A PRELIMINARY ANALYSIS OF VERREAUX'S SIFAKA HABITAT IN KIRINDY MITEA NATIONAL PARK, MADAGASCAR

By

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ABSTRACT

Kirindy Mitea National Park contains one of the largest continuous tracts of dry forest left in Madagascar. Most of the dry, deciduous forest of western Madagascar is degraded and fragmented after years of deforestation from slash and burn agriculture and logging. Kirindy Mitea is a new research site, so little is known about the park as a whole and the species living there. This focal species of this project is the park's largest lemur, Verreaux's sifaka (*Propithecus verreauxi verreauxi*). The goals of this project were to determine the average home range size and group size of the species in Kirindy Mitea, and then compare those numbers to two other sites in southwestern Madagascar, Beza Mahafaly Special Reserve and Kirindy Forest/CFPF. In addition, GIS analyses were performed to look at the land cover changes that took place in Kirindy Mitea during a 16 year period. The results of that analysis were used to perform a GIS based threat analysis of the forest in the park, in order to determine what areas are at the highest risk of deforestation in the future.

I found that the average home range size of Verreaux's sifaka in Kirindy Mitea is larger than the average home range sizes in Beza Mahafaly and Kirindy CFPF (p=0.010). In addition, the home ranges have less overlap with neighboring groups in Kirindy Mitea, most likely due to a difference in habitat and a lack of tamarind trees. The land cover change analysis revealed that during 1990-2006, there has actually been a gain of over 4,000 ha of forest. However, during the most recent time period, 2000-2006, there was an overall loss of almost 2,000 ha of forest, and these areas of forest loss were concentrated around the park boundary and the savanna. The threat analysis determined that the factors that will most likely lead to deforestation in the future in Kirindy Mitea are proximity to the park boundary, the roads in the park, and the savanna. Using the results of the threat analysis, I was able to determine that about 10,500 ha of viable lemur habitat in the park is at high risk of deforestation in the future.

Currently, the forest in Kirindy Mitea is quite continuous, and there is an adequate amount left to support large lemur species like Verreaux's sifaka. It will be important for park managers to continue protecting the forest so that it does not become fragmented like most of the dry forest left in Madagascar. I recommend creating a buffer area around the park boundary and investing in additional security and park staff to monitor the remaining forest around the park boundary and near roads and savanna. Kirindy Mitea is a rare park in that it actually contains a large amount of continuous forest, so conserving those remaining large tracts of forest should be a top priority for park managers.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Section 1: Background

1.1 Introduction

Years of deforestation from slash and burn agriculture and logging have left the dry forests of western Madagascar extremely degraded and fragmented (Dietmar et al., 2001). Kirindy Mitea National Park, a large protected area located in the dry forest, contains a wealth of unique flora and fauna, however little is known about the park as a whole and the species living there. My project looks at the habitat of the large, diurnal lemur Verreaux's sifaka (*Propithecus verreauxi verreauxi*), a species that has never been studied in Kirindy Mitea. In addition, the project looks at the forest cover change in the park over the last sixteen years in an effort to observe the current patterns of forest loss and create recommendations that will better protect the park in the future.

Madagascar contains many unique ecosystems that are home to an abundance of rare and endemic species. Humans arrived on the island only 2000 years ago, but since that time, numerous species have gone extinct from habitat loss and over-hunting (Green and Sussman, 1990). The widespread deforestation in Madagascar has led to highly fragmented landscapes. Fragmentation poses many threats to animals that reside in the forest. For example, small populations that eventually become isolated risk extinction due to low genetic diversity. Moreover, edge effects from increased fragmentation can markedly change a forest habitat, again threatening the species living there (Irwin et al., 2005).

Habitat fragmentation is especially detrimental to forest dwelling species, such as lemurs. Lemurs are an excellent species for biodiversity planning because they are highly endangered, but well known across the globe. In addition, lemurs are a large part of the ecotourism industry in Madagascar, as well as an umbrella species for other smaller animals (Laurance and

Bierregaard, 1997). Any forest fragment that is large enough to support a lemur population will also protect many other species living in the forest (Ganzhorn et al., 2000).

Kirindy Mitea National Park contains one of the largest continuous tracts of dry forest left in Madagascar. Further research is needed in the park to learn about the species and habitats present there. Verreaux's sifaka is the largest lemur living in the park, and is the focal species of this study. This species has been studied in many other areas in western Madagascar, however nothing is known about it in Kirindy Mitea. By determining the particular characteristics of Verreaux's sifaka in Kirindy Mitea, the park managers can create a better conservation plan for the species. In addition, managers must adequately protect the habitat of these lemurs in order to maintain long-term viable populations. It is important to know the patterns of forest loss in a protected area in order to halt deforestation and better preserve the remaining forest. By analyzing the specific threats to the forest in this park and determining high-risk areas, the park managers can protect the highly threatened dry forest in the park and maintain it into the future.

1.2 Objectives

I have three main objectives for this project:

1) Determine the average group size and home range size of Verreaux's sifaka in Kirindy Mitea.

    a) Compare these numbers to two other sites in southwestern Madagascar.

2) Analyze the land cover change in Kirindy Mitea from 1990-2006.

    a) Use this analysis to determine where forest has been lost in the park over the last 16 years.

3) Perform a GIS based threat analysis of the forest in the park.

    a) Use the threat analysis to determine lemur habitat at highest risk of deforestation.

Section 2: Study Area

2.1 Madagascar

With a total area of 587,000 km^2, Madagascar is the fourth largest island in the world. It separated from Africa approximately 170-180 million years ago, and is now located 400 km off the southeastern coast of Africa (Green and Sussman, 1990). Most of the plants and animals on the island originally arrived there by crossing a water barrier. Consequently, these species remained isolated on the island for the last 50-55 million years. They evolved independently on Madagascar until humans arrived about 2,000 years ago (Sussman et al., 1994).

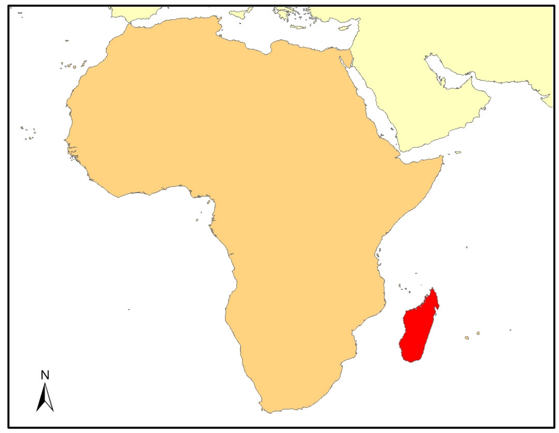

Figure 1 Location of Madagascar

The island is widely known for its exceptionally high levels of biodiversity and endemic species (Green and Sussman, 1990). Designated as one of the biodiversity hotspots, Madagascar contains thousands of endemic flowering plants, hundreds of terrestrial vertebrates, and 28 species of endemic lemurs (Smith et al., 1997). In addition, Madagascar contains a wide variety of vegetation types. The eastern half of the island contains lush rainforest, the west holds the dry, deciduous forest, and the southern end of the island contains dry, spiny forest (Du Puy and Moat, 1998).

In addition to this abundance of distinctive flora and fauna, Madagascar is known for an exceptionally high rate of forest clearing, fragmented forests, and land degradation due to shifted agriculture practices (Smith et al., 1997). Deforestation is prominent in Madagascar for a variety of reasons: widespread poverty, a rapidly increasing population, and a lack of resources and adequate techniques to augment agricultural practices (Sussman et al., 1994). The current population of Madagascar is 19,448,815 people (CIA World Factbook, 2007), and it is growing rapidly, doubling every 22 years. The per capita annual income on the island is only US $230. Nearly 80% of the population is rural, leading to a very high level of subsistence agriculture (Laurance and Bierregaard, 1997). The primary threat to forests is a type of slash and burn agriculture called *tavy*. People cut and then burn the forest, and use the area to grow crops such as rice. After a few years of cutting and burning, the poor quality tropical soils are devoid of nutrients, and consequently abandoned. Though the soils are still nutrient poor after 10-15 years of sitting, people continue to burn and use them repeatedly until the soils are completely impoverished. The resulting landscape is barren secondary grassland, which is completely desolate and unusable (Ingram & Dawson, 2005.) In addition, it is traditional to cook with charcoal or dead wood in Madagascar. However, in many areas there is not enough dead wood for cooking, so large charcoal industries have formed to help meet the demand. These industries massively clear forests for charcoal, resulting in completely barren landscapes that remain unused (Sussman et al., 1994). A recent assessment of forest cover by Nelson and Horning (1993) estimated that only 11% of the island remains forested, when originally it was almost completely forest (Laurance and Bierregaard, 1997).

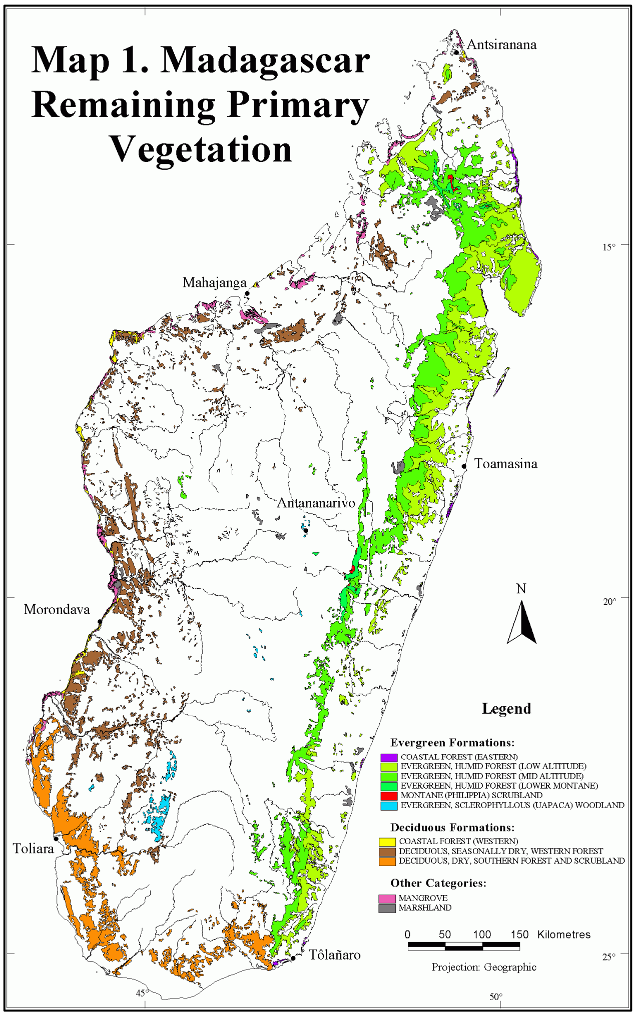

Figure I Remaining vegetation in Madagascar. The bright green is rainforest, and the dark brown is dry forest. [1]

[1] From: http://www.kew.org/gis/projects/madagascar/primary_veg.html

Of all the vegetation types on the island, the dry, deciduous forest is the most inadequately protected. Du Puy and Moat (1998) found that the dry forests have the least amount of land located within protected areas. Only 2% of the remaining dry forest is protected, while 5.3% of the lowland rainforest is protected (Seddon et al., 2000). In addition, the dry forests of Madagascar experience a far higher deforestation rate than the rainforests, making them a high priority for conservation (Sussman and Rakotozafy, 1994). The average deforestation rate in the dry forest from 1950 to 1990 was 61,000 ha per year. By 1990, only 2.8% of the dry forest remained on the island (Laurance and Bierregaard, 1997). Some areas of eastern rainforest remain protected because they fall on steep slopes where deforestation is difficult; however, there are no steep slopes to protect the dry forest, as the western half of the island is flat (Sussman et al., 1994).

