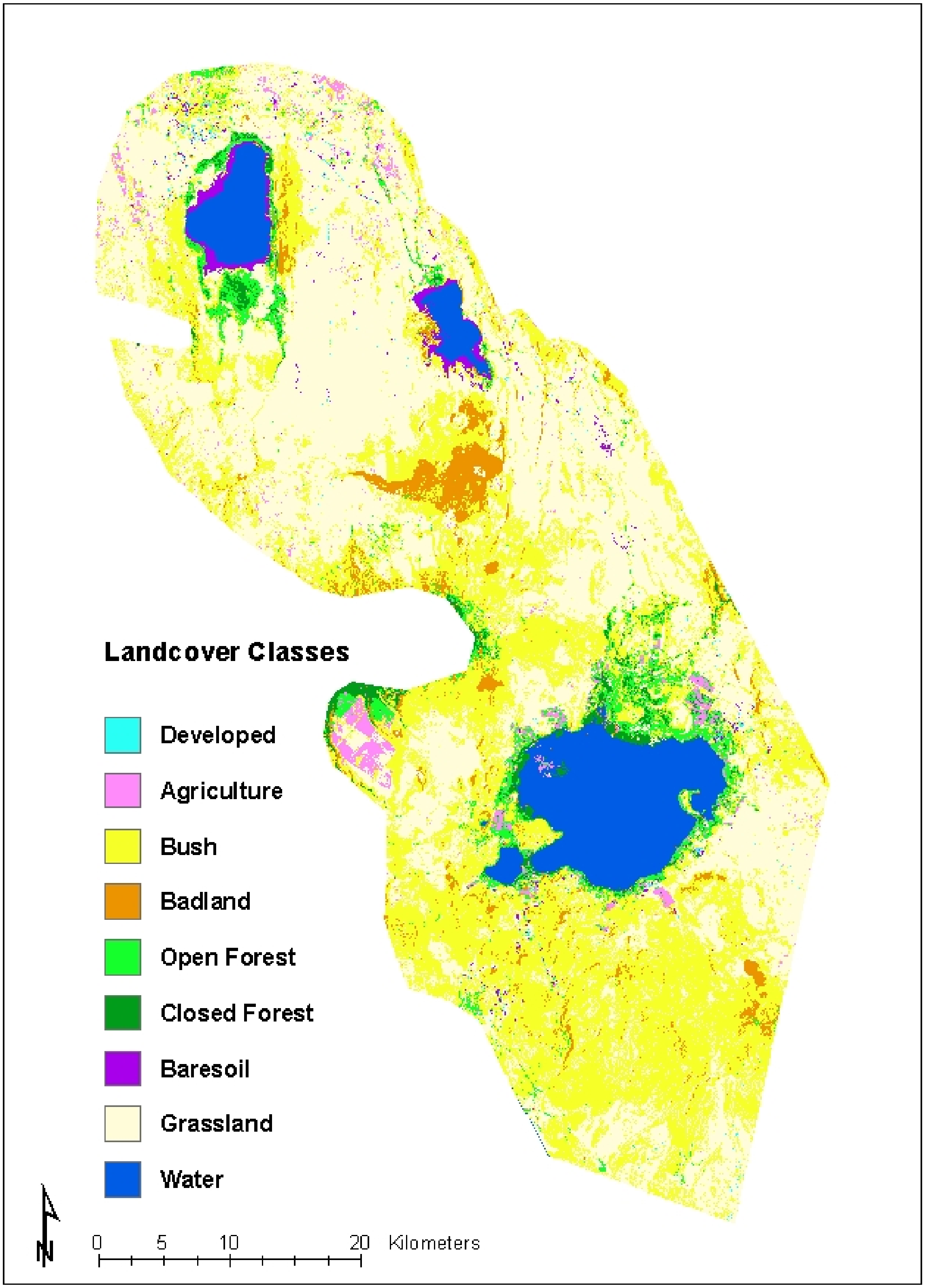


Figure 5. 1986 landcover classification. Thematic Mapper image of Nakuru Wildlife Conservancy, Kenya, 28 January 1986.

