OF MONKEYS AND MEN: GEOSPATIAL HABITAT ASSESSMENT FOR CAPUCHIN CONSERVATION

by

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(Under the Direction of Marguerite Madden)

ABSTRACT

Brazil and Costa Rica, two of the most biologically diverse countries in the world, are facing unique environmental, social, and economic pressures influencing the conservation of habitats supporting a variety of species. This research aimed to explore two distinct habitats threatened by increased development and large scale agriculture that are both inhabited by wild capuchin monkeys. By integrating global positioning system (GPS) coordinates documenting capuchin monkey home range, historical and current satellite imagery, and a geographic information system (GIS) to characterize and spatially assess the scenes, these analyses produced quantitative information to strengthen policy and management decisions in Brazil and Costa Rica. Results improved understanding of: 1) use of a time series of medium resolution satellite imagery to model risk of rapid land use/land cover (LULC) change on bearded capuchin monkey habitat in Brazil; and 2) assessment of white-faced capuchin monkey habitat in Costa Rica using high resolution satellite imagery.

INDEX WORDS: Geographic information system, Global Positioning System, Landsat, RapidEye, Spatial assessment, Conservation, Capuchin monkeys, Costa Rica, Brazil

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DEDICATION

For Iroquois, and all of her kind.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION, RESEARCH OBJECTIVES, AND STUDY AREA

The best laid plans of mice and men/Often go awry – Robert Burns, 1785

Introduction

Perhaps one of the most famous literary references of all time can remind us that even when we mean no harm, our actions can be destructive. For as long as humans have been modifying the environment, other organisms have been affected. The third wave of animal geography is a subfield of Geography that focuses on the complex entanglements of human-animal relations with space, place, location, environment, and landscape (Urbanik 2012). This modern subfield of critical biogeography (Sarmiento 2012) in conjunction with innovative applications in geospatial technology is changing the ways in which environmental concerns, policy decisions, and conservation efforts can be approached and addressed. The ability to integrate global positioning system (GPS) field data, remotely sensed satellite data, and geographic information systems (GIS) allows scientists to more accurately assess and monitor evidence of human-animal interactions and impacts on Earth's resources.

Brazil is considered to have the greatest biodiversity of any country on the planet. Although the Amazon biome is well known for housing at least 10 percent of the world's biodiversity (WWF 2014) the Brazilian Cerrado region covers percent of the country and supports more than 160,000 species of plants, animals and fungi (Ratter, et al. 1997). One of its many mammals, the bearded capuchin monkey (*Sapajus libidinosus)*, has received attention for its relatively newly discovered ability to use tools, which has raised awareness of the recent human threats to habitat conducive to this tool use (Figure 1.1).

Figure 1.1: Bearded capuchin engaged in tool use behavior (photo by Thomas Jordan)

The Etho*Cebus* team, made up of researchers who study the behavior of capuchin monkeys, first documented their percussive tool use in 2003, making it the only known non-ape primate to possess this skill (Fragaszy et al. 2004). The bearded capuchin monkeys in northeastern Brazil crack open palm nuts using stones as hammers and anvils. Tool use by primates is of great interest to these and other scientists because it offers insight into the animal's cognitive processes and may lead to a further understanding of human evolution (Visalberghi et al., 2006). While this topic remains popular in the field of Primatology, there is rising concern that the landscape supporting both the capuchins and this behavior is under threat. Increased demand for large agricultural fields for food and biofuel is affecting the Brazilian savanna and its wildlife by clearing natural forests and shrublands for monoculture agricultural production (Figure 1.2).

Figure 1.2: Clear-cutting in the Brazilian savanna (photo by Allison Howard)

Similarly diverse, Costa Rica is home to four species of monkeys and presents some of the world's greatest challenges and opportunities for biodiversity conservation due to increasing development for ecotourism and agriculture (Broadbent et al. 2012). Its extraordinary number of species per unit of area explains its reputation for being one of the world's richest hot spots for biodiversity (Myers et al. 2000 and Kohlmann et al. 2010) (Figure 1.3). Interestingly, Costa Rica has the most ecotourists per km^2 worldwide (Kohlmann et al. 2010).

Figure 1.3: Costa Rican Cloud Forest (photo by author)

White-faced capuchin monkeys (*Cebus capucinus*), a resilient species native to the forests of Central America, are coming into increasingly frequent contact with humans and human modified environments (Figure 1.4). These flexible, human-commensal populations use a broad range of habitats and have the opportunity to exploit alternative food resources (Lehman 2004). Supplemental feeding, whether in the form of crop-raiding, tourist handouts, or active provisioning, has the potential to be one of the most influential forms of anthropogenic disturbance, affecting primate ecology, demographics, and social behavior (McKinny 2010).

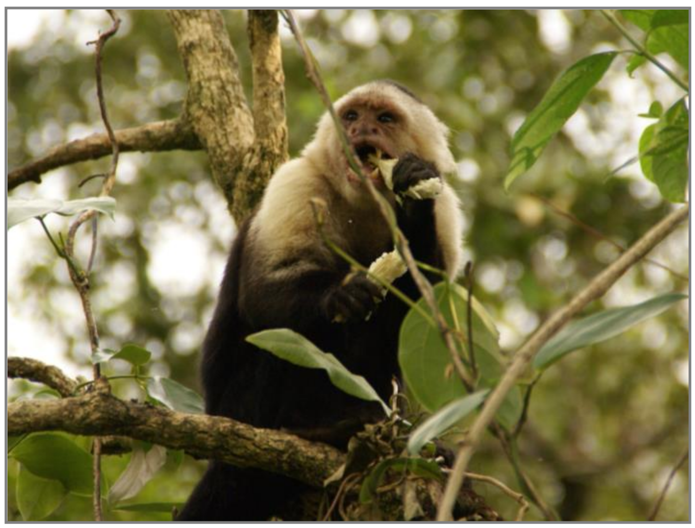

Figure 1.4: White-faced capuchin eating sugar cane (photo by Jeanice M. Plourde)

The bearded capuchin of Brazil and the white-faced capuchin of Costa Rica both have foraging methods that are reliant on two major components: the landscape and local traditions/cultural transmission (Figure 1.5). The latter indicates a high degree of social learning for food acquisition and many other behaviors. Studying these primates is vital to our understanding of human evolution and behavior. Additionally, their behavioral plasticity and high level of social learning allow them to adapt and respond quickly to both obvious and obscure changes in their environment, potentially making them a useful indicator species for environmental change through observable changes in their behavior. While these monkeys are common in the media and laboratories, their natural habitats are at risk, along with many other species.

Ground truth data, consisting of GPS coordinate points representative of capuchin home range, were collected at the Etho*Cebus* research site in Piaui, Brazil. Massive agricultural expansion for biofuel is threatening this fragile ecosystem. Thus, one of the goals of this research is to use the advantages of remote sensing and geospatial techniques to specifically assess threats to capuchin monkey habitat. GPS coordinate points representative of capuchin habitat were also gathered in the cloud forest of San Luis de Monteverde within and surrounding the University of Georgia's Costa Rica campus (UGA Costa Rica). Since UGA purchased the land in November of 2001, sustainability initiatives have been integral to the management of the campus. Treading lightly on the landscape and developing strong social bonds within the community were and remain characteristics evident in the operation of UGA Costa Rica, even as it has grown in size and scope (UGA Costa Rica 2014). This research seeks to produce the first documented geospatial work analyzing capuchin monkey habitat in this area.

The stakes of understanding the geographies of human-wildlife relations are high and speak to fundamental questions about how we see ourselves inhabiting this planet (Urbanik 2012). Comprehending environmental change is a challenge worth tackling so that we are better prepared to handle the challenges that face our society and future generations. This study aims to do so through an investigation of human-animal interaction and impacts on ecologically important environments.

Figure 1.5: White-faced capuchin in San Luis, Costa Rica and bearded capuchin in Piaui, Brazil (photos by Jeanice M. Plourde and Thomas Jordan, respectively)

Research Objectives

Brazil and Costa Rica are both biodiversity-rich countries with highly dynamic cultural landscapes experiencing deforestation, agricultural growth, reforestation, and development pressures of tourism. Human land use activities have transformed these areas and it is important to understand the extent and implications. Fortunately, we are armed with the data, tools, and technology to explore this reality and attempt to address the associated environmental concerns. Since 1972, National Aeronautics and Space Administration (NASA) Landsat satellites have collected imagery that enables scientists to study Earth's natural resources, ecosystems, geology, and land use. The long data record allows investigators to evaluate the changes caused by both natural processes and human practices. This research seeks to quantify and visually demonstrate the impacts of land use and land cover change on capuchin monkey habitat in Northeastern Brazil using a time series of imagery spanning the past 26 years. An additional goal of this work is to simultaneously examine human and capuchin land use within and surrounding the University of Georgia's (UGA) Costa Rica campus so that current capuchin monkey habitat choice throughout this anthropogenic landscape can be visualized and quantified. The methodologies created for this project can be used to effectively assess and monitor these habitats in the future.

The research objectives are as follows:

1) Land use/land cover (LULC) classification: Use remote sensing techniques to detect, map, and illustrate LULC in Brazil and Costa Rica.
2) Spatial assessment: Integrate GIS, GPS, habitat modeling, and satellite imagery to spatially assess human impacts on habitat.
3) Application: Assist decision-makers and local people in understanding land transformation, emphasizing habitat conservation.

Study Area

This thesis had two study areas: Northeastern Brazil (Study Area 1) and UGA Costa Rica (Study Area 2). Study Area 1 (Figure 1.7) encompasses the area covered by the Landsat satellite image used for the LULC classification and spatial assessment. The GPS data were collected at the Etho*Cebus* field site located in northeastern Brazil at the southern tip of the state of Piauí (9° 39'S, 45° 25'W). The field site, where capuchin monkey tool use behavior has been observed, has an area of 100 km^2 and is approximately 420 m above sea level (Oliveira and Marquis 2002). It is the area in which ground data for satellite image georeferencing and data on vegetation and tool use behavior were previously collected (Hinely 2006).