The remaining dry forest is highly fragmented, threatening the species that live there. Degradation of the unique western dry forest is so widespread that by 2020-2040, it is unlikely that many of the large animal species living there will sustain viable populations. Conservation must be a top priority in these areas in order to reverse the fragmentation trend. In addition, more protected areas are needed, as well as additional staff and guards for current protected areas (Ganzhorn et al., 2001). The remaining areas of dry forest in Madagascar are biologically rich and important, and conserving them is an exceptionally high priority (Laurance and Bierregaard, 1997).

2.2 Kirindy Mitea National Park

Kirindy Mitea National Park is a large park located on the western coast of Madagascar. It has an area of 86,736 ha, and is part of a region in the west known as the Menabe (ANGAP, 2002). The Menabe contains some of the largest tracts of dry forest left on the island. The human population in the Menabe region is low density, however people largely depend on the forest for survival. Rice cultivation, raising livestock, and hunting are common practices of the local people (Goodman and Benstead, 2003).

Kirindy Mitea is approximately 70 km south of Morondava, a coastal city on the Mozambique Channel (ANGAP, 2002). It became a National Park on December 18, 1997, and is now the fifth largest protected area in Madagascar. Kirindy Mitea is a remote park that contains primarily dry, deciduous forest. In addition, it contains spiny forest, mangroves, coastal forest, and large coral reefs off the coast (Goodman and Benstead, 2003). It is the transitional zone between the dry forest of western Madagascar and the spiny forest of southern Madagascar, making it especially unique (Dietmar et al, 2001). It is one of the largest continuous tracts of dry forest left on the island, so conservation is an extremely high priority for this park (Goodman and Benstead, 2003). There is little published research about Kirindy Mitea, as it is a new research site and is not well studied. There are no main roads running through the park, or even remotely close to it. The nearest national highway is in Morondava. The main access to the park is a one-lane dirt road runs across salt flats, and then passes through the spiny forest and into the dry forest. It is primarily used by the local Malagasy people as an oxcart trail, however only 2-3 oxcarts use the road daily. People generally use the road in Kirindy Mitea to travel from several villages located about 10 km outside the park to the coastal villages along the Mozambique Channel. There are no people living within Kirindy Mitea, as it is a very dry

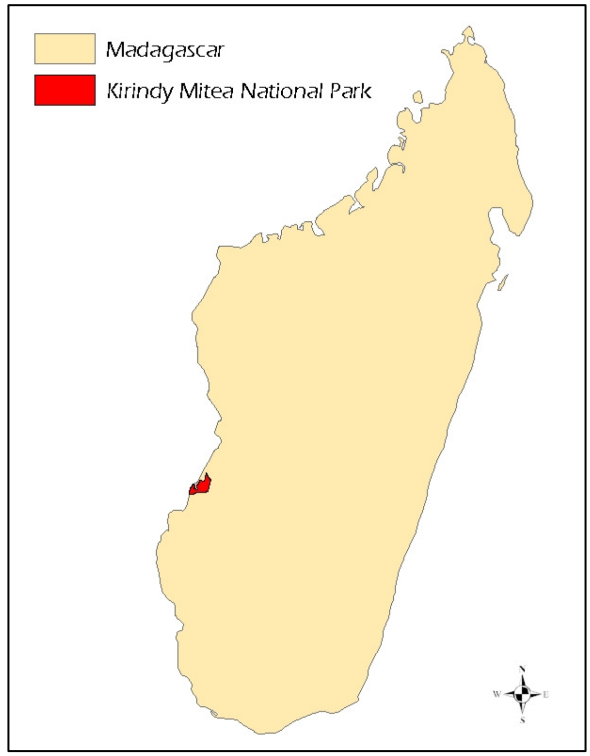

Figure 3 Location of Kirindy Mitea National Park in Madagascar

forest with no rivers running through it (Lewis, personal communication). The closest village is a small fishing town called Belo Sur Mer, located about 10 - 15 km from the park edge.

Figure 4 The main road in Kirindy Mitea, with a baobab tree in the background

Climate and rainfall data are not available specifically for Kirindy Mitea. However, it is located between two other parks, Beza Mahafaly Special Reserve (hereafter BMSR), a small protected area located in a larger, unprotected forest, and Kirindy Forest, part of a forestry concession operated by the Centre Formation Professionelle Forestière de Morondava (hereafter CFPF), that receive 600mm and 800mm of rain per year, respectively (Goodman and Benstead, 2003). Kirindy Mitea has similar climate to both CFPF and BMSR. The dry season lasts for most of the year, from April to November. The wet season lasts only about four months, from December to March.

Kirindy Mitea is home to abundant wildlife due to its remote nature. It contains the towering baobab trees and occasional tamarind trees (Dollar, 2005). The park is home to two carnivores: the fossa *(Cryptoprocta ferox)*, and the mongoose (*Mungotictis decemlineata decemlineata*). There are several amphibian and reptile species, along with over 55 bird species. The park contains at least eight species of lemur, including the diurnal lemurs Verreaux's sifaka (*Propithecus verreauxi verreauxi*) and red fronted brown lemur (*Eulemur fulvus rufus*). There are numerous nocturnal species: the sportive lemur (*Lepilemur ruficaudatus*), the mouse lemur (*Microcebus murinus* and *Microcebus myoxinus*), the giant mouse lemur or coquerel's mouse lemur (*Mirza coquereli)*, the fork-marked lemur (*Phaner furcifer)* and the fat-tailed dwarf lemur

(*Cheirogaleus medius)*. In addition, the park is the northern most range of the diurnal ring-tailed lemur (*Lemur catta*). No one has ever seen this species north of Kirindy Mitea (Dietmar et al, 2001).

Kirindy Mitea is recognized as a priority area for research and management, as it is one of the largest National Parks in Madagascar, and very little research has been done there. In addition, the forest is beginning to recover from years of logging, so it is an important area to study now that it is regenerating (Dollar, 2005). However, local people still practice slash and burn agriculture and selective logging in the forests in this region. In addition, invasive species like cattle, feral dogs and feral pigs often run free in the forests, competing with native species for food, and threatening them with disease. Though the forest in and around this park have suffered from human activities, there is still a lot left to be preserved (Dietmar et al., 2001).

Figure 5 The savanna in Kirindy Mitea

2.3 Verreaux's sifaka (Propithecus verreauxi verreauxi)

My study focuses on Kirindy Mitea's largest lemur, Verreaux's sifaka (*Propithecus verreauxi verreauxi*). They are diurnal folivores found throughout the southwestern region of Madagascar (Lewis and Kappeler, 2005). They are vertical clingers and leapers, which means they move vertically through the trees, jumping with their powerful back legs. Verreaux's sifaka generally weigh about 3.6 kg (Richard and Dewar, 1991). While no one has studied Verreaux's sifaka at Kirindy Mitea,

Figure 6 Verreaux's sifaka
(Photo by Julie Rushmore)

they have been extensively researched during long-term studies at both BMSR and CFPF (Norscia et al., 2006; Lewis and Kappeler, 2005; Richard et al., 1993; Brockman, 1999; Lawler et al., 2003). They live in matrifocal social groups that generally range in size from 2-13 individuals. Verreaux's sifaka are territorial animals, with at least 0.6-1.8 ha of the area in their home range being a core area that other groups do not enter (Nowak, 1999). Their home ranges average 4-6 ha at BMSR and average seven ha at CFPF. At BMSR, most groups contain 4-8 members (Richard et al., 1993), and at CFPF groups have 4-6 members (Lewis, unpublished data). They are listed as vulnerable on the IUCN redlist, as their habitat is threatened by deforestation and fragmentation from slash and burn agriculture, charcoal production and logging (Nowak, 1999). In addition, people in and around the Kirindy Mitea region hunt Verreaux's sifaka. Hunting is especially prominent during the dry season, when there is a lack of food (Goodman, 2003).

Figure 7 Verreaux's sifaka leaping

Section 3: Gathering Verreaux's sifaka GPS locations

3.1 Identifying and marking social groups

In July 2006, three social groups of Verreaux's sifaka were located in a continuous block of forest in a one square kilometer grid by Dr. Rebecca Lewis, a professor at the University of Texas-Austin. The location of the three sifaka social groups in Kirindy Mitea can be seen in Figure 8. Throughout the months of July and August, Dr. Lewis and her team cut trails into the grid every 25 m. The outline of this grid is also seen in Figure 8. Twelve individuals were captured, each individually marked with either a radio collar or colored nylon collar during brief anesthesia. They were blowpipe darted by an experienced Malagasy technician. The animals were returned to their social groups within 1-2 hours of darting. Each animal was given a different colored nylon collar with a different colored and shaped tag for easy identification. In addition, five animals were given radio collars for later tracking.

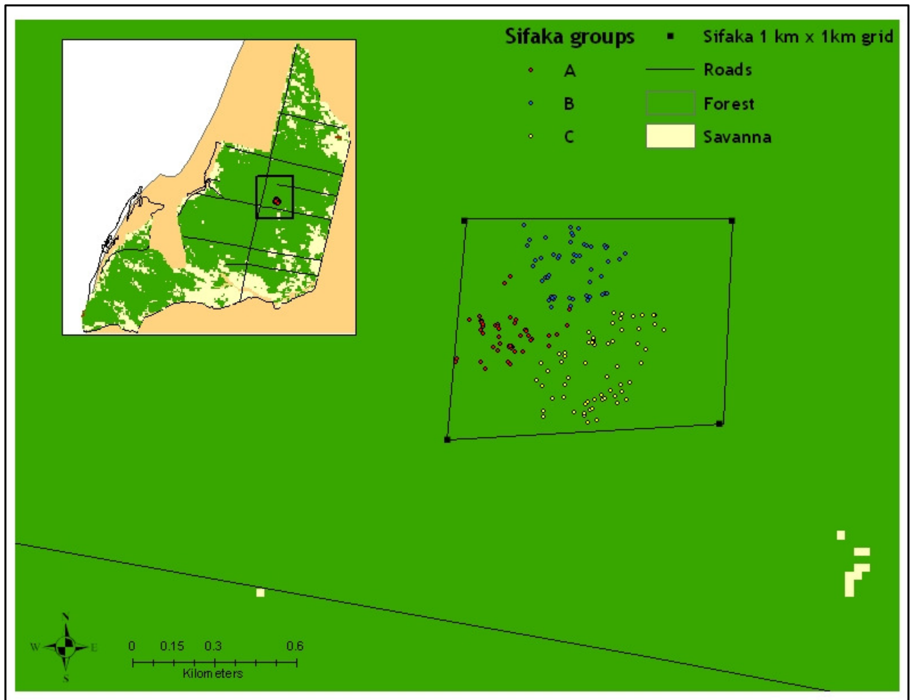

Figure 8 Locations of Sifaka social groups

3.2 Collecting GPS data and habituating

I collected independent GPS points for each social group twice a day for a period of 30 days. I went out once in the morning, at 6:30 am until about 11:00 am, and then went out again at 2:00 pm until about 5:30 pm. I used an animal telemetry antenna and receiver to locate the groups. I went to each group once in the morning, and then to each group again once in the afternoon. I rotated which group I started with everyday, so that I was not always going to the same group at the same time. After I located a group, I took a GPS waypoint of the tree they were sitting in. I always stood within 5 to 10 meters of the tree in order to get the most accurate reading possible. These sifakas were in trees 100% of the time that I

Table 1 Individuals in each of the three social groups that I tracked

Group	No. of Males	No. of Females	No. of Unknown	Total
A	1	2	1	4
B	2	2	0	4
C	2	5	2	9

saw them, and almost all the time the whole group would be in the same tree together. The few times the groups would separate, the rest of the group would always be in a neighboring tree, so it did not affect the GPS waypoint. Table 1 displays the number of males and females in each group. The unknown individuals are lemurs that were not darted, so they do not have collars and were not definitely identified as male or female.