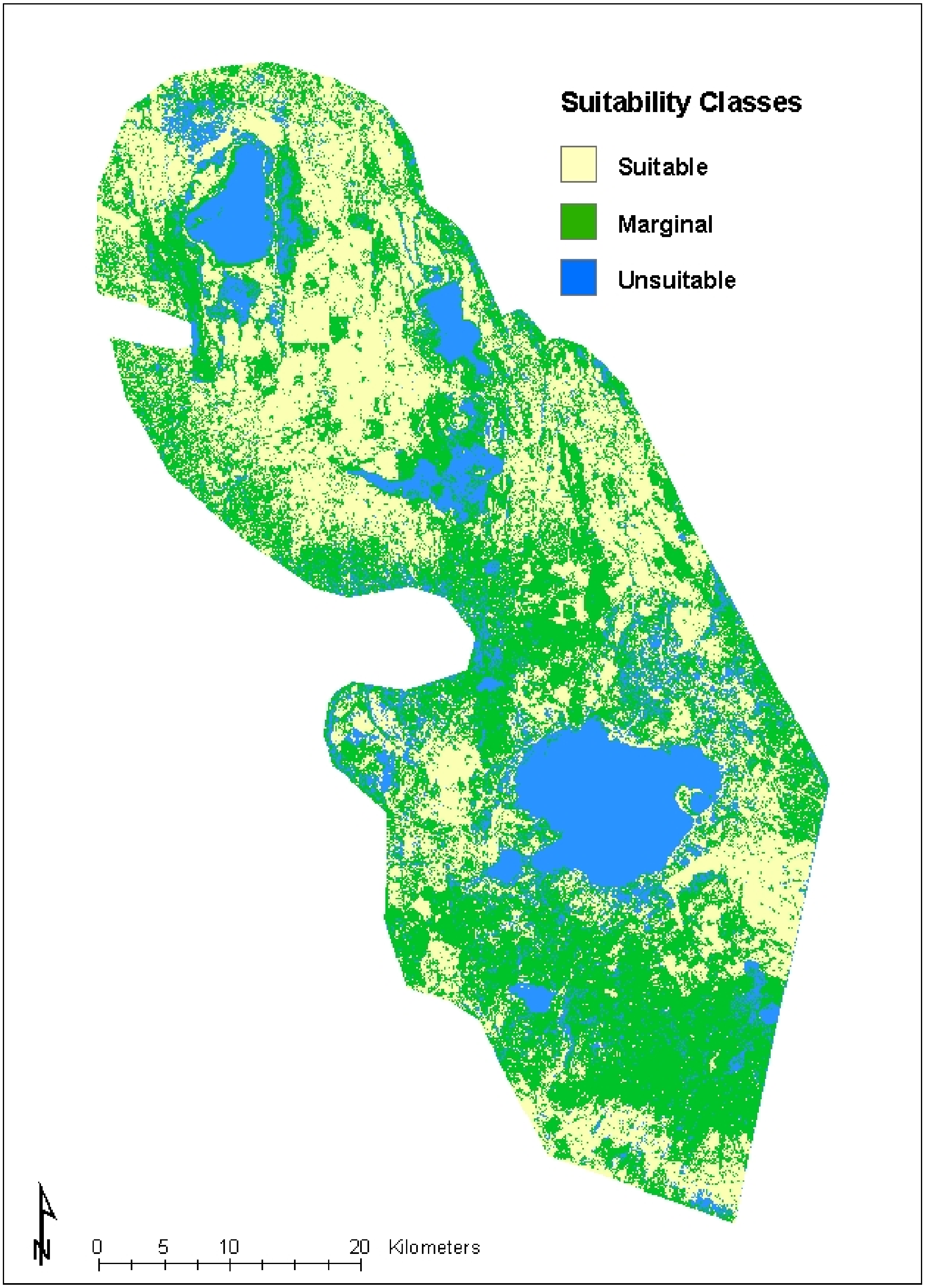


Figure 6. 2003 suitability classification. Enhanced Thematic Mapper image of Nakuru Wildlife Conservancy, Kenya, 04 February 2003.