The most common vegetation type in this area is called Cerrado and represents a heterogeneous canopy cover, divided into five different physiognomic structures: *cerradão, cerrado sensu stricto, campo cerrado, campo sujo,* and *campo limpo*. The height of the trees varies among the five physiognomies with the lowest tree heights averaging 4 meters in *Campo cerrado* and the greatest tree heights averaging 20 meters in the *Cerradão* (Vourlitis and Rocha

2011). The Cerrado understory is composed of mixed grasses, small shrubs, and ground palms producing the palm nuts the capuchin monkeys exploit through their unique use of tools in this area (Figure1.6).

Figure 1.6: Cerrado vegetation found at the Etho*cebus* field site (photo by Thomas Jordan)

This region's climate is described as seasonally dry with an average annual rainfall of 1,100 mm and average dry season rainfall of 230 mm (Visalberghi et al. 2006). The field site is a plain with low-nutrient sandy soils punctuated by sandstone ridges, pinnacles, and mesas, composed of sedimentary rock, rising steeply to 20-100 m above the plain (Visalberghi et al. 2007). These sandstone ridges and mesas are known as morros. Sandstone boulders that break off of these formations, in addition to logs, are the main objects used as anvils. The water that cuts the anvil boulders from the top of the morros flows through ephemeral stream beds which erode into the lower levels. This frees the siliceous stones from the conglomerate layer and makes ideal hammer stones for the capuchin monkeys (Hinely 2006). This unique combination of landscape characteristics facilitates capuchin tool use.

Figure 1.7: Study Area 1 – Northeastern Brazil

Study Area 2 (Figure 1.9) is located in San Luis, Costa Rica and is nestled adjacent to the Monteverde Cloud Forest Reserve along the continental divide. The UGA Costa Rica field station encompasses 62 hectares and varies in elevation between 700 and 1,400 m (Holdridge 1966). The mean temperature is 16-18° C and annual rainfall is 299 cm. Three major types of native flora converge at the UGA Costa Rica Campus: premontane species from both Pacific and Atlantic Slopes, lower montane species from higher elevations and riparian species from middle to higher elevations (Figure 1.8). This diversity of influences increases the region's biodiversity. It is estimated that there are at least 3,200 plants species in the Monteverde region.

Figure 1.8: Cloud forest vegetation found within the UGA Costa Rica campus (photo by author)

The UGA campus is managed for multiple uses. Sixty percent of the 62 hectares are maintained in protected forest reserve as part of Costa Rica's National Network of Private Reserves. Thirty percent of the property is managed for sustainable agricultural production. The remaining ten percent is managed as “built space” which includes facilities for academic instruction, research, food service, residences, recreation, and maintenance (UGA Costa Rica 2014).

Figure 1.9: Study Area 2 – UGA Costa Rica

CHAPTER 2

REVIEW OF LITERATURE

This chapter provides an overview of the literature and key concepts fundamental to this project. The following topics will be reviewed: 1) Ecological region, policy, and capuchin monkeys; 2) Spatial assessment; and 3) Applications for conservation.

The Cerrado, Brazilian Policy, and the Bearded Capuchin Monkey

Tropical Savanna biomes are known for their vast ranges of plant and animal diversity (Hill & Hanan et al. 2011). The Brazilian savanna, referred to as Cerrado, is estimated to support 160,000 species in its 2 million km^2 area (Oliveira 2002). Cerrado is the second largest of Brazil's biomes, after the Amazon. It is present in ten Brazilian states, and ranges from 0 to 1,800 m in elevation (Vourlitis and Rocha 2011). There are several subclasses of Cerrado based on height, cover, and density of vegetation.

More than half of the Cerrado has been transformed into pasture, cash-crop agriculture, and other uses in the past 35 years. Pastures cover at least 500,000 km^2, and crops cover more than 100,000 km^2 and the area under conservation is roughly 33,000 km^2 (Klink and Machado 2005). It is estimated that deforestation in the Cerrado is occurring at twice the rate of deforestation in the Amazon (MMA 2009). The current broad-scale agricultural investments with international partnerships are made possible and legal because of earlier state laws and land grabs (Oliviera 2013). The process of increasing agricultural land requires deforestation, water supply, and soil treatment which directly impacts the native species inhabiting the area. Unfortunately, the effects of increasing agriculture in the Cerrado outpace protective legislation.

The widespread transformation of the Brazilian Cerrado and the threatened status of many of its species have led to increased attention and conservation initiatives from government, nongovernmental organizations (NGOs), researchers, and the private sector (Klink and Mochado 2005). This motivated more restrictive government regulation that limited purchases by foreign individuals or enterprises. However, broad-scale agricultural investments in various links of agricultural production chains continue to take place (Oliveira 2013).

The 2006 proposal to the United Nations Framework Convention on Climate Change (UNFCCC) of a global fund for positive incentives for reducing deforestation can be viewed as a landmark of the evolution of the Brazilian position (Carvalho 2010). Since then, Brazil has gained political weight in climate change and forest negotiations. The country's position is backed by a legal and institutional framework designed in 2008 with the Amazon Fund and the National Climate Change Plan, and in 2009 with the launching of the voluntary quantified emission reduction commitments inscribed in a national law. Despite important achievements, deforestation and desertification are still a threat to environmental services at the local, regional, national, and global levels (Carvalho 2010; Souza and Oyama 2010).

The bearded capuchin monkey (*Sapajus libidinosus*) is a new world monkey that inhabits the Brazilian Cerrado. This species has received attention for its relatively newly discovered ability to use tools. At the Etho*cebus* field site in Northeastern Brazil, researchers observed monkeys using stones as hammers to crack open nuts placed on stone or log anvils. The presence of anvil sites, abundant in this region, contributes to the monkeys' routine exploitation of palm nuts via cracking them with stones (Visalberghi et al. 2007). To do so, capuchins combine three elements in a specific way: an encased food, an anvil-like surface, and a hammer-like stone (Fragaszy et al. 2004). All three of the above elements are essential resources for tool use. These resources are not uniformly spatially distributed (Visalberghi et al. 2007) and anvil sites tend to be located near the base of morros on a moderately steep slope (Hinely 2006). The nut cracking behavior is believed to be directly related to the unique characteristics of the landscape.

Environmental conservation efforts are generally focused on preserving global biodiversity. It is well accepted that genetically unique populations and subspecies of wild organisms and even breeds of domestic animals, are worthy of conservation efforts. However, the outcomes of gene–environment interactions, namely morphological, physiological, and behavioral traits, have been relatively neglected (Caro and Sherman 2012). Preserving behavior, including the rare behavior of the bearded capuchin, is a worthy conservation goal for the following reasons: 1) loss of behavioral diversity may prevent a population from adapting to future environmental changes; and loss of behavioral flexibility within an individual may prevent it from adapting to sudden habitat alterations, 2) disappearing behaviors may signal the loss of mechanisms that predispose individuals to behave in a certain way; or absence of environmental conditions that allow a particular behavior to develop or to be manifested; or, in the case of population extinction, loss of all individuals that behave in a particular manner, and 3) behavioral diversity provides a window to social and ecological challenges that are important enough in a population's evolutionary history to result in presently observable behavioral responses (Caro and Sherman 2012).

Studying the mechanisms underlying cooperation, reciprocity, inequity, aggression, tool use, and responses to environmentally induced stress in non-human primates shed light on human behavioral evolution. Bearded capuchins living in the Brazilian Cerrado display a behavior and ability that was previously thought to have emerged two million years ago at the time our genus (*homo*-great apes including modern humans) originated. The discovery of this

New World monkey behavior forced scientists to question the convergence of tool use in human and non-human primates. While this topic remains popular in the field of primatology, there is rising concern that the landscape supporting both the capuchins and the aforementioned behavior is being threatened.

Capuchin monkeys are not only behaviorally significant, but also ecologically important. Seed dispersal is a key process in forest maintenance (Howe and Smallwood 1982) and capuchins are considered effective seed-dispersers. In some forests, the loss of an animal group (such as primates) has been suggested to cause a significant reduction in plant species diversity (Chapman and Onderdonk 1998). It is clear from the literature that habitat is as vital to the monkeys as the monkeys are to the habitat.

The Cloud Forest, Costa Rican Policy, and the White-Faced Capuchin Monkey

In contrast to the deforestation in Brazil, some provinces in Costa Rica are experiencing reforestation. Conservation policies have certainly played a role in this positive LULC change, but it is important to recognize that social, economic, and political drivers are also influencing change. These drivers include broad-scale, structural dynamics such as price shifts in international markets and national development policy changes. They also include fine-scale, proximate dynamics such as changes in the local labor market and the lifecycle of rural families. Furthermore, these dynamics interact across scale and over time. This complexity makes unraveling the causal relationships between social processes and land use cover change difficult to understand (Calvo-Alvarado 2009).

Costa Rica is considered to be one of the world’s leaders in biodiversity conservation (Sun 1988). It gained this reputation by reversing dramatic rates of historical deforestation (Broadbent et al 2012). The country has been working towards forest conservation and management through legislative changes over the last four decades. The first Forestry Law, enacted in 1969, regulated forest use on public land and established a national parks system. In the 1980s, Costa Rica adopted the concept of sustainable development (Calvo-Alvarado 1990). It created an Environment Department and introduced subsidies for reforestation and forest management on private land. In the 1990s, it introduced a National System of Conservation Areas called SINAC to decentralize forest management and conservation. The second Forestry Law passed in 1996 introduced a permit system to restrict timber extraction and forest-cover change on private land. Additionally, the law established Payment for Environmental Services (PES), which provided direct incentive to landholders to engage in four conservation categories: carbon sequestration, water protection, biodiversity protection, and scenic beauty (Ferraro and Kiss 2002).