These animals were not habituated when I began my study. The time they were darted and radio collared was their first contact with humans, so they were naturally very afraid of me when I first started tracking them. Although they were frightened, I was always able to locate them with the telemetry equipment and take a GPS point before they moved. To help habituate them to humans, after taking the GPS waypoint I would stand quietly near the tree they were in for 20 to 30 minutes and just observe and allow them to get accustomed to my presence. On many occasions, they would get scared or bothered by me standing near them, so they would flee. I would follow the group for as long as possible until they went too far into the forest for me to follow them. They are able to leap through the trees extremely quickly, so it was often difficult to keep up with them. Though not completely habituated by the time I finished my study, they were much more accustomed to me. They did not flee nearly as much, and often I was able to stand within a few meters of them.

After collecting a GPS point and then habituating a group for at least 20 minutes, I would then move on to the next group and repeat the same process. I did this almost everyday for a period of 30 days. I ended up with 167 GPS waypoints for all three groups. Occasionally I would run into a group again when I was walking through or leaving the grid, so there are days when I have more than two GPS waypoints for a group. All these waypoints are independent locations, so it is not important that some groups have more waypoints than others do.

Section 4: Determining Verreaux's sifaka home range sizes in Kirindy Mitea

My goal for this objective is to determine the average group size and home range size of Verreaux's sifaka in Kirindy Mitea. I want to find out if these sifaka differ from other sifaka in the same region, as this will have important implications for the conservation of this species.

4.1 Mapping the GPS locations

I typed all of my GPS waypoints into an Excel spreadsheet, in the format of degrees, minutes and seconds. I then converted these points into decimal degrees in Excel. In addition to the latitude and longitude columns, I also entered data of the date and time the waypoint was taken, group number and the activity that they were doing when I took the point (sitting, eating, etc.). I converted this data to a dBase table, and imported it into ArcMap 9.2. Finally, I projected the points into the World Geodetic System 1984, Universal Transverse Mercator Zone 38N projection.

4.2 Determining home range size

In order to determine the home range size of each group from the GPS points, I used Hawth's tools, a tool in ArcMap. I used the minimum convex polygons tool, which determines the area covered by all of the specified points. In this case, I put in my sifaka locations as the points, and chose to have the polygons separated by group, so there would be an individual polygon for each group. The polygon areas determined from the minimum convex polygons tool are listed in Table 2, above. Norscia et al. (2006) used the minimum convex polygon method to determine home range size for their study of sifaka in CFPF. The 167 GPS points and an estimation of the three social groups' home ranges can be seen below in Figure 9.

Table 2 Home range sizes of the three social groups

Group	Home range size (ha)
A	8.46
B	7.65
C	11.89
Average	9.33

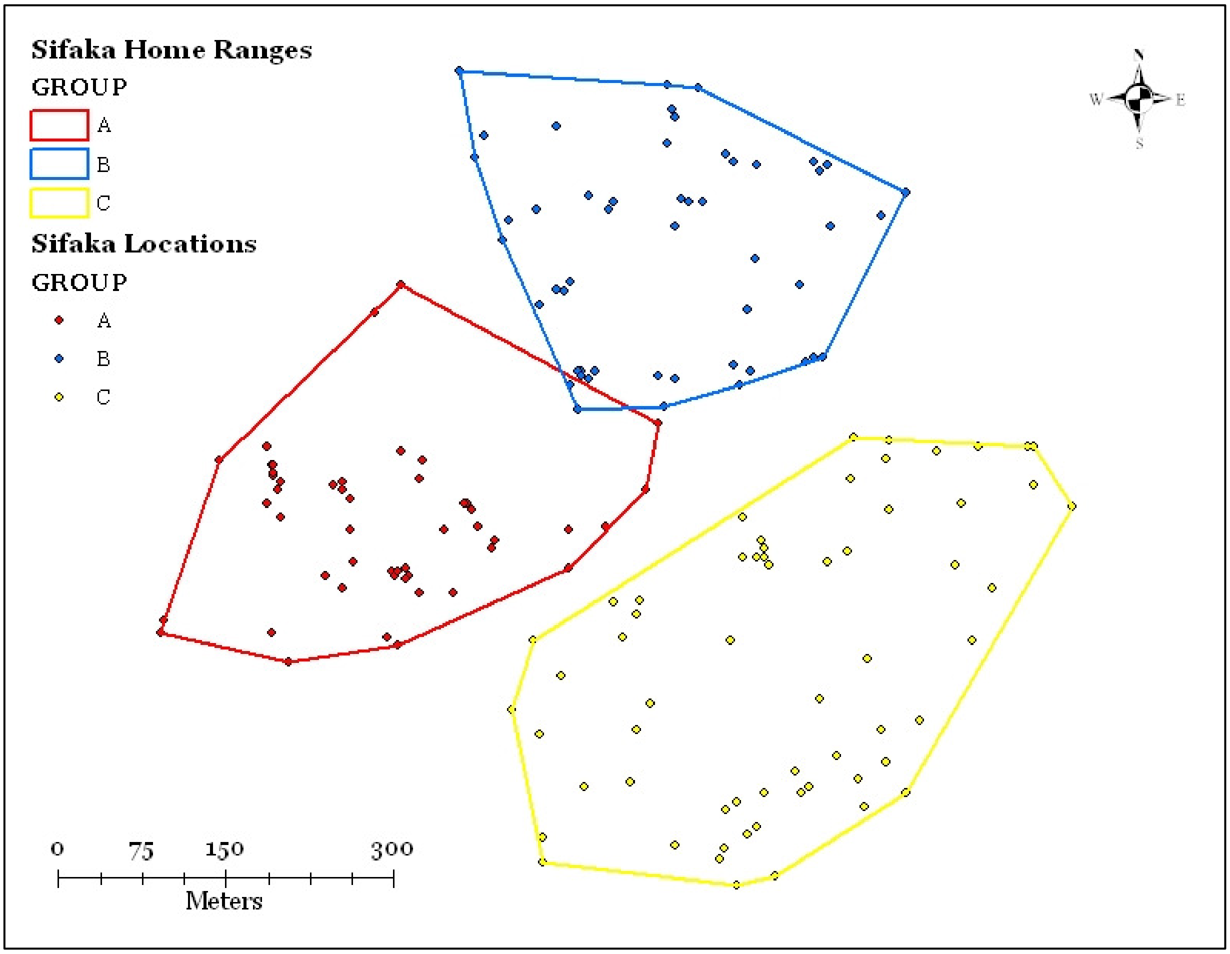

Figure 9 Verreaux's sifaka locations and home ranges

4.3 Verifying the home ranges

I collected 167 waypoints in 30 days, and from the maps I created, it seems as though each group is in fact staying within a specific home range. In order to verify that I collected enough data points to determine that these are the actual home ranges of the three Verreaux's sifaka groups, I created Area Accumulation Curves. These curves were created with the statistics program R, using a code provided by Duke doctoral candidate Scott Loarie. The curves plot the number of observations against the area of the home range, in order to see how the lemurs are moving in the range. If the curve increases and then begins to approach an asymptote, this means that their movements are beginning to stay within a certain area, and this area is

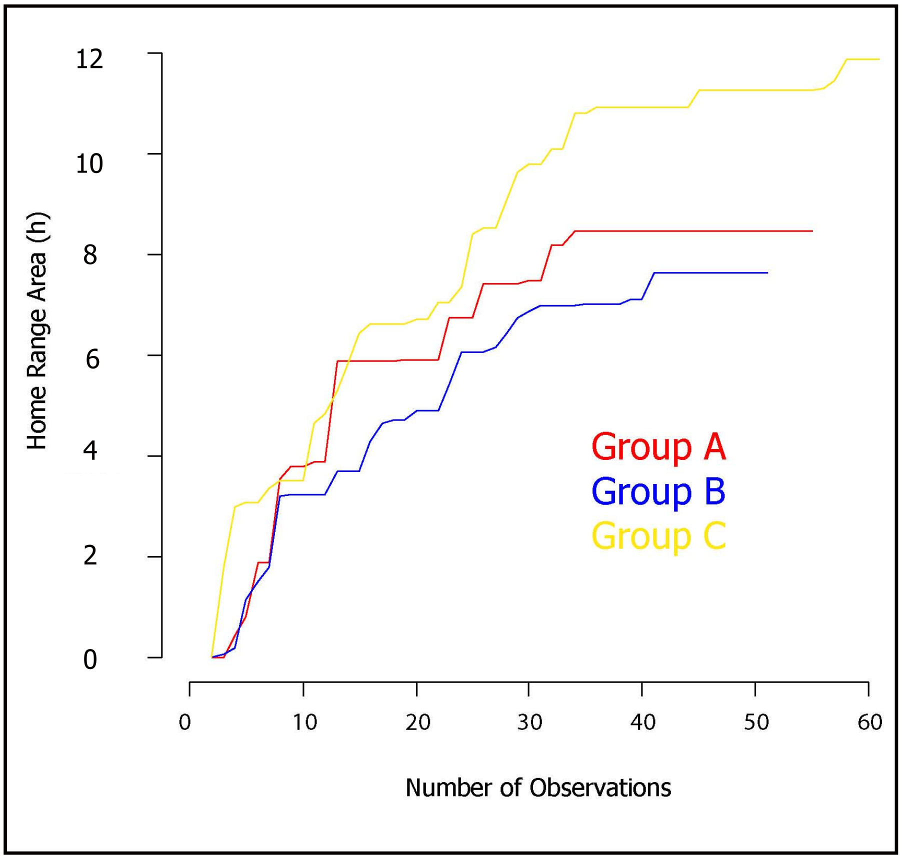

Figure 10 Area Accumulation Curves of the three home ranges

defined as their home range. If the curve increases and continues to increase without leveling off, the lemurs are continuing to move around, and the GPS points are not adequately defining their entire range. From the graph, it is obvious that the curves for all three groups begin to approach asymptotes, so the areas I defined are in fact their home ranges. Since these animals have small home ranges and tend to stay within these confined areas, it is much easier to define their home ranges in a short time. The extensive home ranges of larger primates could not be determined as easily.

Section 5: Comparing Kirindy Mitea sifakas to BMSR and CFPF sifakas

Kirindy Mitea, BMSR and CFPF are located in the dry forest in western Madagascar. BMSR is a series of two small reserves located within a larger, but unprotected forest. The two forest patches are approximately 10 km apart. The smaller parcel is about 80 ha, and primarily contains gallery forest. The other parcel is larger, about 520 ha, and is mostly spiny brush habitat that is well suited for the dry climate. BMSR is mostly flat, and there is a river running through the reserve that dries up during the dry season. CPFP is a large tract of forest located within a privately owned, but unprotected forestry concession. Since 1978, the CFPF forestry program has conducted research relating to ecology and silviculture in Kirindy Forest, and more recently has looked for ways to promote the sustainable use of forest resources to the local people. CFPF consists mostly of dry forest, however it has been sustainably logged since 1978. Similar to Kirindy Mitea, both of these sites are threatened by slash and burn agriculture, cattle grazing, and logging. Unlike Kirindy Mitea, Verreaux's sifaka has been extensively researched at both of these sites (Goodman and Benstead, 2003).