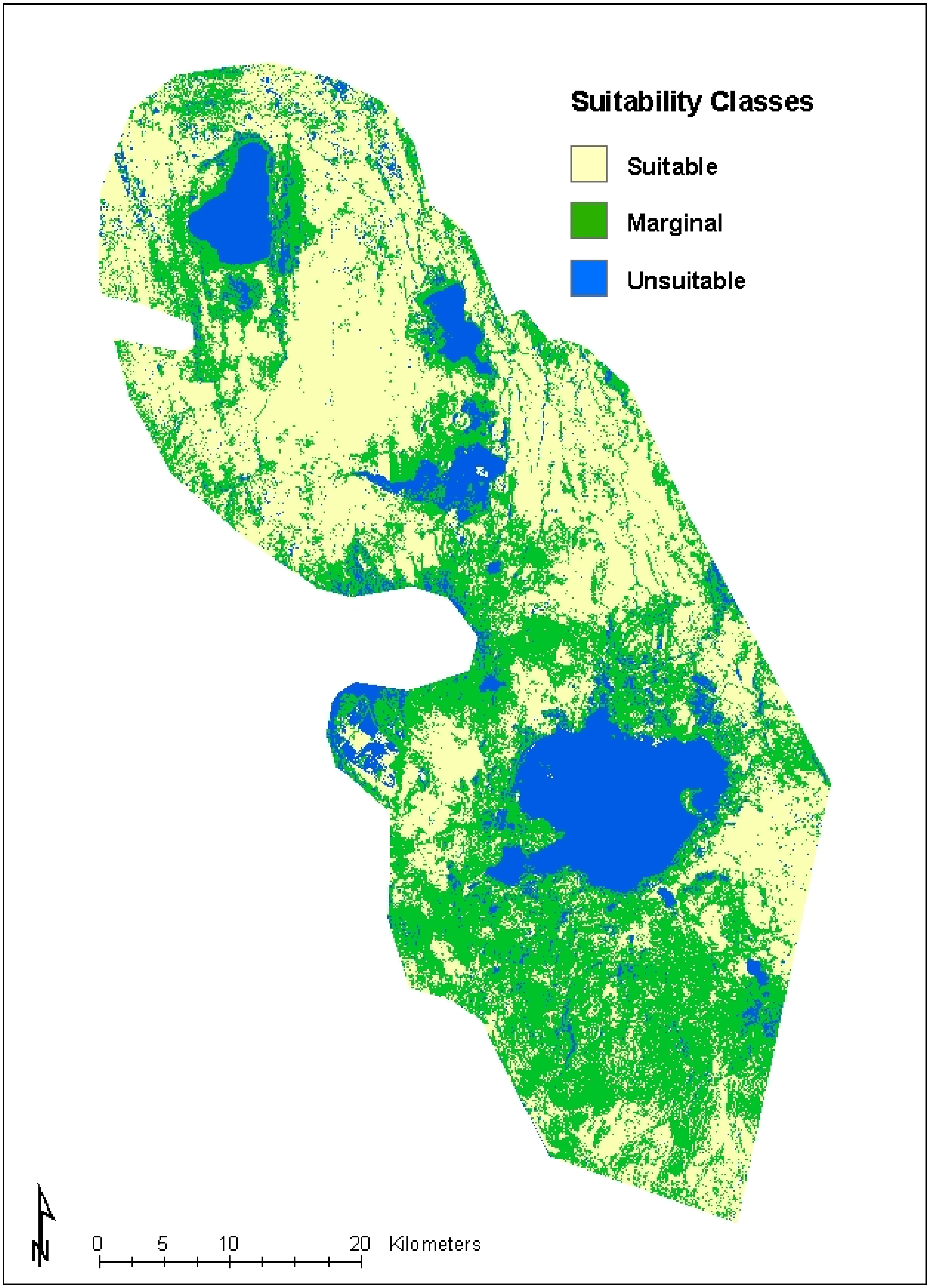


Figure 7. 1986 suitability classification. Thematic Mapper image of Nakuru Wildlife Conservancy, Kenya, 28 January, 1986.

The problem with closed forest vs. open forest is similar to grass vs. bush. These landcover classes occur along a continuum. Also, if open forests have a closed canopy, they could easily be confused with closed forest. Eleven of the misclassifications occurred between bush and open forest. Confusion between these landcover classes is not surprising considering the similar make up of green trees/ bushes interspersed with grass.

The overall accuracy for the three-class 2003 classification was 73.8%. The problems with this classification were similar to those for the nine class classification, most notably the misclassification of bush and grass resulting in the misclassification of the suitable and marginal habitats.

Table 4. Accuracy results for 2003 landcover classification

Overall accuracy: 70.3%
Kappa Statistic: .5824

Class	Kappa	Producers Error	Users Error
1	0.6640	100.00	66.67
2	0.5803	25.00	60.00
3	0.4967	74.51	69.72
4	0.8951	75.00	90.00
5	0.8437	27.27	85.71
6	0.2411	33.33	25.00
7	0.8280	62.50	83.33
8	0.4800	77.63	63.44
9	1.0000	100.00	100.00

Table 5. Accuracy results for 2003 suitability classification

Overall Accuracy: 73.8%
Kappa Statistic: .5766

Class	Kappa	Producers Error	Users Error
1	0.4611	77.63	62.11
2	0.5871	72.73	80.00
3	0.7899	70.83	82.93

Landcover Change

Habitat suitable for cheetah and its prey decreased between 1986 and 2003 from 113,970 ha (46.5% of the landscape) to 95,969 ha (39.1% of the landscape), respectively. This is a loss of 18,001 ha, or 15.8% of suitable landscape in a 17-year period. During this same time, marginal lands increased from 94,891 ha (38.7%) to 108,843 ha (44.4%), an increase of 13,952 ha, or 14.7%. Unsuitable area also increased, from a low of 36,202 ha (14.8%) in 1986 to 40,339 ha (16.5%) in 2003, an increase of 4,137 ha, or 11.4%. The increase in marginal areas was due to a growth of the bush class and a large increase in the bare soil class that comprised the marginal category. Bush increased by 10,654 ha (12.9% increase) while bare soil increased by 6,934 ha, an increase of 290%. The increase in unsuitable areas was due mostly to an increase in developed areas, from 562 ha to 2,517 ha, an increase of 349%. Table 6 summarizes landcover changes between 1986 and 2003.

There were also changes in patch dynamics over the 17-year period. The average size of grassland and suitable patches, calculated as the sum of the area of all patches of a particular type divided by the total number of patches of that type, decreased between 1986 and 2003. Grassland patch size decreased from 16.04 ha to 13.8 ha. The number of patches for this class remained about the same between years (1986: 7,158; 2003: 7,084). Suitable patches decreased from 15.4 ha to 12.4 ha. The number of patches also remained about the same for this category (1986: 7,391; 2003: 7,744).

The marginal category saw an increase in the number of patches, from 7,958 to 9,360, but the average size of the patches remained about the same (1986: 11.92 ha; 2003: 11.62 ha). Within the marginal category, the number of patches of bush decreased (9,354 to 7,865) but the average size of those patches increased (8.85 ha to 11.88 ha), possibly indicating the consolidation and growth of patches originally found in 1986. Baresoil patches stayed about the same size (1986: 2.55 ha; 2003: 2.50 ha) but there was a dramatic increase in the number of them, from 939 to 3,736.

For the unsuitable category, average patch size decreased from 5.36 ha to 3.86 ha, but the number of patches increased from 6,758 to 10,440. Urban areas increased in patch numbers (1986: 934; 2003: 1,380) and in average patch size (1986: 0.60 ha; 2003: 1.82 ha) (Table 7).