Calvo-Alvarado et al. (2009) found that relative to regional socioeconomic change, conservation policies made a small contribution to the observed forest re-growth in Guanacaste, Costa Rica. A far greater impetus for forest recovery came from the decline of the cattle industry and the increase in economic opportunities associated with the booming tourism industry. Ecotourism has become a large industry contributing to the country's economic stability by providing income for local residents and serves as an alternative to farming the land. However, an increasing visitor population has the potential to threaten critical forest habitat as well. There is concern that the emerging land development and agribusinesses have the potential to significantly increase the economic incentive to deforest, and current conservation policies can only go so far to prevent this deforestation from occurring (Calvo-Alvarado 2009).

The Manuel Antonio region of Costa Rica is an example of an area experiencing simultaneous positive and negative land use/land cover change. Its highly dynamic landscape is experiencing deforestation, from agriculture, cattle ranching and oil palm plantations; and also reforestation from abandonment of land holdings and nature oriented tourism (Broadbent et al 2012). Manuel Antonio's forested areas increased from 1985 to 2000, but oil palm expansion could soon isolate the park geographically, as the last remaining forested corridor connecting the park to core primary forest areas is cut off. Similar dynamics of fragmentation and isolation, in particular from the expansion of palm plantations, are likely occurring throughout the many low lying park areas in Central America (Broadbent et al 2012).

The UGA Costa Rica campus is located within the Pájaro Campana Biological Corridor (PCBC). Despite its relatively small total area of 664 km^2, the region reflects Costa Rica's astounding biodiversity and is an area of high endemism and speciation, including over 500 species of orchids among over 2,000 identified plant species (Nadkarni & Wheelwright 2000). UGA Costa Rica's land use goals are to serve as a working demonstration of how the seemingly conflicting goals of biodiversity conservation, agricultural production, and the built out environment of an academic campus and hotel operation can be successfully interwoven. Demonstrating commitment to biodiversity conservation, UGA Costa Rica is formally registered as part of the National Network of Privately-Owned Reserves in Costa Rica, having designated 60 percent of its total property as a protected forest reserve. UGA Costa Rica's carbon offset reforestation program has helped to enrich forest regeneration within some of the pastures and cleared areas that are no longer used in production (UGA Costa Rica 2014).

The white-faced capuchin (*Cebus capucinus*) is a highly adaptive species found in a variety of forests. However, they appear to prefer older, primary forests. (DeGama-Blanchet & Fedigan 2006). A 2006 study concluded that older fragments of forest with dry season standing water, and a substantial amount of evergreen forest should be preferentially protected to enhance the conservation of white-faced capuchins in Costa Rica (DeGama-Blanchet and Fedigan 2006). Studies like this are important for producing conservation management plans and can be improved further by considering behavioral factors that impact survival.

As mentioned earlier, capuchins are important for seed dispersal. A study conducted in Santa Rosa National Park in Costa Rica found that white-faced capuchins consumed the fruit of 39 different seed-bearing plant species (Valenta and Fedigan 2008). Because plants have limited mobility, seed dispersal is often reliant on animals. Dispersal is predicted to play a major role in the origin and maintenance of species diversity (Caswell et al. 2003).

Many primate behaviors have clear adaptive functions while others are speculated upon. A behavioral tradition can be defined as a practice that is relatively long-lasting and shared among members of a group, each new practitioner relying to some extent upon social influence to learn to perform it (Perry et al. 2003). Social learning and the maintenance of traditions are critical for the development of foraging techniques of white-faced capuchins.

Taking into account environmental and behavioral factors, conservation can be approached from more than one angle and broaden understanding of human impact on wild species. The white-faced capuchin has long been sympatric with humans throughout their geographic range (Fuentes 2006). As humans modify natural habitats, the monkeys exploit alternative food resources. Supplemental feeding comes in many forms, including tourist handouts, active provisioning, and crop-raiding. One of the principle concerns regarding the effects of anthropogenic dietary changes among nonhuman primates is the maintenance of species typical foraging behavior. There is evidence that social learning is necessary for the development of foraging behavior among young primates (Gunst et al. 2008; Jaeggi et al. 2010; Rappaport and Brown 2008; Schiel and Huber 2006). The foraging methods of *Cebus capucinus*, for example, appear to consist of local traditions (O'Malley and Fedigan 2006; Panger et al. 2002), indicating a high degree of social learning for food acquisition.

Furthermore, juvenile primates spend more time than adults interacting with humans and eating provisioned foods, and quickly associate humans with food rewards. Based on previous behavioral research, it is reasonable to ask whether these young animals will lose vital opportunities to learn species-typical foraging behavior when the adults of their community have shifted their attention to anthropogenic food items (Sabbatini et al. 2006). The loss of adaptive components of behavioral diversity resulting from anthropogenic habitat alterations is of greatest concern from the conservation perspective (Caro and Sherman 2012).

Spatial Assessment

Remote sensing has played a pivotal role in informing national governments and organizations and the international community of rapid and unprecedented changes in land cover (Lucas et al. 2004). Satellite sensors such as the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) have been used since the 1970s and 1980s, respectively, to monitor global natural resources (Lillesand et al. 2008). Routine observations by these sensors drew attention to the dramatic changes in forest extent that has occurred over the past 50 years (Lucas et al. 2004).

Many remote sensing studies of LULC use various dates of Landsat images to conduct post classification change detection analyses to document land cover change (Lillesand et al. 2008, Lucas et al. 2004). Change-detection techniques, the processes of identifying differences in the state of an object or phenomenon by observing it at different times, are applied to detect LULC change using digital remote-sensing data (Coppin et al. 2004). The post-classification-comparison technique, using independent thematic classifications of images for two different dates, can generate different maps with change information that is easy to interpret. The problem of normalizing for atmospheric and sensor differences between two dates is minimized by the separated classification of each data; however, the accuracy of the change detection is dependent on the two individual classifications (Coppin et al. 2004, Jensen 2005). Ideally, ground truth data should be collected to verify the results of the classification. Because field work can be expensive and time consuming, ground truth data is often never obtained and aerial photographs or higher resolution satellite imagery is alternatively used for verification (Paine and Kiser 2003).

Image classification and analysis operations are used to digitally identify and classify pixels in the data. A classification is usually performed on multi-channel data sets and this process assigns each pixel in an image to a particular class based on the statistical characteristics of the pixel brightness values (Lillesand et al. 2008). Supervised classification procedures require a human analyst to provide training areas, which form a group of pixels with known class label, so as to assemble groups of similar pixels into correct classes. An unsupervised classification divides all pixels within an image into corresponding class pixel by pixel (Babykalpana and Thanushkodi 2011).

The utility of Landsat multi-spectral data depends both on the degree to which surface properties can be estimated from the radiometric measurements and on the ability to observe the surface through the atmosphere (Asner 2000). Clouds are a major obstacle to optical remote sensing of humid tropical regions, and therefore repeat data observations in relatively cloud free periods, such as early morning or dry seasons, are often necessary to obtain clear views of the land surface (Lucas et al. 2004). In some cases, images obstructed by cloud cover are the only ones available because satellite multispectral scanner images of the Earth’s surface, such as

Landsat, have relatively infrequent revisiting periods (Song and Civco 2002). Fortunately, procedures such as the Closest Spectral Fit Approach have been developed to replace clouds and cloud shadow pixels with the most similar pixels at cloud-free areas in the same image. The closest Spectral Fit approach allows for the accuracy of removing clouds and cloud shadows to be diagnostically checked when it is applied (Meng et al. 2009). Techniques for accurate cloud removal are imperative for studying tropical areas with remotely sensed imagery.

Applications for Conservation

Remote Sensing for Conservation

Since the first Landsat satellite was launched by the United States in 1972, satellite remote sensing has become an important source of data for better understanding the nature and sustainability of the earth’s natural resources, and particularly the impact of human activities at the local, regional and global levels (Baker and Williamson 2006). Professional land managers have learned that much of the information desired about forest lands can be readily seen on various types of aerial imagery (Reeves 1975). General LULC classifications of major categories such as forest, agriculture, or water are evident on medium scale resolution satellite imagery such as Landsat. It is ideal when ground truth data is obtained to compliment the remotely sensed data and used to assess accuracy and confirm the presence of the species of interest. This project was fortunate to obtain ground truth data for both sites to confirm the presence of capuchin monkeys and LULC information.

Scientists have used satellite imagery of Brazil for more than 30 years to learn about its diverse ecosystem and the patterns and processes of land cover change. This technology continues to advance and a new study shows that NASA satellite images can allow scientists to quickly and accurately assess deforestation in the Amazon. Researchers from Brazil’s National

Institute for Space Research (INPE) of Sao Jose dos Campos, Brazil compared multiple years of data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites to data collected from the higher resolution Landsat satellite. They found that even MODIS images can rapidly and reliably detect changes in Brazil's Amazon land cover. (Goodard Space Flight Center 2005).

Satellite imagery, and Landsat images in particular, have been used effectively to determine rates of deforestation, particularly in the tropics where there are large expanses of relatively inaccessible land. Using Landsat imagery, deforestation and forest restoration trends in Guanacaste, Cost Rica were successfully documented (Calvo-Alvarado et al. 2009).

Socioeconomic and climatic factors

Land use/land cover change is a complex phenomenon that involves interactions between social and natural systems. Although the size and scope of land use practices vary greatly around the globe, they generally impact the environment negatively by disturbing natural resources for immediate human needs. Human land use provides crucial, social, and economic benefits, even while leading to possible long term declines in human welfare through altered ecosystem functioning. Society faces the challenge of developing strategies that reduce the negative environmental impacts of land use across multiple services and scales while maintaining social and economic benefits (Foley et al. 2005).