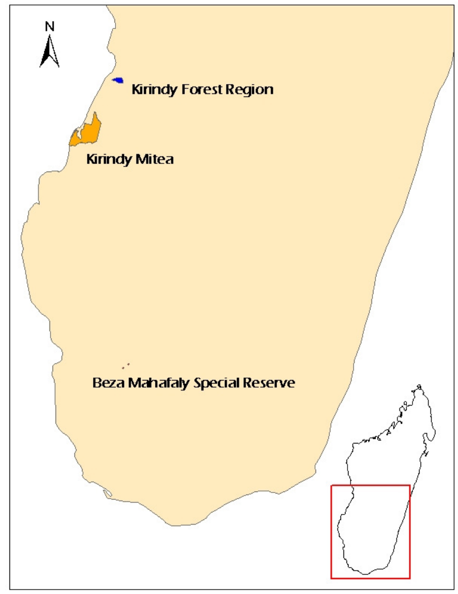

Figure 11 Location of BMSR and CFPF

I will be comparing group size and home range size among the three sites using an analysis of variance test, or ANOVA. This test simply looks for a difference in the means of whatever variable I am comparing for the three sites. I gathered the data for group size and home range sizes in BMSR and CFPF during a literature review, and also with the help of Dr. Rebecca Lewis.

5.1 Group size

The group size is simply the number of individuals in a group. Before performing the ANOVA test, I hypothesized that there would not be a significant difference in group size. The data used for this analysis is from a long-term study at BMSR by Richard et al. (1993), and from the dissertation work of Dr. Rebecca Lewis (Lewis, 2004) at CFPF. Although the number of individuals in a group can vary, the data show that the average is about six individuals at all three sites. I gathered all the data into an Excel spreadsheet, and then exported it to a comma-delimited file. I performed the ANOVA test using the statistics program R. I read the data into R and used the function "aov" to run a one-way ANOVA test. The p-value that resulted from the test is 0.6997, which is not significant at the alpha level of 0.05 (n=13, df=1). It turns out that there is not significant difference in group size for the three sites, which matches my original hypothesis. A boxplot of the group sizes can be seen in Figure 12 at the right.

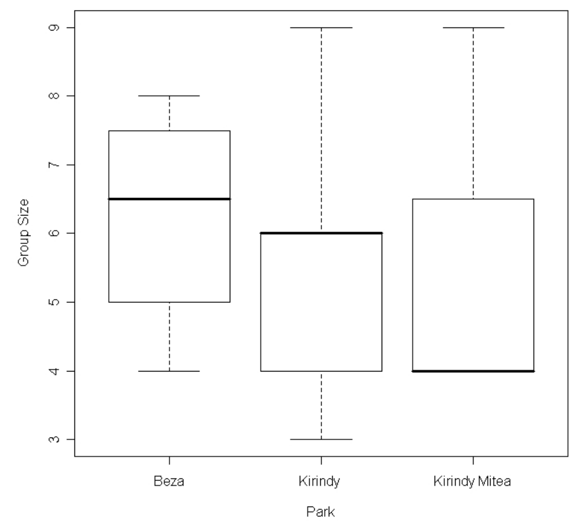

Figure 12 Boxplot of the group sizes at three different sites in southwestern Madagascar

5.2 Home range size

The test for home range size was very similar to the test for group size. However, in this case I did expect to see a difference in home range size for the three sites. BMSR sifakas have an average home range size of about 4 ha, CFPF sifakas have an average home range size of about 7 ha, and I found the Kirindy Mitea sifakas to have an average home range size of about 9 ha, as seen in Figure 13. The data used for this analysis is from a long term study at BMSR by Richard et al. (1993), and long term research conducted by Dr. Rebecca Lewis at CFPF (unpublished data). I gathered the data again in Excel and read it into R just as for the group size data. After running the ANOVA, I ended up with a p-value of 0.010, which is significant at the 0.05 alpha level (n=9, df=2). Therefore, there is a significant difference in the home range sizes of all three sites.

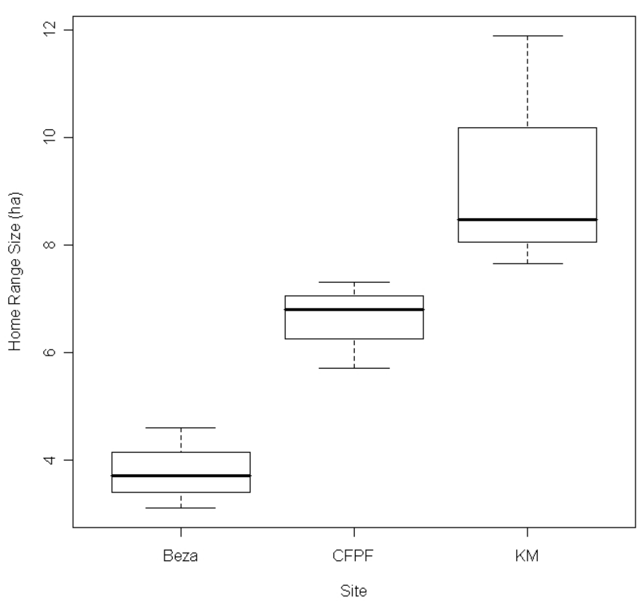

Figure 13 Box plot of the home range sizes at three sites in southwestern Madagascar

5.3 Home range size controlling for group size

I ran the ANOVA test again in R using the previous home range and group size data. This time, however, I controlled for group size, just to see if that had any sort of effect on the results of the test. However, the p-value stayed nearly the same ($p=0.01643$, $df=2$). Therefore, there is still a significant difference in the home range sizes of all three parks.

5.4 Summary of results

There is less overlap between groups in Kirindy Mitea. At CFPF, Verreaux's sifaka is found in densities as great as 40 groups/km^2 (Lewis, personal communication). The sifaka social groups at BMSR generally overlap with at least two or three other groups, and at times up to five other groups (Richard et al., 1993). At Kirindy Mitea, preliminary field analysis shows a possible density of 10 groups/km^2. The forest in Kirindy Mitea is much different from CFPF and BMSR, and one large difference between these two forests is the presence of tamarind trees. Tamarind trees are quite prominent in CFPF and BMSR, however they are rarely found in Kirindy Mitea (Lewis, personal communication). Lemurs feed on tamarind leaves and fruit, so the tamarinds provide a food source for Verreaux's sifaka at the other two sites (Goodman and Benstead, 2003). This is a major food source they do not have in Kirindy Mitea, which could be one explanation as to why home ranges are much larger and there is less overlap with neighboring groups in Kirindy Mitea.

Section 6: Land cover change analysis

The goal of this objective is to determine where the forest has been lost in the park during the period 1990-2006. I will be looking at the areas where forest changes to savanna using satellite images gathered for 1990, 2000, and 2006.

6.1 Land cover maps and other data

The three land cover maps used in my project were created with supervised classifications of three different satellite images. I downloaded satellite imagery for the years 1990 and 2000 from the Global Land Cover Facility (GLFC) website (http://glcf.umiacs.umd.edu). The images downloaded are Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images, path 161, row 74, which covers all of Kirindy Mitea National Park. Both of these images are from the dry season. The 1990 image was taken in July, and the 2000 image was taken in June. The images are in the datum World Geodectic System 1984 and the Universal Transverse Mercator Zone 38N projection, with a resolution of 30m x 30m. I downloaded all bands, except for band six, for both of these images and combined them into one raster using the "composite bands" tool in ArcMap. I then classified the images using a supervised classification in Erdas Imagine, a program commonly used for remote sensing work. I created training points for the images so that they would be more accurate than simply allowing the program to guess at what the land cover types were. I created these training points with the help of Google Earth (http://earth.google.com/), which is very recent, high resolution data. It is very easy to see land cover types using Google Earth. In addition, I took ground truth points of many areas in the park during the two months I was there, which aided in the creation of training points. Moreover, I am generally familiar with the landscape of the park after walking extensively through it during the course of the summer. In the end, I classified the images into two main groups, forest and savanna. The park also contains mangroves along the coast and spiny forest along the western border of the park, however these areas were removed from the analysis. Only areas of dry, deciduous forest or savanna were included in this analysis. The areas of forest and savanna are what I will hereafter refer to as the "study area".

The satellite image from 2006 is the most recent for the area, and is not readily available on the GLFC website. This image was purchased for the master's project of another Master of Environmental Management candidate, Amanda Whitehurst, and therefore I did not have access to this image. Amanda performed a supervised classification on the image as her master's project, and I received the final land cover classification map. Therefore, the methods used to create that land cover map will not be discussed here.

The final land cover maps used for my analysis are shown in Figure 15. The amount of forest in the study area stays constant all three years, generally somewhere between 62,000 ha and 68,000 ha of forest. The savanna, however, actually decreases from 1990 to 2006. The areas of forest and savanna in 1990, 2000 and 2006 can be seen in Table 3.

The vector datasets used for this analysis came from a variety of sources. John Fay, GIS professor at the Nicholas School, gave me shapefiles of Madagascar and Kirindy Mitea. I received a shapefile of all the protected areas in Madagascar, and simply selected Kirindy Mitea out from this file. I also selected the shapefiles of Beza Mahafaly and Kirindy Forest out of this file. Amanda Whitehurst created the roads shapefile as part of her master's project.

Table 3 Amount of forest and savanna in the three land cover maps

Year	Forest (ha)	Savanna (ha)
1990	62,090.01	16,805.61
2000	67,306.41	11,589.21
2006	66,173.04	12,722.58