Table 6. Landcover change in the Nakuru Wildlife Conservancy, (NWC), 1986 to 2003

Landcover class	1986 (ha)	2003 (ha)	Change (ha)	% Change
Suitable	113975	95969	-18006	-15.80
Grassland	114824	97767	-17057	-14.85
Marginal	94909	108843	13934	14.68
Bush	82822	93461	10640	12.85
Baresoil	2388	9324	6935	290.39
Open forest	8954	5416	-3538	-39.52
Unsuitable	35777	40339	4562	12.75
Developed	561	2517	1956	348.75
Agriculture	4351	3930	-421	-9.68
Badland	7876	9196	1321	16.77
Closed forest	3569	5165	1596	44.72
Water	19316	18376	-941	-4.87

Table 7. Class metrics for the 1986 and 2003 classifications

Landcover class	1986 Number of patches	2003 Number of patches	1986 Average patch size (ha)	2003 Average patch size (ha)
Suitable	7391	7744	15.42	12.39
Grassland	7158	7084	16.04	13.80
Marginal	7958	9360	11.92	11.63
Bush	9354	7865	8.85	11.88
Baresoil	939	3736	2.55	2.50
Open forest	2954	4963	3.03	1.09
Unsuitable	6758	10440	5.36	3.86
Developed	934	1380	0.60	1.82
Agriculture	3188	4066	1.37	0.97
Badland	2551	4892	3.16	1.88
Closed forest	1107	2582	3.22	2.00
Water	35	101	558.60	181.94

Prey Densities

The density of preferred prey species in grassland habitats was estimated to be 0.628 animals per hectare (95% CI = [0.422, 0.934], CV = 18.7%). In bushland habitat the density estimate was 0.147 animals per hectare (95% CI = [0.048, 0.454], CV = 57.3%). The preferred prey density estimates are significantly higher in the grassland habitat than in the bushland areas (T = 3.328, P<0.003). Prey densities for individual species that make up the preferred prey group are also significantly different between the two habitat types. Thompson's gazelles are found at a density of 0.442 individual per hectare (95% CI = [0.273, 0.715], CV = 22.0%) in grass and 0.068 individuals per hectare in bush (95% CI = [0.022, .207], CV = 57.4%) (T = 3.532, P =0 .003). Impala and grant's gazelle were analyzed together. Their density in grass was 0.190 individuals per hectare (95% CI = [0.096, 0.374], CV = 33.9%) and 0.042 individuals per hectare in bush (95% CI = [0.010, 0.174], CV = 73.0%) (T = 2.080. P<0.05). The large prey and small prey groups did not have statistically significant differences in densities between grass and bush. A summary of density estimates for all groups can be found in Table 8.

Table 8. Density estimates for prey species in grassland and bushland habitats.

	Habitat					
	Grass			Bush		
Species/ Group	Density (ind./ha)	CI	CV (%)	Density (ind./ha)	CI	CV (%)
Preferred prey*	0.628	0.422, 0.934	18.7	0.147	0.048, 0.454	57.3
Thompson's gazelle*	0.442	0.273, 0.715	22.0	0.068	0.022, 0.207	57.4
Grant's gazelle and impala*	0.190	0.096, 0.374	33.9	0.042	0.010, 0.174	73.0
Large prey	0.138	0.070, 0.271	34.4	0.097	0.045, 0.207	36.5
Small prey	0.147	0.035, 0.613	68.3	0.342	0.180, 0.649	31.1

* indicates statistically significant differences between grassland and bushland densities.

The large coefficient of variation seen in some of the density estimates is due to a low number of sightings of individuals in those groups. It is also due to the patchy distribution of individuals in the habitats. Some species were counted on some transects but not on others. For example, thompson's gazelles were counted on all transects for the grassland areas but were missing from three transects conducted in bush. This pattern was also found for large prey. Grant's gazelle and impala were missing from five bush transects but were counted on all grass transects. DISTANCE gives unbiased results even with low sighting numbers so the results are valid. Though significant differences were not found in the group densities of large prey and small prey between habitat types, this could be due to the large CV. More transects may have reduced the coefficient of variation and pulled out differences in these groups, especially the small prey groups. However, the small prey that make up the group have an average body mass of less than 4 kg. Even if there were significant differences in densities, it is unlikely that the differences in biomass between habitats, when combined with the other groups, would be enough to significantly impact a cheetah's decision to exploit grassland versus bushland areas.

The biomass of preferred prey in suitable areas is 1505 kg/km^2 (95% CI = [1011, 2238]). The biomass of preferred prey in marginal areas is 384 kg/km^2 (95% CI = [125, 1186]). Using Gros et al. (1996), in 1986, the NWC could support a potential cheetah population of 73 (51-107) individuals in suitable areas and 19 (9-49) in marginal areas for a total of 92 (60-156) cheetahs. In 2003, suitable areas could support 62 (43-90) individuals while marginal areas could support 21 (10-56) individuals for a total population of 83 (53-146) cheetahs.

Using the method espoused by Emmons (1987), suitable areas could support 85 (57-127) cheetahs while marginal could support 18 (6-56) in 1986 for a population total of 103 (63-183). In 2003, the potential cheetah population size in suitable areas was 72 (48-107) individuals and 21 (7-64) in marginal areas for a total of 93 (55-171) cheetahs (Table 9).

Table 9. Potential cheetah population estimates as predicted by prey biomass.