Increased demand for food and fuel has worldwide consequences on land use and has led to an intense 'food versus fuels' debate (Young et al. 2009), though the degree of impact varies according to what feedstock is being considered and where it is grown. Soybeans and oil palm are increasingly important not only as a source of food products for humans and domestic animals, but more recently, for biofuel production (Estrada 2013). In addition, soybean and oil palm production in pristine areas requires the construction of massive transportation networks and other infrastructure projects. This in turn sets free a number of indirect consequences associated with opening up large, previously isolated environments to population migration and to other land uses (WWF 2006). Increasing population is also raising the demands for crop production. It has been asserted that feeding nine billion people by 2050 with existing Western diets produced with present Western technologies would require the need for almost twice the presently used cropland area (Kastner et al. 2012).

According to the United Nations Convention to Combat Desertification, desertification means “land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities". In Brazil, the most susceptible regions to desertification are located within the semi-arid area of Northeast Brazil (SANEB) (Souza and Oyama 2010). Climatic impacts of partial desertification (based on land cover maps derived from future environmental degradation scenarios for SANEB) follow the southward expansion of desertification. Random desertification (based on random desert areas placed within SANEB) leads to climatic impacts spread over the whole SANEB. In both partial and random desertification, a quasi-linear precipitation reduction is found as desertification extension increases, although the anomaly magnitude is larger for random desertification (Souza and Oyama 2010).

Land conversion can alter regional climates through its effects on net radiation, the division of energy into sensible and latent heat, and the partitioning of precipitation into soil water, evapotranspiration, and runoff. Modeling studies demonstrate that land-cover changes in the tropics affect climate largely through water-balance changes, but changes in temperate and boreal vegetation influence climate primarily through changes in the surface radiation balance (Foley et al. 2005).

Partnerships and Outreach

When addressing the complex matter of conservation, it is important to consider environemental and social factors. This research will create decision support tools that take both into account. Project partners and local farmers in Brazil and Costa Rica have provided invaluable insight to compliment the remotely sensed data. It is becoming increasingly common to use social data (in the form of surveys, interviews, policy and census data, and participatory mapping) in conjunction with GIS to investigate the interaction between humans and the environment (Broadbent et al 2012, Calvo-Alvarado 2009, and Robligio 2003). Broadbent et al. studied the effect of land use change and ecotourism on biodiversity by combining remote sensing and questionaire data from local families. Calvo-Alvarado undertook a retrospective analysis of the social dynamics of deforestation and restoration and studied the socioeconomics as well as the remotely sensed data to understand LULC change. Robligio et al. studied social arrangements that influence land use in Cameroon. The investigators used GIS tools and a social component to ascertain why the land use patterns existed (Robligio et al. 2003). Participatory mapping is a general term used to define a set of approaches and techniques that combine the tools of modern cartography with participatory methods to represent the spatial knowledge of local communities. The process of participatory mapping offers insight on landscape and natural resources management, and illustrates what the communities themselves perceive as important (Robigio et al. 2003).

It is crucial that humans are included as an integral part of the ecosystem. This will allow for a better understanding of the needs of the environment and people. Providing local communities, land owners, decision makers, and agencies with visual tools can be instrumental in promoting conservation efforts.

CHAPTER 3

METHODOLOGY

This chapter provides an overview of the methods used for the land use/land cover (LULC) classification, spatial assessment, and application of end products created for Brazil and Costa Rica. Data preparation, image processing, analysis, and creation of end products were all necessary steps to meet the objectives of this thesis (Figures 3.1 and 3.2).

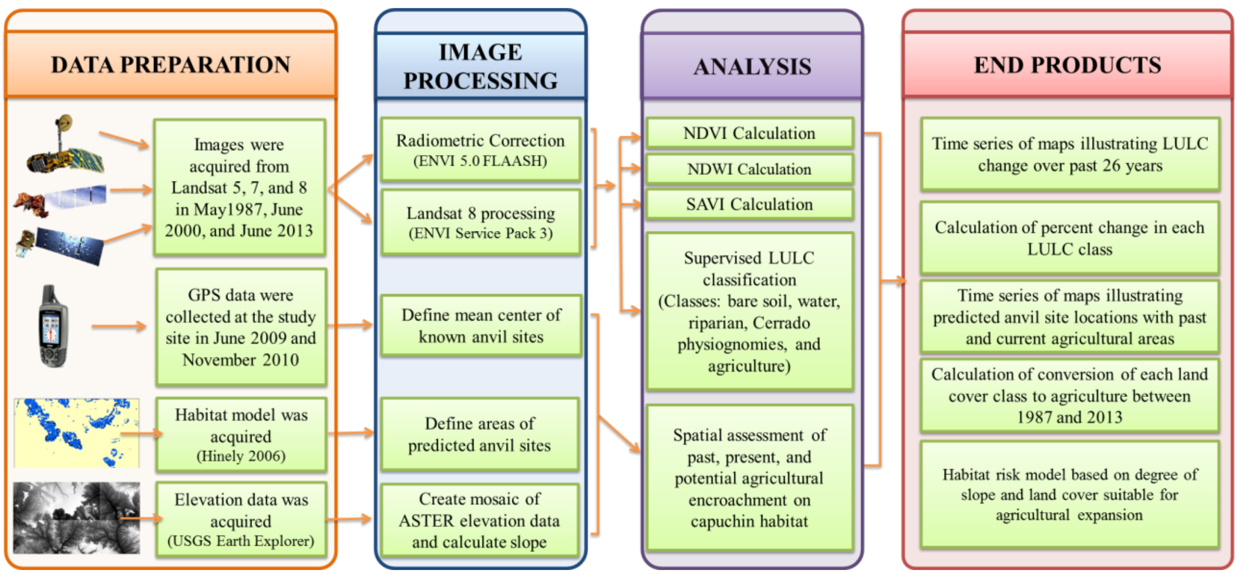

Figure 3.1: Flow chart of methodology for Brazil study

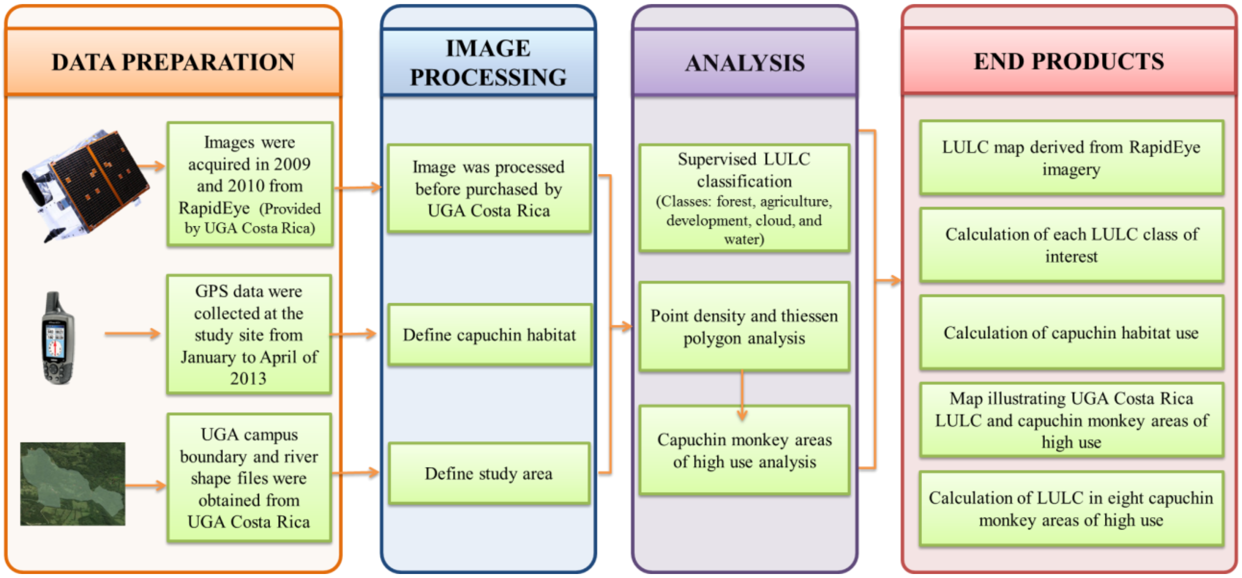

Figure 3.2: Flow chart of methodology for Costa Rica study

Land Use/Land Cover Classification

Brazil

The first objective of this project was to investigate the LULC changes in northeastern Brazil. One scene of Landsat imagery, which covered an area of 31,820 km^2, was selected from the years 1987, 2000, and 2013 (Tables 3.1-3.4). The images were acquired from the United States Geological Survey (USGS) Earth Explorer database, and were processed using Environment for Visualizing Images (ENVI) 5.0. The images were selected from the dry season, and were large enough to include the Etho*cebus* study site. The images analyzed were captured by Landsat 5 on May 28, 1987(LT52200671987148CUB00), Landsat 7 on May 7, 2000 (LE72200672000128EDC00), and Landsat 8 on June 4, 2013 (LC82200672013155LGN00).