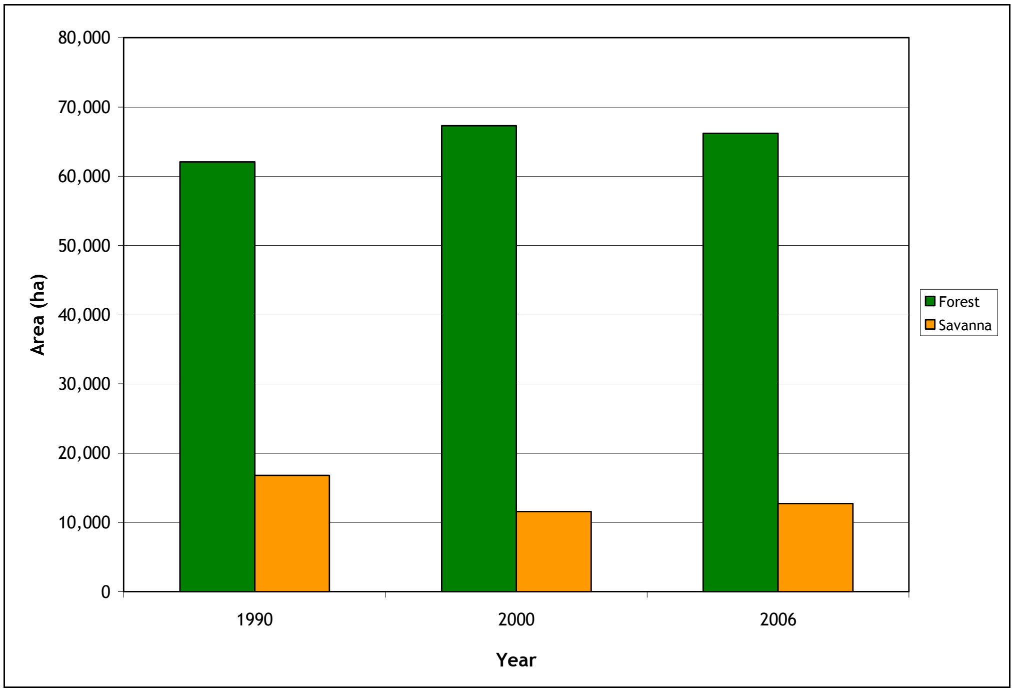

Figure 14 Graph of the amount of forest and savanna in the three land cover maps

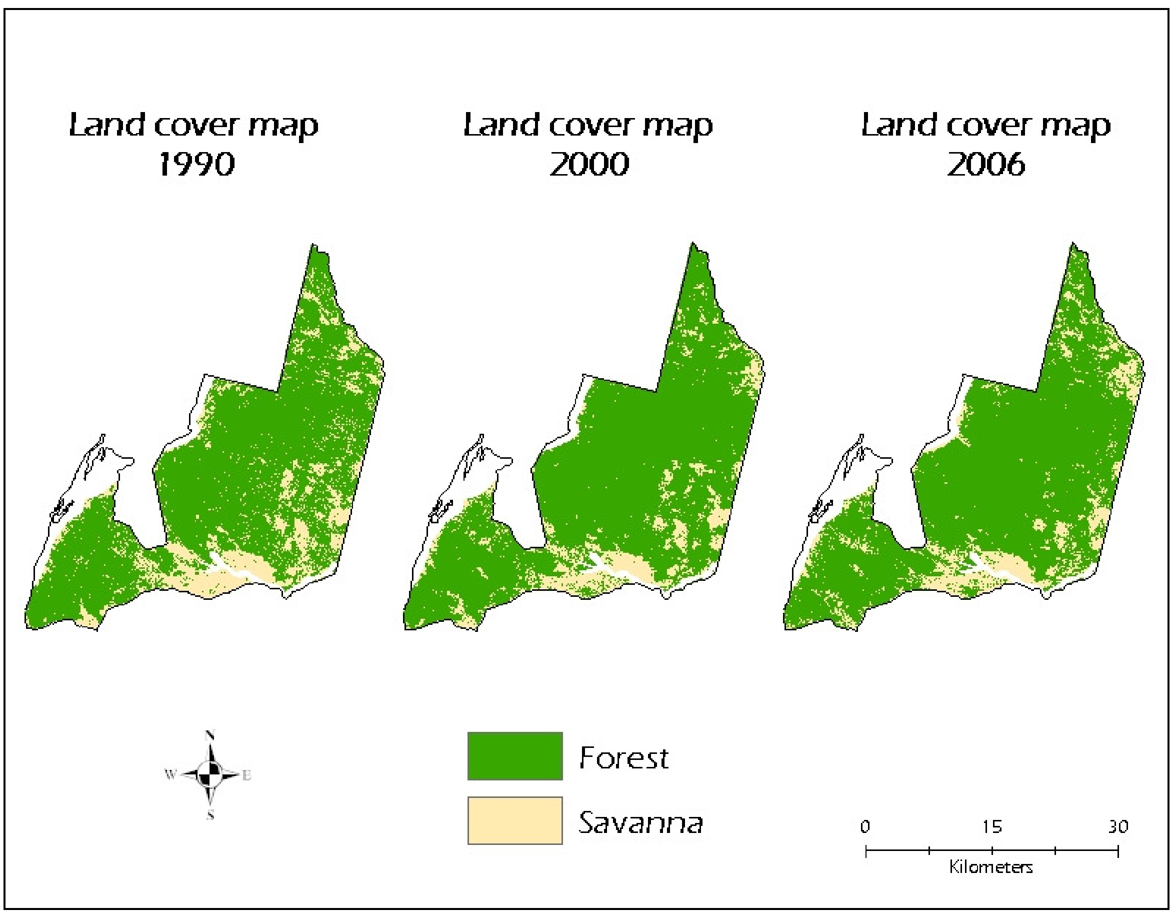

Figure 15 Land cover maps for 1990, 2000 and 2006

6.2 Change analysis

I performed three different change analyses of the forest, from the years 1990-2000, 2000-2006, and 1990-2006. I did this using the three land cover maps discussed previously. I classified the 1990 and 2000 images into only two land cover classes, forest and savanna. However, the 2006 image contained a land cover class called "barren", which consisted of only 319 ha of land. Barren areas were recently cleared or burned, so they are areas of forest loss. In order to easily compare all three land cover maps, I reclassified the "barren" areas into savanna since they are cleared, non-forest areas. The final land cover maps of all three images contain two classes, forest or savanna, so I can easily compare one image to another. Since each image contains two land cover classes, there are four possible directions of land cover change that can take place, as shown in Table 4. I reclassified each individual image into separate codes so that I could easily evaluate the change. After the forest and savanna classes in each image were reclassified, I added them together to make a total of four different land cover classes. I did this two images at a time. I summed the 1990 image with the 2000 image to get the change that occurred during that time. I then summed the 2000 image with the 2006 image to see where the most recent forest changes have occurred. Finally, I added the 1990 image to the 2006 image to see where the overall forest change has occurred over the last 16 years. The final classes that resulted from these analyses were forest to forest, forest to savanna, savanna to forest, and savanna to savanna. The two classes I will focus on for my threat analysis are the areas of forest to forest and forest to savanna. The forest to savanna areas are the most important, as these are the areas where forest has been lost. The

Table 4 Land cover changes that result from the change analysis

		2000	
		10	30
2006	1	Forest to Forest 11	Savanna to Forest 31
	3	Forest to Savanna 13	Savanna to Savanna 33

changes that took place during the three time periods I analyzed are seen in Figure 17. The largest amount of forest that was converted to savanna occurred during 2000-2006, when over 4,800 ha of forest were converted to savanna. In addition, during this time, the least amount of savanna was converted back to forest. Less than half the amount of savanna was converted to forest during this time than what was converted in either 1990-2000 or during the overall period from 1990-2006. This park is a very unusual case in Madagascar in that there has actually been a gain in forest from 1990-2006 of over 4,000 ha. However, for the most recent period, from 2000-2006, there has been an overall loss of almost 2,000 ha. Though the forest has actually regenerated since 1990, it is a major concern that forest loss has occurred during the most recent time period. The areas of forest loss generally occur in the same parts of the study area, particularly close to the park border. In addition, these areas of forest loss seem to be near areas of savanna, so it seems that the savanna areas are either spreading or getting larger.

Table 5 Amount of land cover change from 1990-2006

	Years		
Landcover Change (ha)	**1990-2000**	**2000-2006**	**1990-2006**
Forest to Forest (11)	59,439.96	62,487.27	57,979.62
Forest to Savanna (13)	2,650.05	4,819.14	4,110.39
Savanna to Forest (31)	7,866.45	3,685.77	8,193.42
Savanna to Savanna (33)	8,939.16	7,903.44	8,612.19
	1990	**2000**	**2006**
Total amount of Forest	62,090.01	67,306.41	66,173.04
Total Change from previous year		**5,216.40**	**-1,133.37**
Overall Change from 1990-2006			**4,083.03**

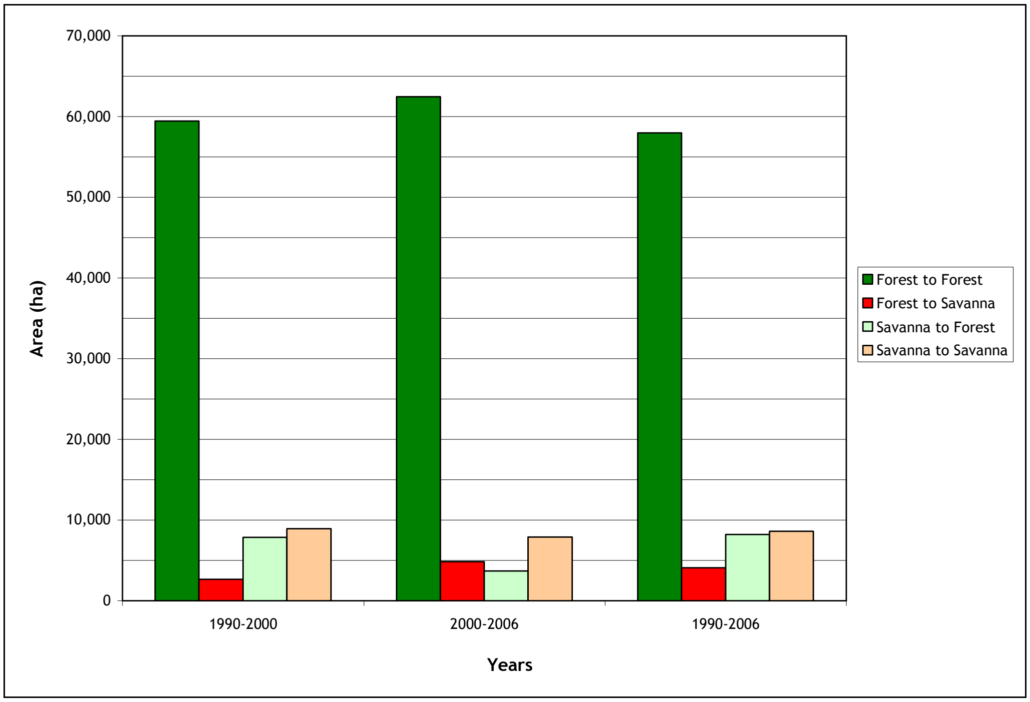

Figure 16 The land cover changes that resulted from the change analysis

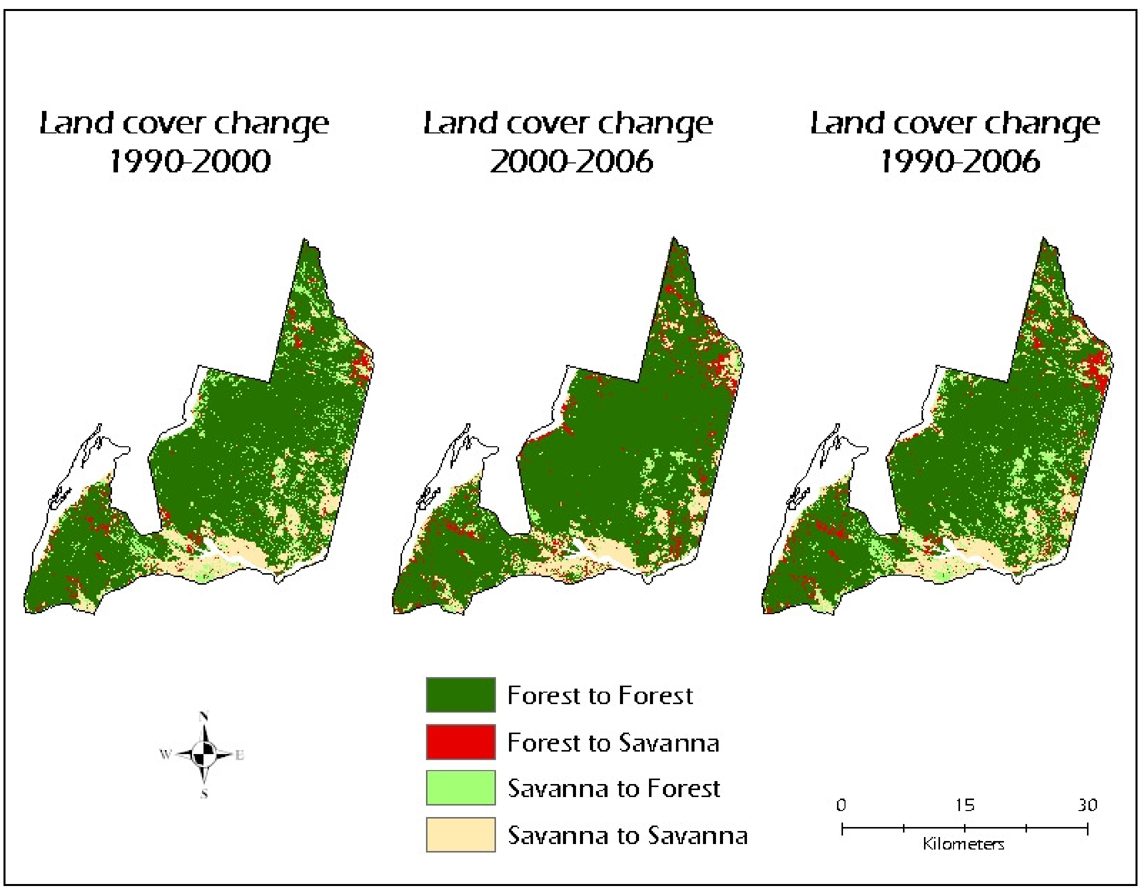

Figure 17 Results of the change analysis

6.3 Determining and mapping viable lemur habitat

In order to determine how large a patch of forest must be to support a viable population of Verreaux's sifaka in Kirindy Mitea, I used the group and home range sizes determined in earlier analysis. I do not have an estimate for minimum viable population size of Verreaux's sifaka in Kirindy Mitea, so I took an estimate from previous studies. According to the literature, 500 individuals is a good estimate of minimum viable population size for a lemur species (Laurance and Bierregaard, 1997). There is an average of six individuals in a group in Kirindy Mitea, so I divided 500 by six to get an estimate of how many groups are needed for a minimum viable population. This turns out to be 83.33 groups. I then multiplied this number by the average home range size of Verreaux's sifaka in Kirindy Mitea, 9.33 ha. This calculates out to be 777.47 ha needed to support a viable population of Verreaux's sifaka. I rounded this number up to 800 ha to have an even, round number to use for further analysis. My calculation of 800 ha is extremely consistent with estimates of minimum patch size for *Propithecus* in other areas of Madagascar (Ganzhorn et al., 2001), so I am confident that this is a good estimate of Verreaux's sifaka patch size in Kirindy Mitea.