Method	Year	Habitat					
		Suitable	(range)	Marginal	(range)	Total	(range)
Gros et al.	1986	73	(51-107)	19	(9-49)	92	(60-156)
(1996)	2003	62	(43-90)	21	(10-56)	83	(53-146)
Emmons	1986	85	(57-127)	18	(6-56)	103	(63-183)
(1987)	2003	72	(48-107)	21	(7-64)	93	(55-171)

Prey Density Changes Over Time

In no instances did population densities increase between 1996 and 2003. Rather, all populations exhibited a decrease of some degree, though regression analyses of changes in prey density indicate a significant decline in only two instances. There has been a significant decline in the density of preferred prey since 1996 from a density of 0.2097 animals per hectare to 0.1207 per hectare (R2 = 0.661, slope = -0.0171, SE = 0.0061). This is due mostly to a decline in thompson's gazelle from 0.1186 animals per hectare to 0.0678 per hectare (R2 = 0.749, slope = -0.0088, SE = 0.0025). Trends for other species were not significant at the 0.05 level. Three trends: large prey, impala and kongoni, were significant at the 0.1 level (large prey: R2 = 0.623, slope = -0.0185, SE = 0.0072; impala: R2 = 0.592, slope = -0.0051, SE = 0.0021; kongoni: R2 = 0.638, slope = -0.0052, SE = 0.0020). A summary of the results for all analyses are given in Table 10. It should be noted that grant's gazelle are often mistaken for thompson's gazelle, so the absolute numbers reported in the census may over-represent thompson's gazelle and under-represent grant's gazelle. However, thompson's gazelle are more common, and I doubt that misidentification occurs often enough to significantly change the results. As more counts are conducted in the NWC area, incidences of significant declines in species may increase. Also, the results from the forum counts should be viewed with some caution. They are designed to count all animals within the census area, but the accuracy of the method is not known, nor is the detection probability for the different species being censused. There is no way of knowing what proportion of individuals of each species is missed in the counts. Also, the participants and their level of experience vary from year to year, and there is no way to evaluate inter-observer differences either within or between years. However, the same methods are applied for every count, therefore the results should be comparable and trends over time should be indicative of overall changes.

Table 10. NWC wide prey density estimates and regression analyses of density changes.

	Density estimates (ind./ha)						R^2	Slope	SE
	1996	1997	1998	1999	2000	2002			
Preferred prey**	0.2097	0.2261	0.1398	0.1272	0.1398	0.1207	0.6610	-0.0171	0.0061
Thompson's gazelle**	0.1186	0.1224	0.0819	0.0830	0.0867	0.0678	0.7492	-0.0088	0.0025
Impala*	0.0715	0.0655	0.0479	0.0353	0.0427	0.0434	0.5918	-0.0051	0.0021
Grant's gazelle	0.0197	0.0382	0.0100	0.0089	0.0104	0.0095	0.3554	-0.0032	0.0021
Large prey*	0.1785	0.1983	0.1054	0.0799	0.1004	0.0854	0.6227	-0.0185	0.0072
Zebra*	0.1189	0.1223	0.0697	0.0598	0.0714	0.0613	0.6348	-0.0106	0.0040
Eland	0.0187	0.0296	0.0158	0.0073	0.0132	0.0109	0.4060	-0.0023	0.0014
Kongoni*	0.0313	0.0388	0.0129	0.0057	0.0094	0.0061	0.6376	-0.0052	0.0020
Waterbuck	0.0096	0.0076	0.0070	0.0071	0.0064	0.0071	0.5118	-0.0004	0.0002

**indicates declines which are statistically significant at the 0.05 level. *indicates declines which are statistically significant at the 0.10 level.

CHAPTER 4
DISCUSSION

Cheetah Population Trends

In 1975, Myers (1975b) estimated the population of cheetahs to be about 15,000 animals throughout their range, possibly half the population size from the 1960's. The Kenya population at that time was estimated to be less than 2,000 animals and under pressure from loss of habitat due to exploitation of rangelands for agriculture and livestock ranching. Gros (1998) estimated, based on available habitat and prey densities, the potential Kenya cheetah population at 10,000, but the actual number was probably closer to 1,000 to 2,000 animals. According to Gros (1998), the Kenya population overall has most likely remained fairly stable. However, in the Nakuru area, the cheetah population appears to have declined. In 1990, Gros (1998) estimated the population to be around 35 animals based on interviews, with the majority of the respondents reporting a decrease. Using the same interview technique in 2002, the Cheetah Conservation Fund reported the Nakuru cheetah population to be about 12 animals (Wykstra, pers. comm.). The interview technique has been shown to be the most reliable indirect method for estimating densities of large carnivores (Gros et al., 1996).

Using the averaging technique (Gros et al., 1996), Gros estimated the cheetah population within Lake Nakuru National Park to be about three animals. In 1996, KWS counted two cheetahs within the park during one of their triannual censuses. One cheetah was counted in 1997. Since then, no confirmed cheetah sightings have been reported and the LNNP cheetah population is believed to be lost. It should be noted that cheetahs do not persist in areas with high densities of other carnivores, especially lions. Lions kill cheetahs and their cubs and are responsible for 73% of the mortality of cheetah cubs in the Serengeti (Laurenson, 1994). Lions were translocated into LNNP during the 1990's and their population flourished. Twenty-seven lions were seen during one of the 2000 game counts. Game numbers remain high within the park so the loss of cheetahs is most likely attributed to the lion population rather than a loss of prey species. But the LNNP cheetah population could recover. In 2002, two rangers were killed by lions within the park and as a result the lions were killed, only lionesses with cubs were allowed to remain per Kenya law. It is thought that the remaining females will also be killed once the cubs are grown. With the loss of the lions from the park, cheetah recovery in that area is possible. While no confirmed sightings of cheetah within the park have been reported since 1997, one questionable cheetah sighting was made in the fall of 2002. There is some controversy about whether it was actually a cheetah or a leopard.