Table 3.1: Landsat imagery information (Path 220, Row 67)

Satellite	Date	Sensor	Resolution	Bands
Landsat 5	05/28/1987	TM	30 m	7
Landsat 7	05/07/2000	ETM	30 m	8
Landsat 8	06/04/2013	OLI	30 m	11

Table 3.2: Landsat Thematic Mapper (TM) spectral bands

Band	Spectral Bands	Band Width (micrometers)	Resolution (meters)
1	Blue	0.45 - 0.52	30
2	Green	0.52 - 0.60	30
3	Red	0.63 - 0.69	30
4	Near Infrared	0.76 - 0.90	30
5	Shortwave IR-1	1.55 - 1.75	30
6	Thermal IR	10.40 - 12.50	120
7	Shortwave IR-2	2.08 - 2.35	30

Table 3.3: Landsat Enhanced Thematic Mapper Plus (ETM+) spectral bands

Band	Spectral Bands	Band Width (micrometers)	Resolution (meters)
1	Blue	0.45 - 0.52	30
2	Green	0.52 - 0.60	30
3	Red	0.63 - 0.69	30
4	Near Infrared	0.77 - 0.90	30
5	Shortwave IR-1	1.55 - 1.75	30
6	Thermal IR	10.40 - 12.50	60
7	Shortwave IR-2	2.09 - 2.35	30
8	Panchromatic	0.52 - 0.90	15

Table 3.4: Landsat Operational Land Imager (OLI) spectral bands

Band	Spectral Bands	Band Width (micrometers)	Resolution (meters)
1	Coastal Aerosol	0.43 - 0.45	30
2	Blue	0.45 - 0.51	30
3	Green	0.53 - 0.59	30
4	Red	0.64 - 0.67	30
5	Near Infrared	0.85 - 0.88	30
6	Shortwave IR-1	1.57 - 1.65	30
7	Shortwave IR-2	2.11 - 2.29	30
8	Panchromatic	0.50 - 0.68	15
9	Cirrus	1.36 - 1.38	30

The three images required radiometric correction, which was performed using ENVI Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH). The LULC classification for Brazil was focused on identifying agriculture and the cerrado physiognomies. It was important to classify and quantify the five types of Cerrado physiognomies associated with the landscape because of the significance the vegetation has on the natural habitat of the bearded capuchin monkeys. The five physiognomies are: Cerradão, Cerrado sensu strico, Campo cerrado, Campo sujo, and Campo limpo (Table 3.5 and Figure 3.3).

Table 3.5: Brazil land use/land cover classes and definitions

Class	Definition
Cerradão	Patches of trees, dense canopy (9 meters or greater)
Cerrado sensu strico and Campo cerrado	Mixed shrubs and grass (from 3 to 9 meters)
Campo sujo	Scattered shrubs and small trees (2 meters)
Campo limpo	Bare soil mixed with grass (one meters or less)
Riparian	Interface between land and river
Bare soil	Soil void of live ground cover
Agriculture	Commercial agricultural land

Figure 3.3: Five physiognomies of the Cerrado

Classifying vegetation from satellite imagery is especially challenging when different types are in close proximity to one another. For that reason, indexes and sample locations were applied to differentiate the vegetation types and classify the remaining land cover categories in the area. The following normalized vegetation, moisture, and soil indexes were applied: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Soil Adjusted Vegetation Index (SAVI). Each index required specific Landsat spectral reflectance bands.

Normalized difference vegetation index mathematically compares reflectance from the red and near-infrared (NIR) bands.

NDVI = (NIR - Red) / (NIR + Red)

Normalized difference water index mathematically compares reflectance from the NIR and green bands.

NDWI = (Green – NIR) / (Green + NIR)

Soil adjusted vegetation index is structured similarly to the NDVI, but with the addition of a soil brightness correction factor.

SAVI = (NIR – Red) / (NIR + Red + o.5)

Using the indexes and appropriate combination of bands, sample training sets were created in the form of polygons that represented distinct sample areas of the different land cover types to be classified. The image could then be classified using reflectance values obtained from training samples.

Ten training samples for each of the seven classes of interest were created. The final classes selected for the supervised classification were: Cerradão, Cerrado sensu strico and Campo cerrado, Campo sujo, Campo limpo, riparian, bare soil, and agriculture. Using ArcGIS, polygons were created around the clearly demarcated agricultural fields present in 2000 and 2013. The 1987 image contained no visible commercial agriculture.

It should be noted that the classification was initially performed as an unsupervised classification, with 25 classes. The number of classes was helpful to differentiate types of physiognomies of the vegetation, agricultural fields, water, and bare soil. However, using NDVI, NDWI, and SAVI in combination with the supervised classification described above provided the most useful output, illustrating the natural physiognomies of the vegetation.

The area of the classes was computed for each year of interest to demonstrate how the landscape has changed over the past 26 years. The classification was validated with high resolution WorldView-2 imagery and ground data collected during the summer of 2013.

Costa Rica

The 5 m resolution RapidEye imagery (©2009, 2010 RapidEye AG, Germany) obtained for this study was provided by UGA Costa Rica (Tables 3.6 and 3.7). Each of RapidEye's five satellites contains identical multispectral push broom imager sensors. The sensor is referred to as JSS-56 (Jena-Optronik Spaceborne Scanner-56). RapidEye Mosaics are geometrically aligned, orthorectified, and uniformly color-balanced when purchased (RapidEye 2010). The image analyzed was a mosaic composed of seven images acquired in September and March of 2009, and January and February of 2010.

Table 3.6: RapidEye imagery information

Satellite	Date	Sensor	Resolution	Bands
RapidEye	09/15/2009 - 02/05/2010	JSS-56	5 m	5

Table 3.7: RapidEye Jenna Spaceborne Scanner (JSS – 56) spectral bands

Band	Spectral Bands	Bandwidth (micrometers)	Resolution (meters)
1	Blue	0.44 - 0.51	5
2	Green	0.52 - 0.59	5
3	Red	0.63 - 0.685	5
4	Red Edge	0.69 - 0.73	5
5	Near Infrared	0.76 - 0.85	5

GPS coordinates were integral to defining the area for the LULC classification. They were collected with a Garmin hand-held GPS in the cloud forest of San Luis, Costa Rica. Points were collected daily from January to April of 2013 and captured the estimated center of each capuchin group observed. The GPS coordinates were differentially corrected by the Wide Area Augmentation System (WAAS) with a 3-4 m range of error. Because the goal was to capture the area the capuchin groups were using, this level of accuracy for data collection was appropriate. Upon arrival to UGA Costa Rica, the study area was traversed daily and points were collected opportunistically as capuchins were sited. After four weeks, the data collection process became more systematic. The investigator returned to every location where a capuchin had been recorded during the initial four weeks as many times as possible for the remaining eight weeks. Locations were checked and points were collected every morning and afternoon possible.

Two groups of capuchin monkeys ranging from 12-18 individuals each accounted for the majority of the observations. There was also a small group of males observed on multiple occasions. Each time data were collected, date, time, weather, number and sex of individuals, and designation of fear or no fear was recorded. After the first four weeks, minimal fear and anxiety behaviors were observed. The identification of fear and anxiety behavior was based on known indicators of each behavior in nonhuman primates. Anxiety behaviors include yawning, self-scratching, body shaking, and teeth grinding. Fear behaviors include fear grimace, crouching, cringing, and freezing (Perlman 2014).This was the first time these types of data were collected at this site.

Additional data used for the LULC classification included boundaries, rivers, and roads provided by collaborators from UGA Costa Rica and the NASA DEVELOP National Program, who partnered to conduct a study focused on forest connectivity within the Pájaro Campana Biological Corridor.

To create a map illustrating the LULC categories of interest throughout the study area, a supervised classification was performed on the imagery. Training datasets were constructed in ArcGIS for five classes of interest: forest, agriculture, development, water, and cloud (Table 3.8). Twenty five training samples were created by digitizing polygons in representative areas within each class of interest. The final result was a LULC map that illustrated the status of the study area. The area of each LULC class was calculated within ArcGIS and percentages were computed. A visual inspection of the classification results in comparison to Google Earth imagery indicated that the classes were acceptable representations of the LULC in the study area.

Accurate information on the status of land use and land cover is crucial for understanding and developing strategies for sustainable land management. Over the past few decades, remote sensing systems/sensors have advanced in increasing spectral resolution and spatial resolution. High spatial resolution satellite data provides the potential to provide more precise classification and mapping results.

Table 3.8: Costa Rica land use/land cover classes and definitions

Class	Definition
Forest	Vegetative growth necessary for flora and fauna
Agriculture	Land characterized for the purposes of farming
Development	Buildings and infrastructures for human use
Water	Rivers, ponds, lakes, streams
Cloud	Clouds obstructing view of land cover

Spatial Assessment

Brazil

Results from the supervised classification of each image included percentages of each LULC class of interest at three distinct points in time and generated a clear picture of LULC change in the study area. With the classification complete, the distance from the commercial agriculture fields (located north and south of the Etho*cebus* site) to capuchin habitat could be measured. Near tables were generated in ArcGIS, which produced exact measurements from the mean center of the confirmed anvil sites to the closest agricultural areas to the north and south. These measurements will provide scientists with quantitative information on agricultural encroachment and habitat degradation.

Additionally, a statistical model revealing locations where capuchin tool use is likely to occur in Brazil (Hinely 2006) was incorporated to this work. Hinely mapped the vegetation, elevation, and linear surface hydrology, and used these layers to build parameters that correlated with the locations where the hammering behavior is performed (Madden et al. 2007). Sample anvil sites predicted by this model were verified in 2009 by staff from the Center for Geospatial Research. Integrating these locations with the LULC maps illuminated predicted site locations that have either already been dominated by agriculture or sites that are currently threatened. This resulted in a time series of maps highlighting predicted anvil site locations and agricultural areas in 1987, 2000, and 2013.