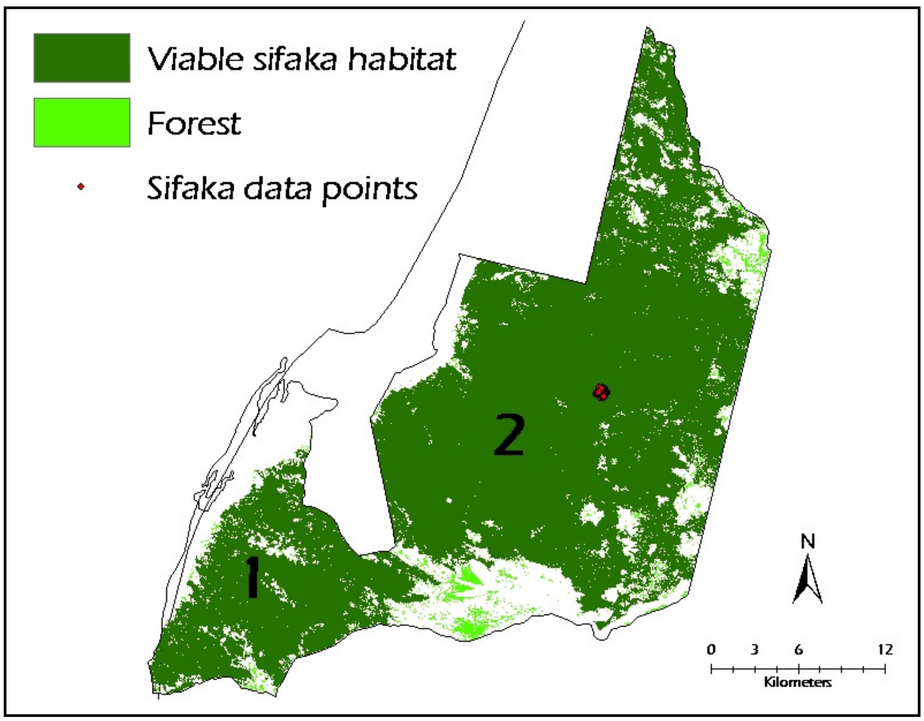

Figure 18 The two forest patches that are large enough to support viable sifaka populations

After determining how large a minimum viable forest patch for Verreaux's sifaka is in the park, I used this to determine which forested areas in the park are large enough to support Verreaux's sifaka. I performed this analysis on only the 2006 land cover map, as this is the most recent map of the park and contains the current forested areas. I first extracted out all the forest in the park using the "Con" tool. I then used the "Region Group" tool to locate all the different forest patches in the park. This tool locates different patches by using a roaming window and grouping together cells of similar composition, using the four nearest neighbor's rule of connectivity. Only cells that touch one of the four walls of another similar cell are grouped together. After using this tool, I ended up with 4,079 total patches of forest. Table 6 shows the number and size of the forest patches that are found in Kirindy Mitea. Almost all of these patches were very small; over 3,800 of them are less than 1 ha. I only wanted patches larger than 800 ha, so I used the "Con" tool again to extract out only forest patches that were larger than 800 ha. This removed nearly all the forest patches, leaving only two patches. However, both of these patches are well over 800 ha. Patch 1 is 14,097.33 ha, while patch 2 is 50,223.06 ha. Both of these patches are more than adequate for supporting lemur populations. In addition, the forest in the park is contiguous, with the majority of it found in the two large patches that are fairly close to each other.

Table 6 The size and number of forest patches in Kirindy Mitea

Size	Number of Patches
< 1 ha	3,878
1 - 10 ha	188
11 - 100 ha	6
101 - 1,000 ha	3
1,001 - 10,000 ha	0
10,001 - 30,000 ha	1
> 30,000 ha	1

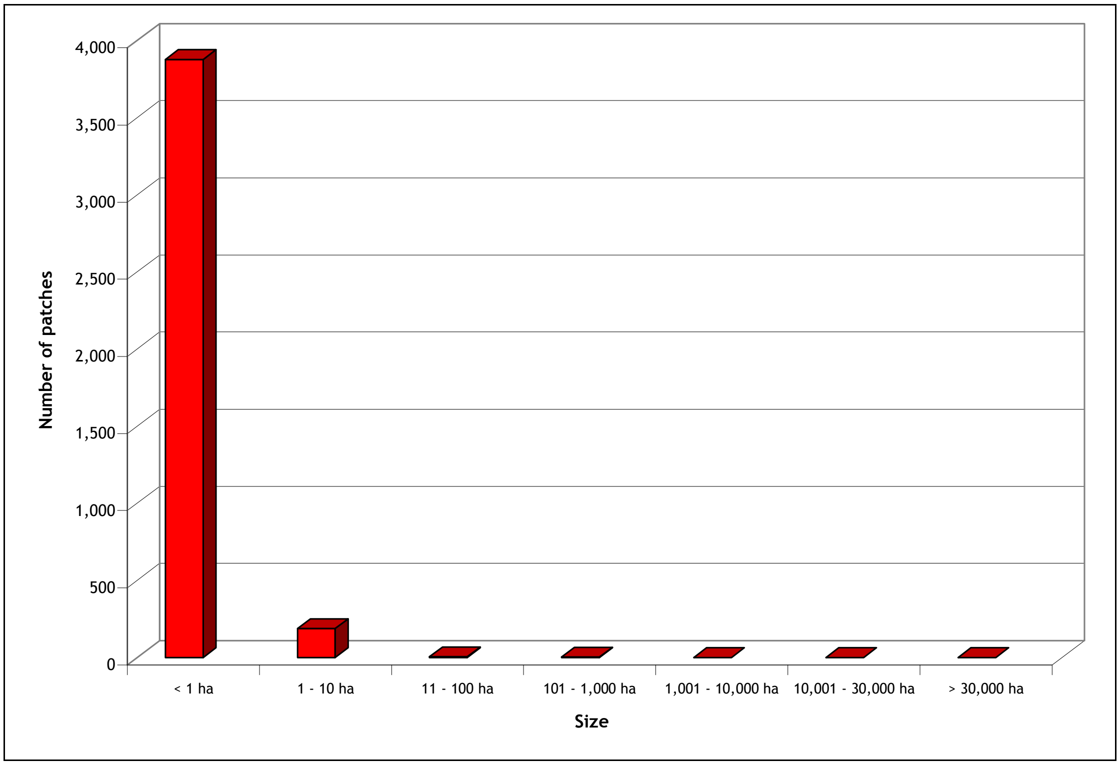

Figure 19 The number and size of forest patches within the study area

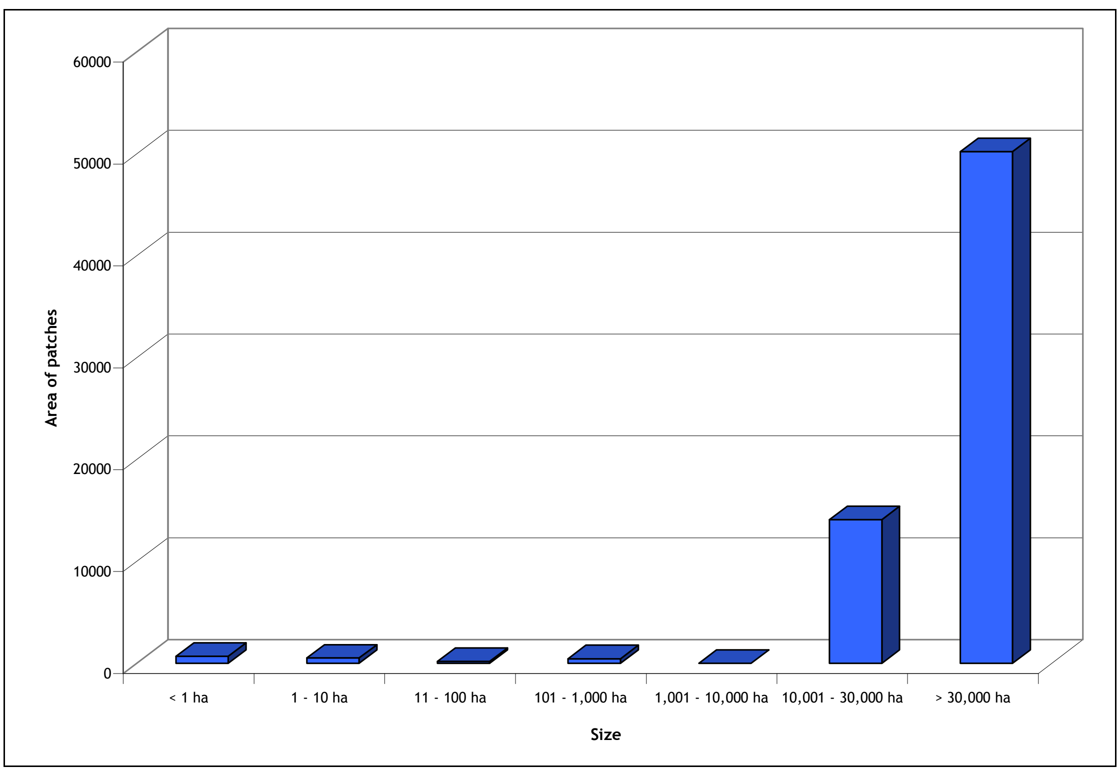

Figure 20 The size and area of the forest patches in the study area

Section 7: Threat analysis of Kirindy Mitea

The goal of this objective is to determine the current patterns of deforestation in the park, and use this to predict where future deforestation may occur in the park. To do this, I will be looking at several different predictor variables. I will use a model to determine how the previous areas of forest loss relate to those predictor variables. The methodology used for this threat analysis is similar to one conducted by Jodie LaPoint, MEM '05, for her master's project entitled "The Loss of Forest Habitat for Lemurs in Ankarafantsika National Park, Western Madagascar".

7.1 Dependent variable

The change analysis described above determined where forest has been lost, and where forest remained forest in the study area during the last 16 years. I will be using the areas where forest remained forest and where forest was lost from 1990-2006 as the dependent variable for the threat analysis. The model will look at how the areas of forest loss relate to three different predictor variables, in order to determine where forest loss has and will possibly occur in the park in the future.