There is also some indication that the distribution of cheetahs within the Nakuru-Naivasha area has changed between 1990 and 2002. Gros (1998) reported 20 cheetahs in the properties north of Lake Naivasha, and 15 individuals in the properties south of it. While the CCF report does not give separate abundance estimates for the two areas, it is clear from the list of sightings that the majority, especially frequent or regular sightings, occurred in the area south of Lake Naivasha. Table 11 summarizes sighting information. Suswa, Hell's Gate National Park, Kongoni Game Sanctuary and Kedong all report regular sightings of cheetah on a weekly or monthly basis. Suswa reports regular sightings of mothers with cubs, most likely more than one family group are present on the property. In contrast, sightings on properties north of Lake Naivasha generally consist of only one or two individuals seen only once or twice.

Table 11. Cheetah sightings in the Nakuru Wildlife Conservancy: 2000-2002

Area of NWC	Property	Group size and composition	Seen regularly?
North of Lake Naivasha	Kekopey Group Ranch	One individual	No
	Kigio	One individual	No
	Kigio	Two individuals	No
	Marula	Two individuals	No*
	Mwariki	One individual	No*
	Soysambu	Two individuals	No
	Soysambu	One individual	No
South of Lake Naivasha	Suswa	Mother with 6 cubs	Yes
	Suswa	Family groups of 3-4 cubs	Yes
	Suswa	Individuals	Yes
	Suswa	Family groups up to 5 cubs	Yes
	Kongoni Game Valley	One individual	No
	Hell's Gate NP	2-4 individuals	Yes
	Hell's Gate NP	One individual	Yes
	Kedong	One individual	Yes
	Kedong	Mother with 2 cubs	Yes
	Kongoni Game Sanctuary	One individual	No
	Kongoni Game Sanctuary	Two individuals	Yes

* seen twice

Landcover Change

Though not quantified, landcover change in the Nakuru Wildlife Conservancy shows some important trajectories. Grassland in many areas of the conservancy has been replaced by the less productive (in terms of ungulate densities) bushland and baresoil categories. The growth of baresoil is especially apparent along the southern portions of Lake Elementaita, to the east of Lake Nakuru National Park, to the southeast of Elementaita town and the very southern portion of the study site. While overgrazing and poor land management practices have been implicated in the degradation of grassland areas (Milton and Dean, 1995; Kellner and Bosch, 1992), stocking rates of livestock for individual properties in this livestock area were not recorded. However, they are likely candidates for the increase of baresoil.

The growth of bush and other woody species in grasslands, termed bush encroachment (Moleele and Perkins, 1998), is a problem faced by land managers worldwide. In Botswana (Moleele et al., 2002), bush encroachment has been implicated in the loss of high quality rangeland while its growth in savanna areas of South Africa (Roques et al., 2001) has been widely observed. In the Nakuru area, this phenomenon is most apparent in the areas north of Lake Naivasha and between Lakes Nakuru and Elementaita. Livestock ranching has been shown to increase the rate of bush enchroachment (Brown and Archer, 1989; Hudak, 1999). The spread of bush in grasslands occurs most readily where cattle grazing occurs. The Madikwe Game Reserve in South Africa experienced a 30% relative increase in bush during a 40-year period due in part to long-term cattle grazing in the area (Hudak and Wessman, 1996). A study of shrub encroachment in Swaziland showed that grazing pressure was a key determinant in the spread of woody species in a lowveld savanna (Roques et al., 2001). Bush encroachment has been shown to radiate out from focal points such as a paddock or water trough, a trend found on a cattle ranch in Tanzania (Tobler et al., 2003). Bushland cover decreased from areas of high cattle intensity to the more extensively used game reserve. Moleele and Perkins (1998) examined fifteen environment variables to explain bush encroachment in Botswana and found that high cattle density was responsible for bush encroachment around boreholes and cattle troughs. Bush encroachment in the Nakuru area is most likely to be caused by cattle due to the importance of this land use in the area.

Another important land-use change for the area is the growth of developed areas. Nakuru town has grown extensively along with Naivasha town. But most obvious is the increase in developed areas along the southern shore of Lake Naivasha. The commercial flower industry has grown enormously since 1986; almost no trace of it can be found in the 1986 image. The developed areas seen in the 2003 images are greenhouses and housing for the thousands of workers who support the industry.

Direct Consequences of Landcover Change

It is unlikely that the loss of grassland habitat or the increase in bush have had any direct negative effects on the Nakuru cheetah population. While cheetahs prefer open grasslands, they are able to use a wide variety of habitat types, from open grassland to heavy bush. In fact both are necessary to provide food and cover from predators and the heat of the day (Caro and Collins, 1987; Schaller, 1972). In Karamoja region of Uganda, cheetahs prefer open habitats with less than 50% woody cover and grasses of medium length (Gros and Rejmanek, 1999). In Nairobi National Park in Kenya and Serengeti National Park in Tanzania, cheetahs use the grassland areas but are also found in the woodlands (Eaton, 1974, Caro, 1994; Schaller, 1972). Myers (1975b) and Hamilton (1986) report that cheetahs are frequently found in bushlands, often because other, more suitable habitats are not available. It is also unlikely that changes in the configuration of marginal and suitable habitats have had a negative effect. In areas where the appropriate habitat makes up more than 20-30% of the total landscape, patch configuration and arrangement are of less importance than habitat amount (Andren, 1994; Fahrig, 1997). This is truer for generalist species and landscape species able to move through less appropriate habitat types to reach suitable patches than for habitat specialists or species sensitive to spatial-temporal pattern of patches (Sunquist and Sunquist, 2001). In 2003 suitable habitat comprised 39% of the landscape while marginal comprised over 44%, both above the threshold level of 30%. Fragmentation is unlikely to play a role in determining the Nakuru cheetah population size until the availability of appropriate habitat, both suitable and marginal combined, falls below that 30% threshold level.