A digital elevation model derived from ASTER data was acquired from the USGS Earth Explorer data base. Slope was derived from the DEM and a suitable range of slope for agricultural development was determined based on the existing agricultural land in the study area. Pixels with a slope from zero to eight degrees represented 90.86 percent of land that was agriculture in 2013. The slope data was combined with land cover data into one single raster dataset so that each pixel contained an associated slope value as well as a value for land cover. A simple count of every combination of slope and land cover was made both inside known agricultural areas and across the entire study area (approximately 30,000 km^2). These counts were used to calculate the likelihood of each pixel with its specific combination of attributes existing within an agricultural area. The potential agricultural use was divided into four classes: Highly Unlikely (1-3 perecnt), Unlikely (3.1-13 percent), Likely (13.1-49 percent), and Highly Likely (49.1-73 percent). This information was used to model potential areas for agriculture expansion based on 2013 land cover and slope data. Finally, confirmed capuchin tool use sites were overlaid on this model to display their proximity to areas at the highest risk for agrcilture expansion.

Costa Rica

After completing the LULC classification of Costa Rica from the RapidEye imagery, a new map incorporating the Capuchin GPS points was created. The point density spatial analyst tool was used to calculate a magnitude per unit area from point features that fell within a neighborhood around each cell.

Thiessen polygons were created to apportion each point into a distinct region. Each thiessen polygon defined an area of influence around its sample point, so that any location inside the polygon was closer to that point than any of the other sample points. The data management tool allowed for the centroid of each polygon to be generated. These files were saved and then introduced to the classified LULC map. The centroids in each class were quantified to provide a clearer picture of what type of land the monkeys were using.

After these analyses were complete, the area (m^2) of the Thiessen Polygons in each of the six classes was calculated. The percentage of each class was calculated to facilitate interpretation of the LULC results. Using the point density display of the monkey coordinates, eight individual polygons representative of land that was intensively used by the monkeys were manually constructed. After completion, the polygons were extracted by mask. Because the LULC within the polygons was previously classified, it was simple to visualize each polygon's characteristics. The LULC within each polygon was quantified to provide a more detailed quantitative analysis of areas of high use.

Applications for Conservation

Brazil

A time-series of maps illustrating the historical change in LULC and the quantitative information regarding agricultural encroachment on capuchin habitat will be delivered to researchers at the University of São Paulo and the landowners of the study site. In addition, a time series of maps illustrating changes in LULC in relation to predicted anvil sites will be provided to the Etho*cebus* research team.

Costa Rica

A LULC map and graphics illustrating capuchin habitat use will be delivered to the UGA Costa Rica campus and Pájaro Campana Biological Corridor Advisory Council. The results of the thiessen polygon analysis and high use area analysis simultaneously illustrate human and capuchin land use in this developing area. They demonstrate a strong capuchin presence in anthropogenic landscapes. The project's findings can be added to the corridor's geodatabase and collection of research to expand knowledge on capuchin habitat choice. In addition, they will be made available to the local schools and community.

CHAPTER 4

DISCUSSION AND RESULTS

The ultimate goal of this thesis was to use geospatial techniques to produce quantitative information, maps, and methodologies that can be used to strengthen policy, management decisions, and public awareness of environmental issues in Brazil and Costa Rica. This research illuminated the changes Northeastern Brazil, and bearded capuchin habitat in particular, has undergone using a time series of imagery spanning the past 26 years and a habitat model developed by Adam Hinely. Additionally, by simultaneously examining human and capuchin land use within and surrounding the University of Georgia's Costa Rica campus, current capuchin habitat choice throughout this anthropogenic landscape was visualized and quantified. The methodologies created for this project can be used to effectively assess and monitor these habitats in the future.

Land Use/Land Cover Classification

Brazil

Changes in the vegetation of the northeastern Brazilian Cerrado derived from classified 1987, 2000, and 2013 Landsat imagery revealed Campo limpo (bare soil and grass) increased while Cerradão (patches of trees/dense canopy) decreased between 1987 and 2013, illustrating the risk of desertification. Campo sujo (scattered shrubs/small trees) and Cerrado sensu strico and Campo cerrado (mixture of trees, shrubs, and grasses) decreased slightly. Agriculture increased 12.41 percent from 1987 to 2013. Riparian decreased as a result of agriculture development around the river (Figures 4.1-4.3).

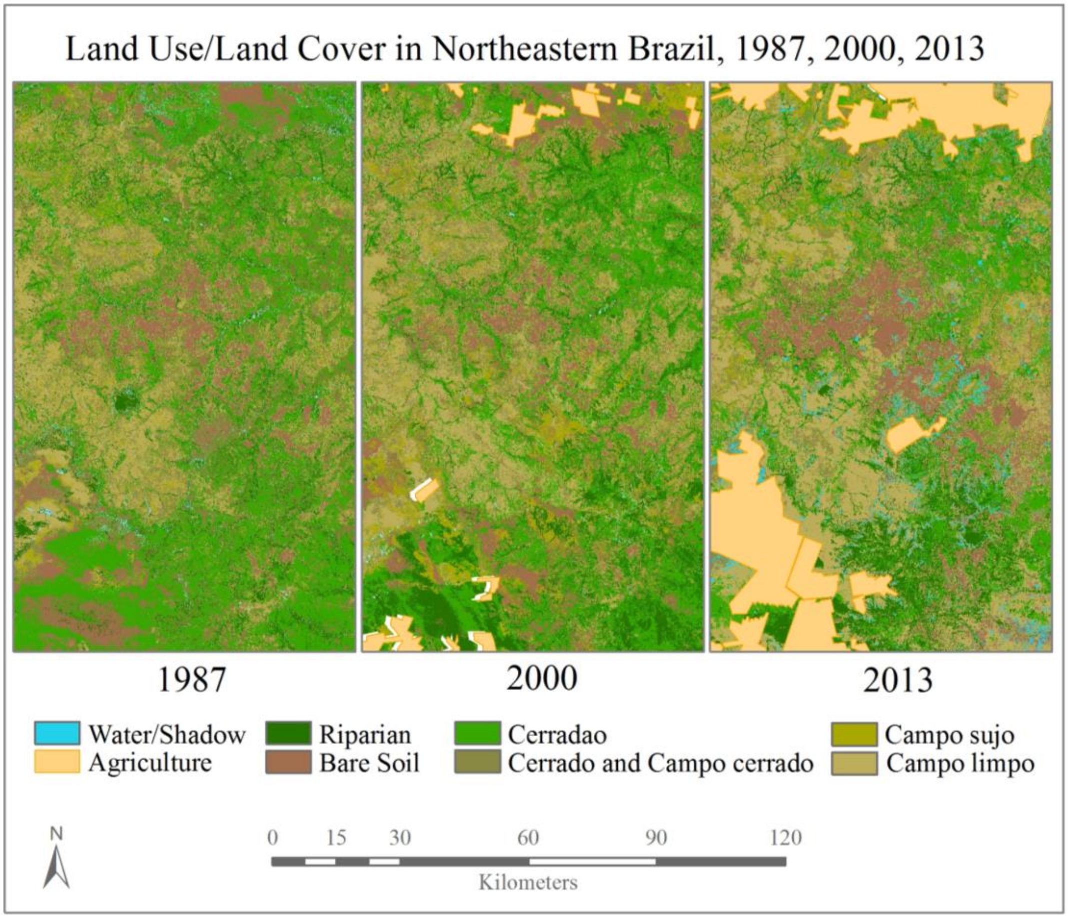

Figure 4.1: Time series of land use/land cover derived from 1987, 2000, and 2013 imagery