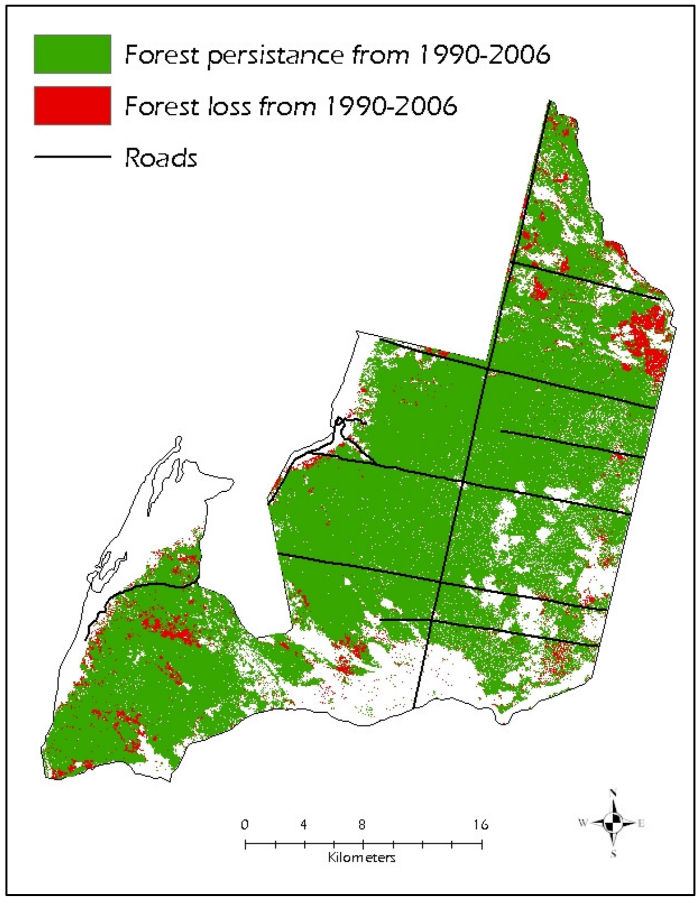

Figure 21 Dependent variable used in the threat analysis

7.2 Deforestation predictor variables

Before beginning the threat analysis, I had to determine which factors would most likely lead to deforestation in the park. Deforestation is prominent throughout Madagascar, and it is primarily due to anthropogenic disturbances.

Forest loss generally occurs very close to humans and to human activities, such as logging and burning. Laurance and Bierregaard (1997) found that proximity to villages and roads were the best predictors of deforestation in the dry forest. In order to do the threat analysis, I will be looking at different ways humans can access the forest in the park, such as through roads and the savanna. In addition, forest close to the park boundary may also be at high risk of deforestation since it is easier for humans to access than the forest in the center of the park. It order to determine the current patterns of deforestation, I will be using three different predictor variables to see how previous areas of forest loss relate to each of the variables. These variables are distance from savanna, distance from roads, and distance from the park boundary, as shown in Figure 22. I used the distance from where the savanna was in the 1990 land cover map. Since my change analysis only involved two land cover classes, forest and savanna, the forested areas lost during 1990 to 2006 almost directly correspond to where savanna is in the 2006 image. However, I wanted to determine whether forest lost during 1990-2006 was close to areas of previous forest loss, and if humans were using the savanna to access the forest in the park. Therefore, I had to use the distance from the 1990 savanna as a predictor variable.

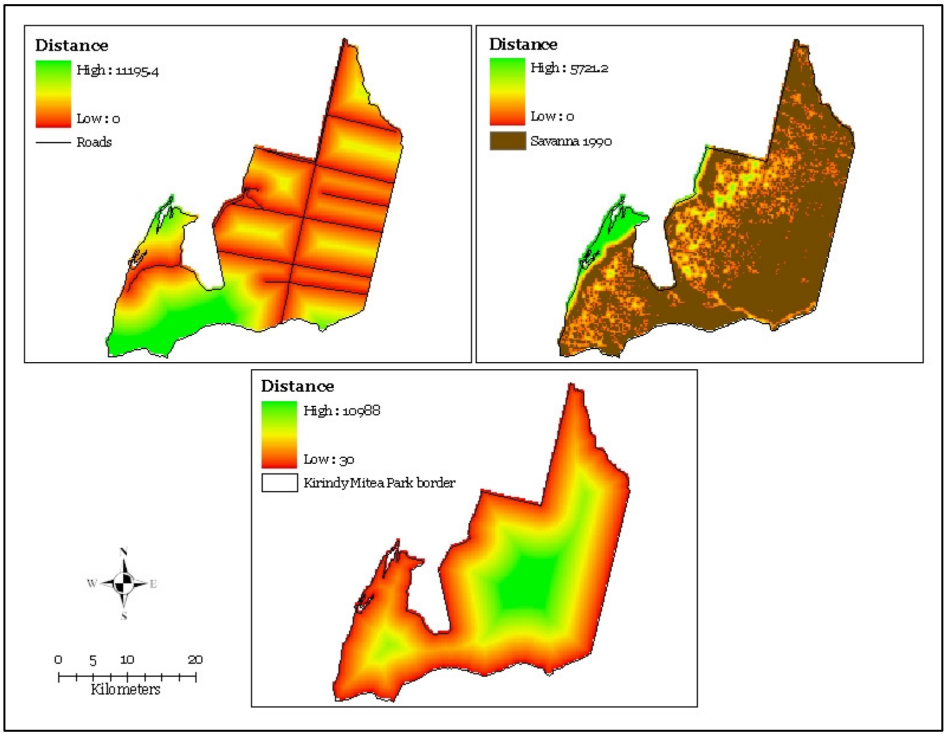

Figure 22 Predictor variables used in the threat analysis

7.3 CART model

I created the model of forest loss using a Classification and Regression Tree, or CART model. CART models explain a categorical dependent variable with one or more explanatory, or predictor, variables. The model works by recursively partitioning the data into groups using rules based off each of the predictor variables. It continues to split the data into subgroups until the final groups are as homogenous as possible (De'ath and Frabricius, 2000). I gathered the data for the CART model using the dependent and predictor variables explained above. Using ArcMap, I created a random sampling of almost 65,000 random points located in areas of forest persistence, or areas of forest loss (the dependant variable). I then got the values from each of my predictor variables, distance from savanna, distance from roads, and distance from the park boundary, for each one of the 65,000 sample points. The "Sample" tool in ArcMap simply looks at a sample point and wherever that point is, it takes the distance values from each of the three distance layers and assigns them to that point. I did this for all 65,000 sample points, and then exported the data to a dBASE file. I

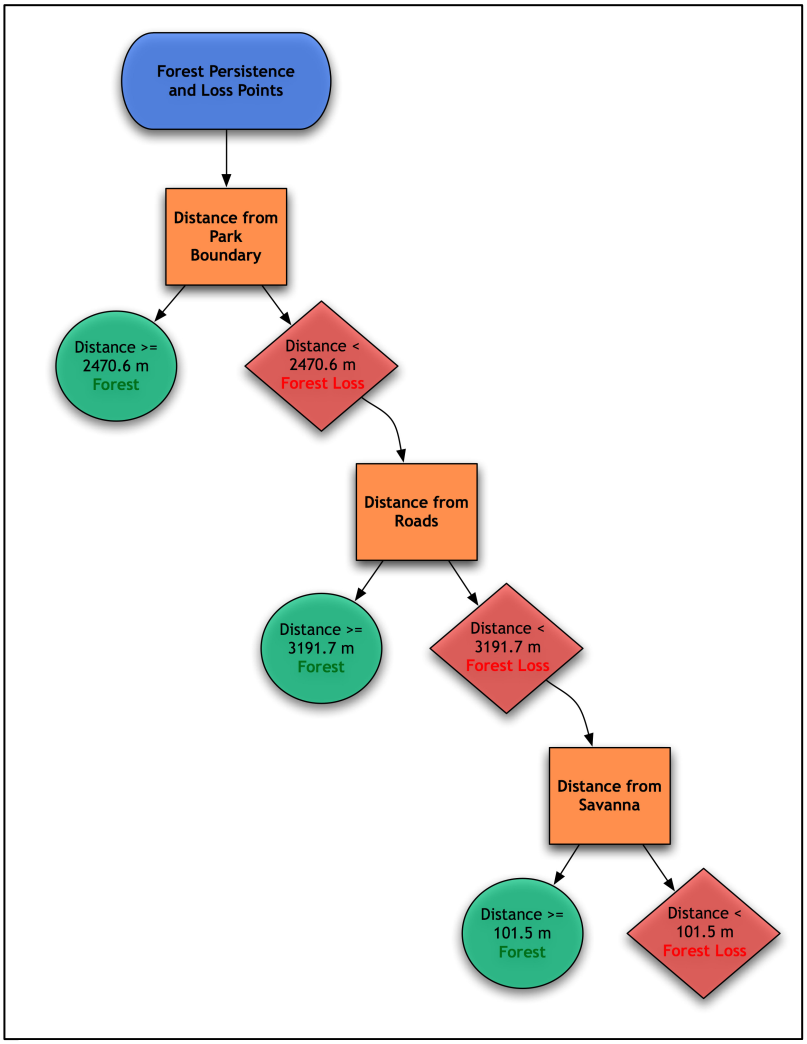

Figure 23 Final CART model for predicting forest loss in Kirindy Mitea

then imported this file into S-plus. Using the tree statistics function, I created a CART model in S-plus. The first model was very large, with 166 different nodes. I pruned this tree at 4 nodes to create a tree that was much simpler and easier to read. The misclassification rate of the model was 0.05551 or 5.6%. The model only misclassified 3638 / 65535 points, which is a very good classification.

7.4 Results of CART model

The final model contains three nodes and all three predictor variables. The most important predictor variable for determining forest loss in the park was distance from the park boundary. This makes sense, as it is easy for local people to access these areas. In addition, distance from roads was the next most important variable. This also makes sense, as roads are the primary way people access the interior forest of the park. Distance from savanna was the third ranked variable, however was still important for looking at forest loss in the park. I then brought the results of the final tree back into ArcMap, and used them to map the areas that are at high risk of future forest loss. I did this using the "Single Output Map Algebra" tool. This tool can perform many different functions, as well as execute mathematical

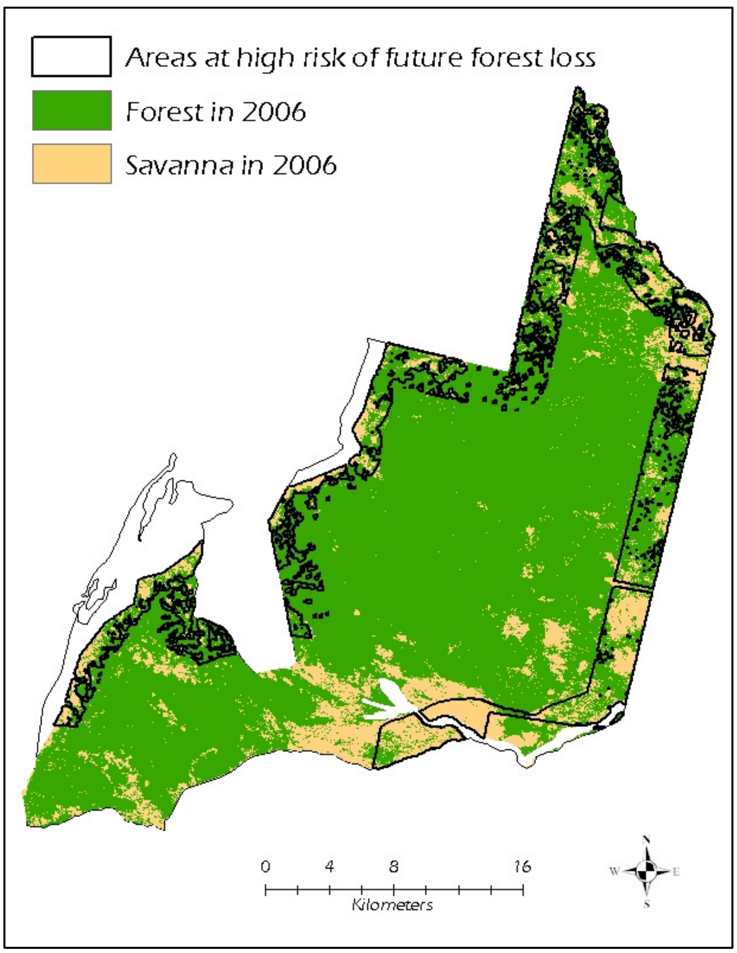

Figure 24 The areas that are at high risk of forest loss in the future as predicted by the CART model

functions on several different layers at once. I used the “Con” function to select out only the areas of the park that met the criteria specified by my CART model. The resulting areas appear in Figure 24. The areas outlined in black are the areas of the park that are at highest risk of future deforestation, as predicted by my model. From this map, it is clear that the northern and western areas of the park are most threatened. The total threatened area based on the results of the model is 22% of the study area. This is less than a quarter of the study area, but the threatened areas are concentrated around the border of the park. It is a positive finding, though, that the forest in the center of the park seems to be protected for the time being.