Of greater importance is the increase in the amount of unsuitable habitat, especially developed areas. Cheetahs are shy (Schaller, 1972; Hamilton, 1986) with low competitive ability against competitors (Durant, 2000; Durant, 1998). They are less tolerant of human presence than other carnivores and are therefore more likely to avoid areas of high human density. The human population in the Nakuru District has increased by more than 300% between 1969 and 1999. Average density was 137 people/ km^2 in 1999, up from 41/ km^2 in 1969 and 118/ km^2 in 1989, with pockets of greater densities centered around the towns and areas of small scale agriculture. Evidence for the increase can be seen along the southern edge of Lake Naivasha where the area of development has increased from almost nothing to running the length of the shore. The area covered by the three principal towns has also increased dramatically. The influence of developed areas on cheetahs and wildlife in general extends well beyond the mere conversion of suitable habitat to unsuitable. The increase in the human population associated with increased development results in a regular or constant human presence in areas adjacent to developed areas. Dogs, lights, noise and traffic all reduce the probability that a cheetah will exploit areas deemed suitable based on landcover classification alone. As the human population increases, cheetahs are more likely to be disturbed with consequent negative effects. Amur tigers have been shown to be more likely to abandon kills and consume less meat after disturbance by humans (Kerley et al., 2002). Bobcats in southern California showed little tolerance of urban activities based on the percentage of their home range composed of developed areas (Riley et al., 2003).

Woodroffe (2001) has calculated the critical human density for which there is a 50% chance of a carnivore population going extinct. Based on Hamilton's (1986) cheetah survey, Woodroffe has estimated the critical human density for cheetahs in Kenya to be 16.5 people/ km^2, far below the current density in Nakuru. In India, however, the cheetah population did not go extinct until mean human density reached 120 people/ km^2 (in 1901) (Woodroffe, 2001). Clearly there is variation in the ability of cheetahs to adapt to increasing human densities. The variation is most likely due at least in part to the amount of persecution and harassment that the cheetahs must contend with, indicating that cheetahs are not as persecuted in the Nakuru area as they are in other parts of their Kenyan range. Yet some intolerance exists as cheetahs also come into direct conflict with humans over resource use. While the members of the NWF are tolerant of cheetahs on their properties and even encourage their presence, other landowners in the area are not as favorably disposed. Cheetahs are large carnivores known to kill sheep and goats (Frank, pers. comm.; Wykstra, pers. comm.; Marker et al., 2003). Many smaller landowners are unable and unwilling to absorb the cost of livestock losses, and will harass or even kill carnivores to protect their stock (Frank, 1998; Marker et al., 2003). Poaching for skins is also an issue in the Nakuru area. Two cheetah skins along with eight leopard skins were confiscated from a poacher in the fall of 2002 by Kenya Wildlife Services.

Indirect Consequences of Landcover Change

While the conversion of grassland to bushland habitats is of minor importance to cheetahs directly, it potentially has a much greater indirect effect through food availability and their preferred prey. Thompson's gazelles, grant's gazelles and impala are found at much greater densities in grassland habitats than in bushland areas. The loss of grass will necessarily result in a reduction of the prey available to cheetahs. This trend is evident in the significant decline of thompson's gazelles since 1995, and in the decline of impalas. Gros et al. (1996) and Laurenson (1995a) have demonstrated that there is a "strong correlation" between the biomass of cheetahs and the biomass of their preferred size class of prey, indicating the importance of prey availability to cheetah success.

The amount of prey biomass available to carnivores has been shown to be an important determinant of the number of carnivores a given area can support (Fuller and Sievert, 2001). A positive correlation between prey biomass and carnivore biomass or density has been found for many carnivore species including cheetahs (Laurenson, 1995a; Gros et al., 1996), leopards (Stander et al., 1997), lions (Van Orsdol et al., 1985), tigers (Karanth et al., 2004) and Ethiopian wolves (Sillero-Zubiri and Gotelli, 1995). The effects of prey depletion can be manifested in a carnivore population in a number of different ways. With a decrease in prey resources, some carnivores expand their home range size in response to the reduced carrying capacity. The Triangle region of the Masai Mara, where prey biomass is comparatively low, supports a lower density of lions with larger home ranges than the Sekenani or Musiara regions of the Mara (Ogutu and Dublin, 2002). Ethiopian wolves in areas with low prey densities have larger home ranges and smaller group sizes than wolves in areas with more prey (Sillero-Zubiri and Gotelli, 1995). When prey depletion is modelled in a tiger population, carrying capacity is reduced, the population size decreases and extinction risk for the population increases (Karanth and Stith, 1999). Other effects of prey depletion include suppressed breeding or increased mortality of cubs (hyenas: Holekamp et al., 1999; lions: Hanby et al., 1995; San Joaquin kit foxes: White and Ralls, 1993; wolves: Boertje and Stephenson, 1992; and cheetahs: Caro, 1994) and increased mortality of adults (lynx: Poole, 1994).