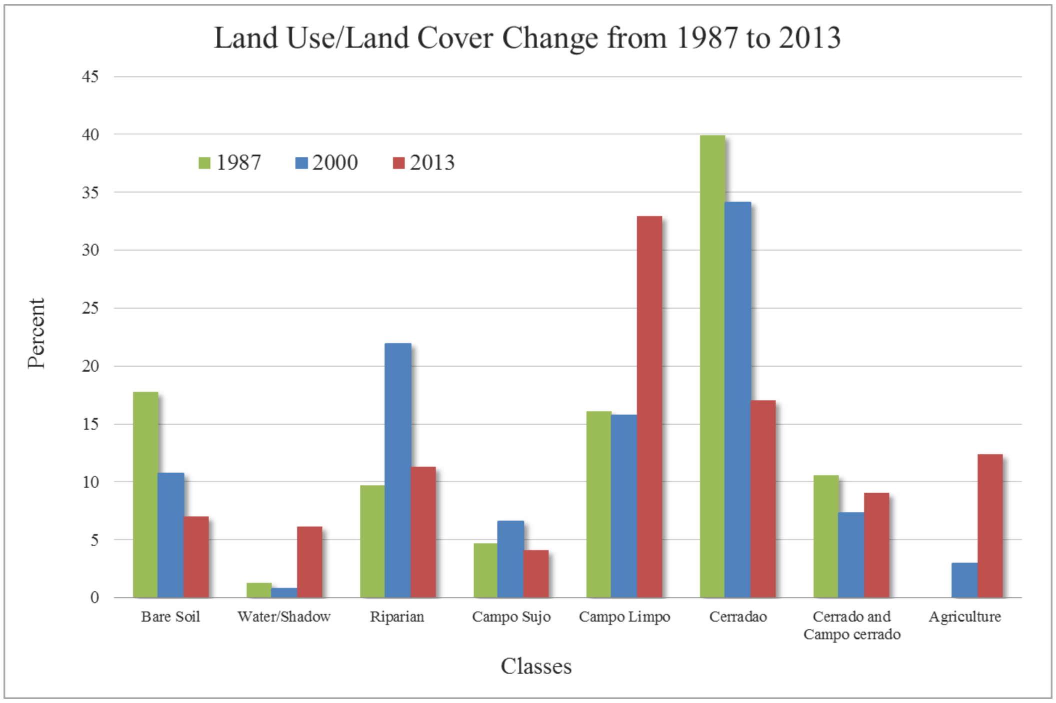

Figure 4.2: Percent change in land use/land cover from 1987 – 2013

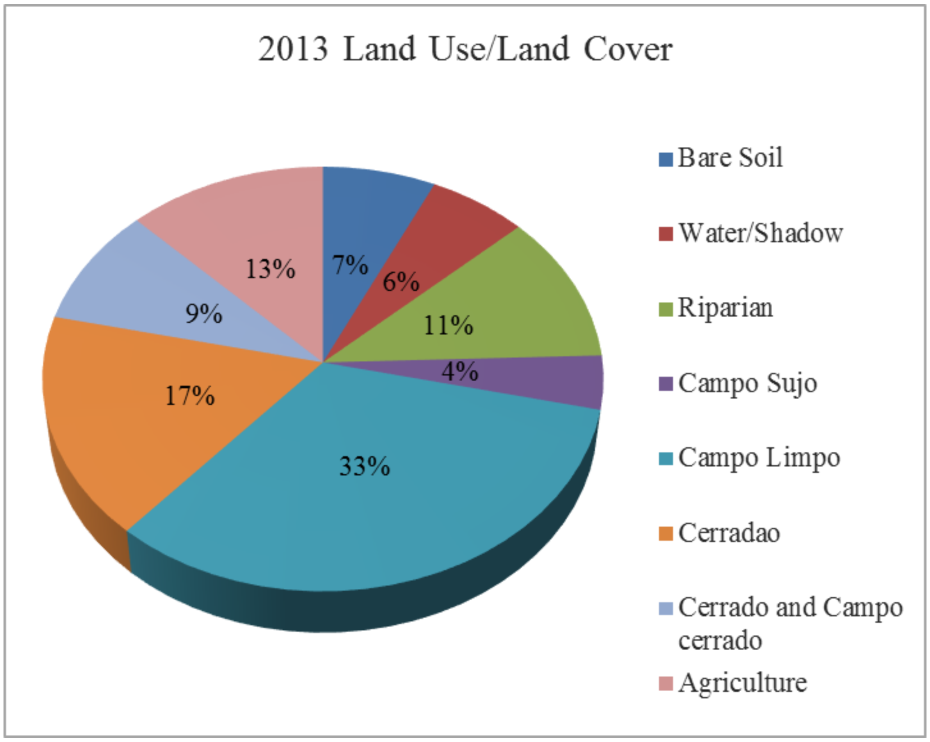

Figure 4.3: Land use/land cover classification results derived from 2013 Landsat imagery

Costa Rica

Results of the LULC classification of the 2009-2010 RapidEye imagery indicated that forested land dominated the study area. Agriculture was the second highest land use class with developed land, cloud cover, and water following it. A map was produced and percentages of each land use and land cover class were calculated (Figures 4.4 and 4.5). The LULC classification provided relatively current quantitative information regarding the LULC of the study area and will be shared with the community and Pájaro Campana Biological Corridor Advisory Committee. The classification was validated using a visual assessment of Google Earth imagery. Based on the validation, the classes appeared to accurately represent the current LULC of the study area.

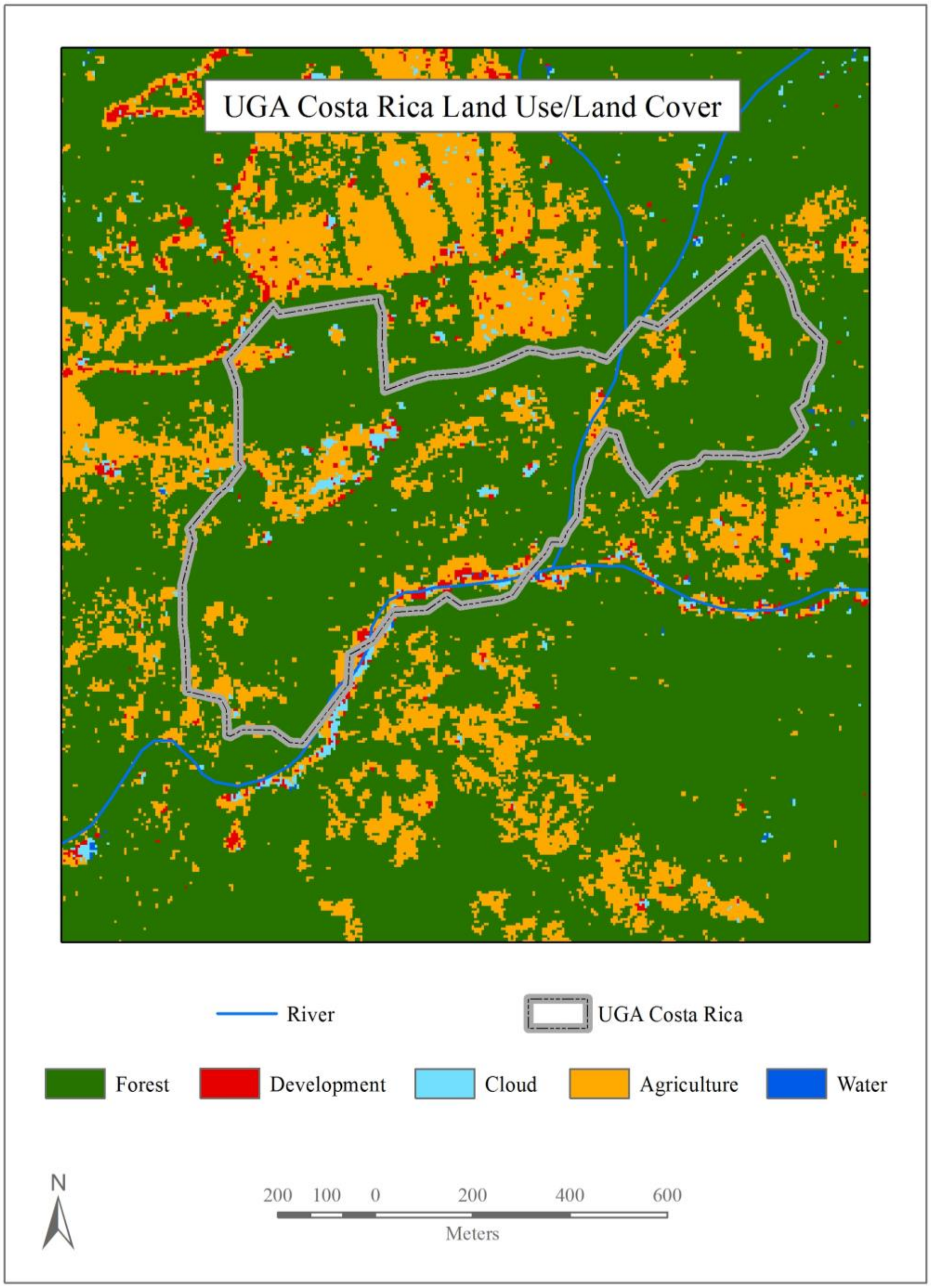

Figure 4.4: Land use/land cover derived from 2009 – 2010 RapidEye imagery

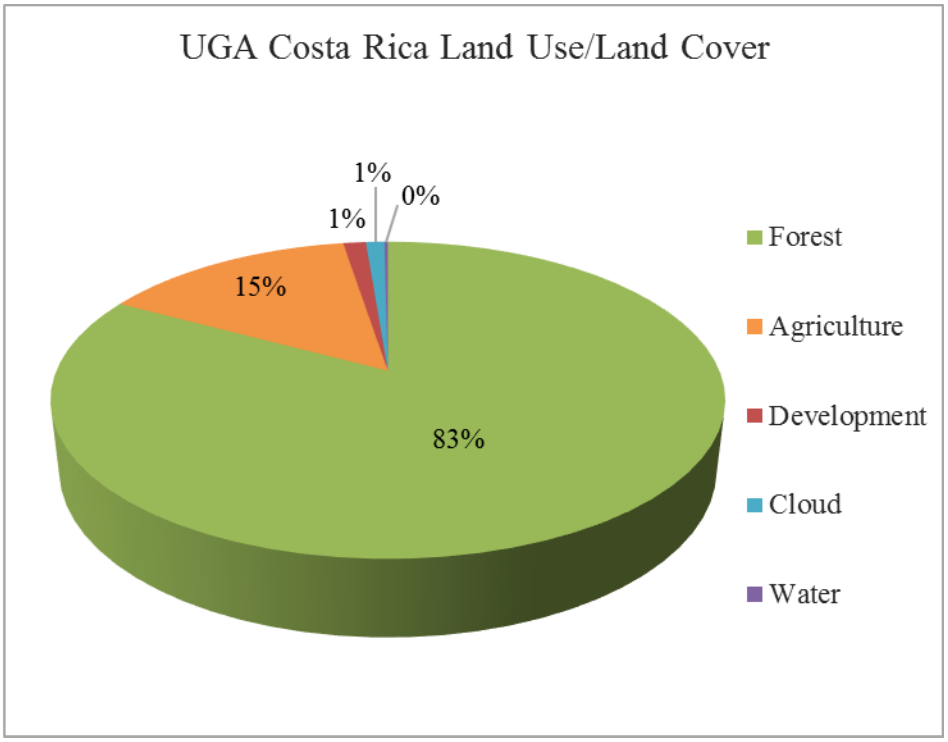

Figure 4.5: Land use/land cover classification results derived from 2009 – 2010 RapidEye imagery

Spatial Assessment

Brazil

Results from the supervised classification of each image made it possible to quantify each class of land use and land cover at three distinct points in time and generate a clear picture of LULC change in the study area. The distance from the commercial agriculture fields (located north and south of the Etho*cebus* site) to the central point of the study site and actual monkey points were measured and provided quantitative information on agricultural encroachment and habitat degradation (Figures 4.6 and 4.7).