Table 7 Areas at high risk of forest loss as predicted by the model

Study Area (ha)	Amount at high risk of future forest loss (ha)	Percent
78,895.62	17,499.78	22.2%

Section 8: Determining lemur habitat at high risk of deforestation

The final goal of my project is to determine the lemur habitat in the park that is at highest risk of future forest loss. I will create a final map that park managers can use to protect the areas of forest that may be lost in the future.

8.1 Mapping the high risk lemur habitat

To map out the high-risk lemur habitat, I used the two viable lemur habitat patches that I described earlier. In addition, I used the map of the threatened areas that resulted from my CART model. I simply placed the threatened areas map over the two viable lemur habitat patches. The threatened areas that remain are shown in Figure 25. The areas in red are the lemur habitat that is at the highest risk of forest loss in the future. The red areas exist primarily around the borders of the park. These areas need the greatest protection; therefore, park managers should concentrate their efforts on finding new and improved methods of protecting them.

Table 8 Areas of viable lemur habitat that are at the highest risk of future forest loss

Patch	Total Area	Area at high risk of future forest loss	Percent
1	14,097.33	1,362.96	9.7%
2	50,223.06	9,190.80	18.3%
Total Viable Forest	64,320.39	10,553.76	16.4%

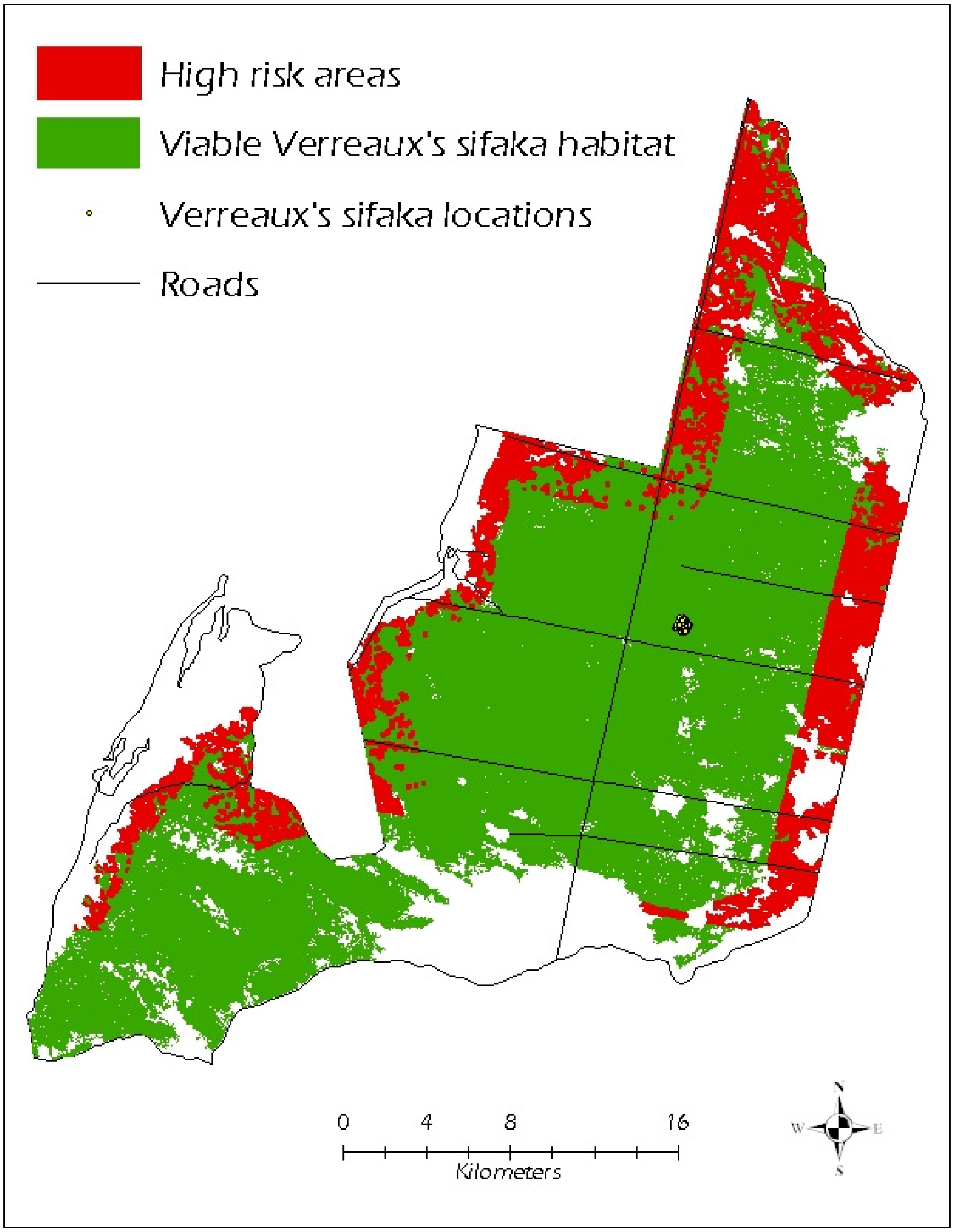

Figure 25 Areas of viable lemur habitat at high risk of forest loss in the future

Section 9: Discussion of Results

Overall, Verreaux's sifaka of Kirindy Mitea seem to differ from the sifakas in BMSR and CFPF. Though their group sizes are similar, the home ranges of the social groups are markedly different. The Kirindy Mitea sifaka live in a unique habitat in southwestern Madagascar, one that is unlike previous research sites for the species. This different environment led to them to adapt larger home ranges, and to have little contact with neighboring groups. This project is the preliminary look at the species in Kirindy Mitea, so it only contains data from the dry season. However, the first GPS data from the wet season has just been collected, however too late to be included in this project. It will be very interesting to see how the dry season and wet season home ranges compare. The first look at this data suggests that the home ranges do in fact shift, and actually may slightly overlap (Lewis, personal communication). However, this will have to be verified when the data is analyzed.

The results of my analyses show that Kirindy Mitea actually contains a large amount of contiguous dry, deciduous forest, and the amount has actually increased since 1990. This is an exciting finding, as most of the dry forest in Madagascar is fragmented, existing now only in small, isolated patches. In addition, very little forest loss has occurred in the center, core area of the park. In order to maintain viable populations of the large species in Kirindy Mitea, it will be extremely important to continue protecting this continuous forest. Currently, the forest is split into two large patches that are much bigger than 800 ha, the amount required for a viable population of Verreaux's sifaka. This amount of forest will adequately support the sifaka groups. Laurance and Bierregaard (1997) stated that forest patches larger than 5,000 ha in size are of greatest importance to conservation, as they support large animal populations and there are so few of them remaining on the island.

The change analysis from 1990 to 2006 shows that, while there has been an overall gain in forest, the areas of forest loss occur primarily near the park boundary and near areas of savanna. My analysis of the threats to the forest shows that the areas along the park boundary and roads are at high risk of future forest loss. It appears as though humans are easily able to access the forest near the edges of the park, and can access interior forest via the roads. Although there is little fragmentation currently in the park, the results of the threat analysis show a possibility of future fragmentation. Several areas of viable lemur habitat may end up isolated if the areas highlighted in red in Figure 25 are indeed deforested in the future. In addition, 22% of the forest near the boundary of the park is highlighted as a high risk area. This suggests that forest loss will start at the outside edges of the park, then work its way in. In addition to causing the overall amount of forest to decrease, this type of forest loss will increase the amount of edge. Lemurs are actually tolerant of edge effects, which may help explain why they persist in Madagascar even through massive habitat destruction (Lehman et al., 2006). Therefore, the increase in edge will not have an immediate negative impact on the lemur populations in the park. However, an overall decrease in the amount of forest and fragmentation of the currently continuous forest in the park will be extremely detrimental. Fragmentation leads to secluded forest patches, which creates small, isolated animal populations. Isolated populations are unable to maintain genetic diversity, and are at a very high risk of extinction (Laurance and Bierregaard, 1997). If lemur populations are to persist in Kirindy Mitea, it will be of utmost importance to prevent fragmentation of the forest in the park.

Section 10: Conclusions and recommendations

Kirindy Mitea is a unique park in that it contains so many different habitat types. This distinctive habitat, and the lack of a major food source like tamarind trees, has led the Verreaux's sifaka social groups to adapt larger home range sizes with little overlap with neighboring groups.

Since these lemurs differ with others in the same region of Madagascar, conservation efforts must also be different. These species do not occur at high densities like at other sites, so they will require more habitat than sifakas at BMSR or CFPF might. It is important to consider this when creating a management plan for the sifaka in this park.

My analyses show that the areas of forest closest to the park boundary, roads, and savanna are at highest risk of deforestation in the future. To protect the forest in the future, park managers should focus their efforts on the high-risk areas, which I highlighted in red in my final map. The forest close to the park boundary is at highest risk, so it is most important to prevent forest loss from occurring in these areas. Creating a buffer area around the park will be very beneficial and help prevent people from simply walking right up the park border and cutting or burning the forest. According to Laurance and Bierregaard (1997), buffers of at least 4-8 km are needed to protect a forested area from human activities such as slash and burn agriculture and hunting. These buffers are especially important for forest patches like Kirindy Mitea that are in close proximity to villages and roads (Laurance and Bierregaard, 1997).

In addition, the roads throughout the park create an easy pathway for people to access the forest. Managers must find a way to monitor the roads to stop people from walking up them and then either selectively cutting down trees or actually burning sections of forest. Additional on-the-ground officers and security that monitor the roads would help to catch people who are illegally harvesting trees, in addition to simply deterring people who might remove trees in the future.

Finally, though there has been an overall gain in forest since 1990, over 2,000 ha of forest has been lost in the last six years. These areas of deforestation during 2000-2006 occurred near areas that were already savanna in 1990. From the change analysis, it is evident that deforestation is spreading from areas of previous forest loss. It is important to halt this trend by also monitoring the areas near savanna, as these are areas also easily accessible to humans.

Similar to other parks in Madagascar and in other tropical countries, Kirindy Mitea park managers have little funding to put towards conservation and protection efforts. This analysis looked at how forest loss occurred in the park over a sixteen-year period, and used these trends to determine the areas at highest risk of deforestation in the future. The most important result of this analysis is the determination of where forest loss is most likely to occur in the future. The park managers can put their limited funds toward conservation efforts that will protect the park most effectively, such as the buffer zone or additional staff to monitor roads. Park managers now have the much needed knowledge of how forest loss is currently happening it the park, and how it may occur in the future. They can use this knowledge to protect the forest that is at high risk of deforestation, and help stop the loss of dry forest that is occurring across the entire western region of Madagascar.

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