In cheetahs, it has been suggested that they expand their home ranges in response to declining prey availability (Caro, 1994). They have also been shown to expand home range size when prey density is high but patchily distributed with areas of low density in between (Caro, 1994). The decrease in density of prey species since 1996 combined with the patchiness of suitable habitat in the study site would result in the reduced carrying capacity of the NWC for cheetahs. When prey densities decline, cheetahs must travel further to locate and acquire sufficient food. Increased energy expenditure to obtain food may have negative consequences on cheetah reproductive rates. Cheetahs generally have large litters with short inter-birth intervals compared to other large felids. The energy requirements to successfully raise a large litter to independence are enormous. When maternal food intake falls below a threshold level of 1.5kg/day, cub growth has been shown to decline sharply (Laurenson, 1995b). In the Serengeti, 95% of cheetahs die before reaching adulthood, with the majority of mortality due to predation by other large carnivores. Only 7% of cub mortality can be attributed to starvation or abandonment (Laurenson, 1994). However, in the Nakuru area, the large carnivores have been either extirpated or their population size suppressed through human intervention. Therefore, cub mortality from depredation has been virtually eliminated, putting greater pressure on cheetah mothers to acquire enough food to raise their large and still intact litters. In this situation, it is probable that prey density would be a more important determinant in survival and reproductive rates of cheetahs than has been previously seen in other systems.

The calculations used to estimate potential cheetah population size based on prey biomass assume that all grassland and bushland patches are equal in their ability to support cheetahs and their prey species. Also, these calculations take into account only preferred prey species, meaning the number the area could support based on total prey biomass may actually be higher. However, the assumption of equal patch quality is not realistic. Not all areas classified as grassland or bushland may be appropriate habitat due to proximity to human habitation or other disturbances. Prey numbers in areas adjacent to high human densities or with poor security may be depressed due to poaching of prey species by people (O'Brien et al., 2003). Snares for ungulates are often found along fence lines and in other areas of high ungulate traffic.

Considering that in 2003 the Nakuru area could have potentially supported a population of more than 60 cheetahs based on available prey biomass, but the actual size of the population was estimated at 12 (Wykstra, unpublished report) suggests that prey depletion is unlikely to be the primary cause of the current decline in the cheetah population. However, prey densities could become a bigger factor if conversion of grassland to bushland and degradation of grasslands continues.

Conclusion

The results of this study indicate that recent (1986-2003) changes in landcover and prey availability within the Nakuru Wildlife Conservancy are insufficient to explain the marked decline of cheetahs in the area. While grasslands within the conservancy are converting to less appropriate landcovers due to bush encroachment and degradation, there is still sufficient habitat and prey available to support a healthy cheetah population.

However, an increase in human density within the conservancy probably plays a significant role in discouraging cheetahs from using the area to a greater degree (Janis and Clark, 2002); this problem will worsen rather than improve with time as the area continues to grow. Support for this possibility is given by the paucity of cheetahs found in the northern part of the conservancy. Cheetahs may find it difficult to pass through the densely settled area around Lake Naivasha. Other issues cheetahs face include more intensive land conversion and subdivision of larger properties surrounding the conservancy rather than change within the conservancy itself. Subdivided land used for subsistence farming will convert land from suitable or marginal to unsuitable and present a barrier to cheetah movement into the area. This landcover change was identified as a threat to cheetahs in the Nakuru area, especially to the north and west, by Gros (1998) during her survey in 1990. Fritz et al. (2003) found that wildlife in the Zambezi Valley of Zimbabwe were less likely to use sections of the river bordered by agriculture. The negative effect of agriculture on density and diversity of wildlife using the area was greatly enhanced once a threshold level was reached (Fritz et al., 2003). It is likely that the growth of agriculture and subsistence farming in the areas surrounding the NWC has had a similar effect.

Members of the Nakuru Wildlife Forum who wish to see a return of cheetahs to their property will have to manage their game populations to maintain a high density of the cheetahs' preferred prey species. They will also need to ensure that poaching of prey species and of cheetahs is deterred and that cheetahs are not harassed if they colonize their property. More importantly though, forum members will need to establish and maintain connectivity between the source population of cheetahs to the south of the

Nakuru area, particularly the Masai Mara, and the rest of the conservancy. The Nakuru area has never maintained a high cheetah population. More likely the area was used as a corridor to pass from the southern part of the country to the central highlands and the Laikipia Plateau. But the growth of settled and densely populated areas may have reduced or even closed that corridor.

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BIOGRAPHICAL SKETCH

Meredith Evans received her B.A. in biology with a minor in chemistry from California State University, Chico in December 1994. She then worked as a math and biology teacher for 2 years in a secondary school in Malawi as a Peace Corps volunteer. After returning home in 1997, she worked as an assistant on a variety of different research projects including a study of salmon and steelhead in northern California, small mammal diversity and abundance in Tanzania and primate demography and anti-predator behavior in Kenya. In 1999, she joined the Laikipia Predator Project and worked as an assistant looking at human-carnivore conflicts in the Laikipia District of Kenya. She began her M.S. degree in the School of Natural Resources and Environment at the University of Florida in 2001. For her research, she investigated the decline of cheetahs in the Nakuru District of Kenya. She will begin the Ph.D. program upon completion of her thesis.