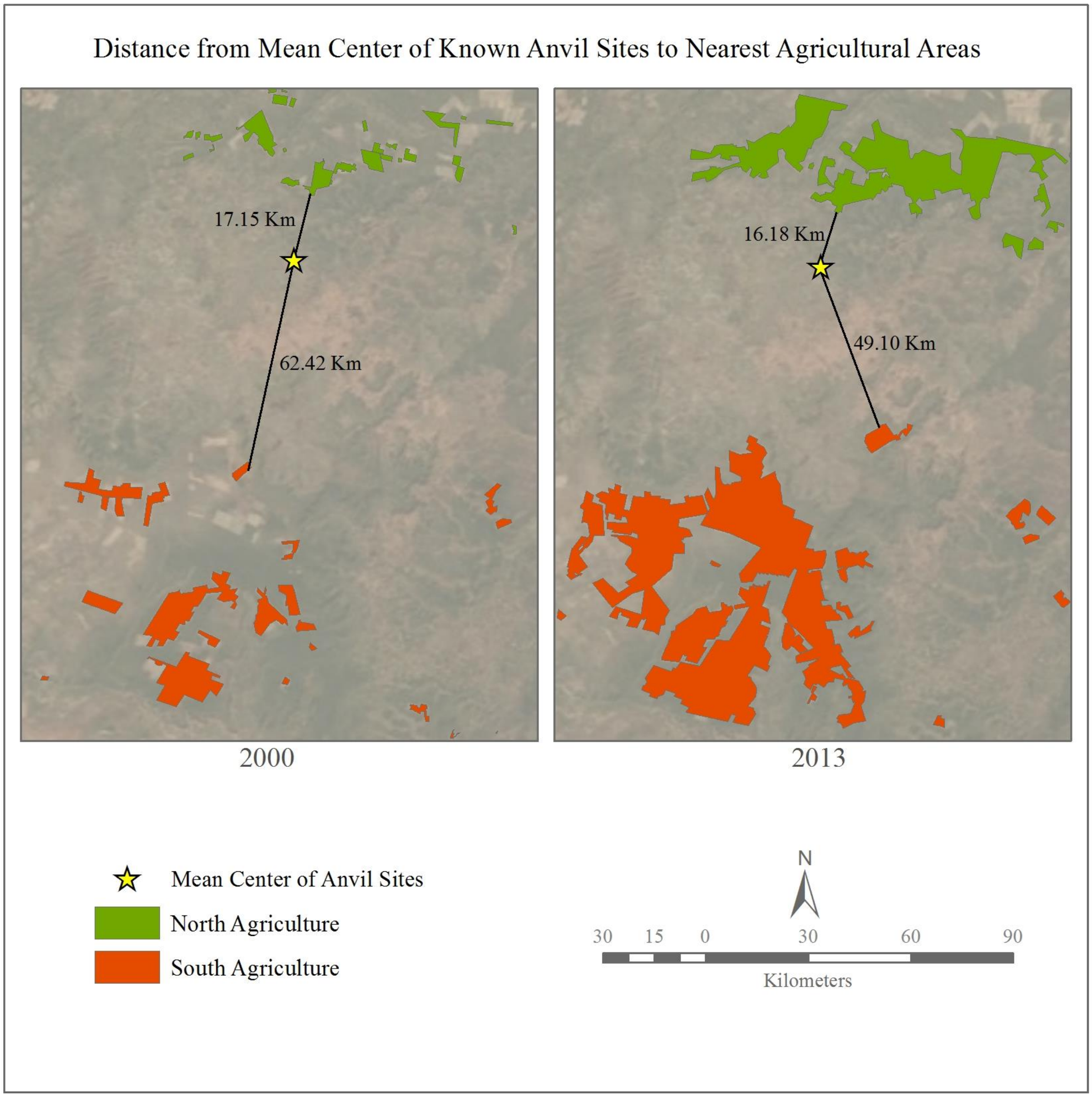

Figure 4.6: Distance from mean center of anvil sights to nearest agricultural fields

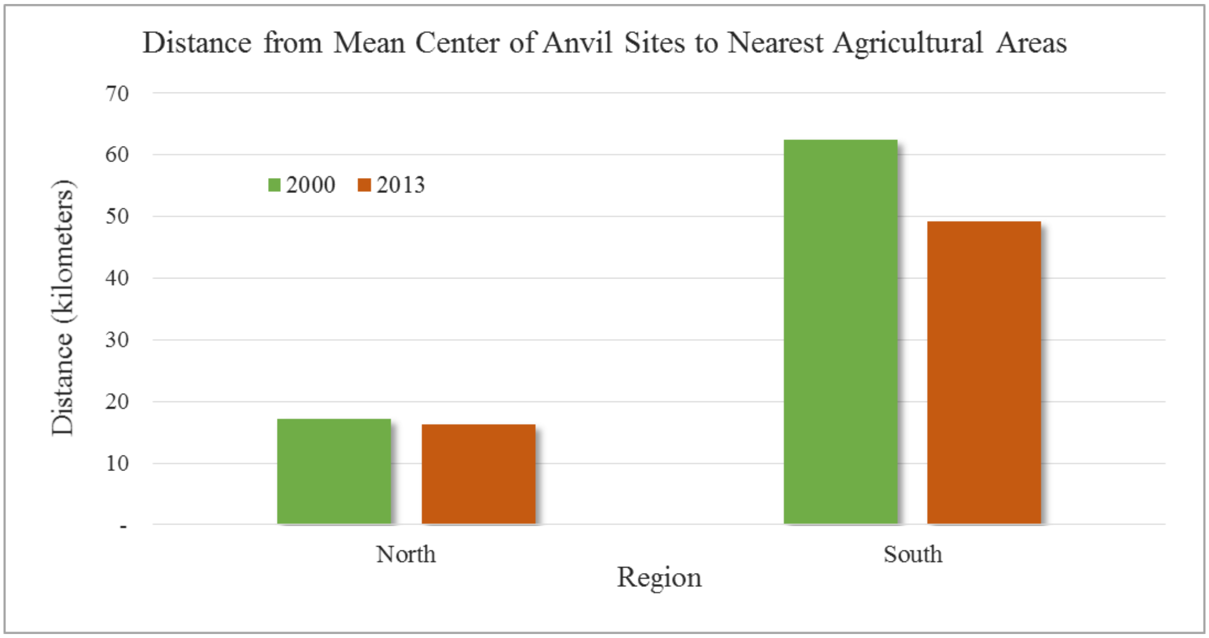

Figure 4.7: Distance from center of anvil sights to agricultural areas in 2000 and 2013

Additionally, an accurate habitat suitability model to predict locations where bearded capuchin monkeys may use a hammering behavior to crack palm nuts (Hinely 2006) was incorporated to this work (Figure 4.8). The model showed that there was a correlation between anvil sites and landscape data such as vegetation and terrain (Madden 2007).

Integrating these locations with the current land use/land cover conditions illuminated current and predicted areas of capuchin tool use that have either already been dominated by agriculture and areas that are being threatened. The resulting map can be used to steer future conservation efforts (Figure 4.9).

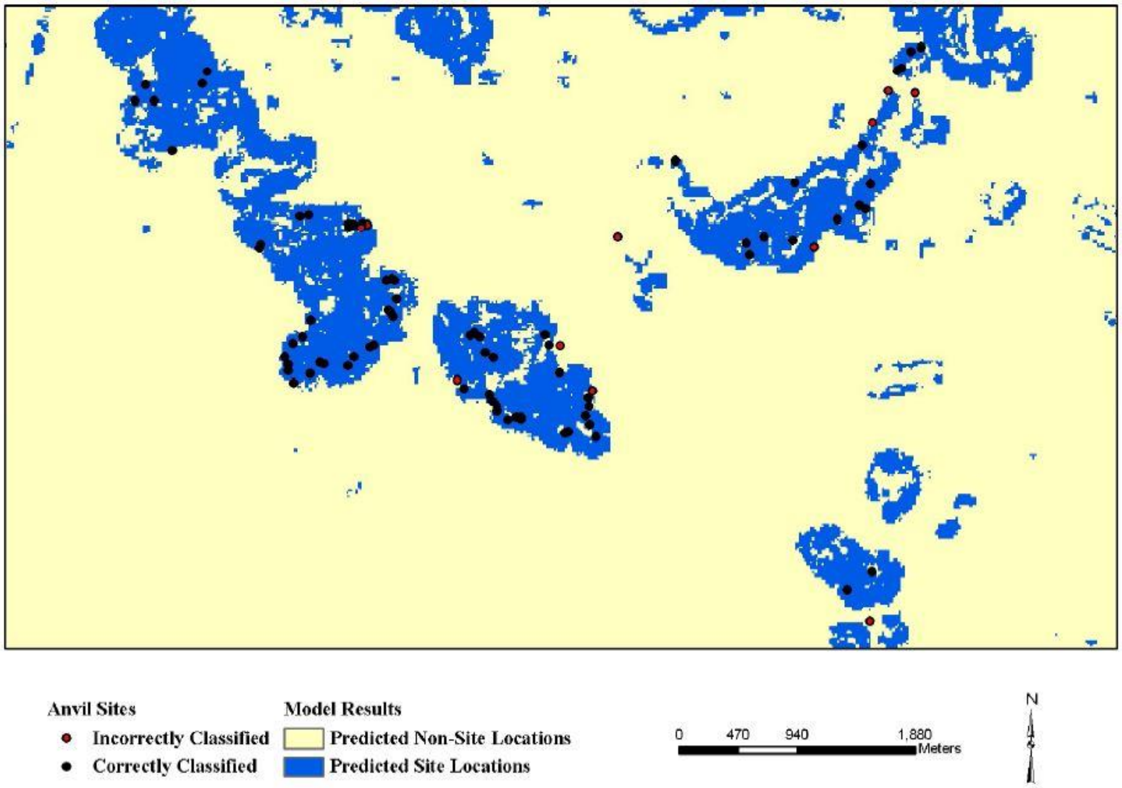

Figure 4.8: Map of Adam Hinely's habitat model results

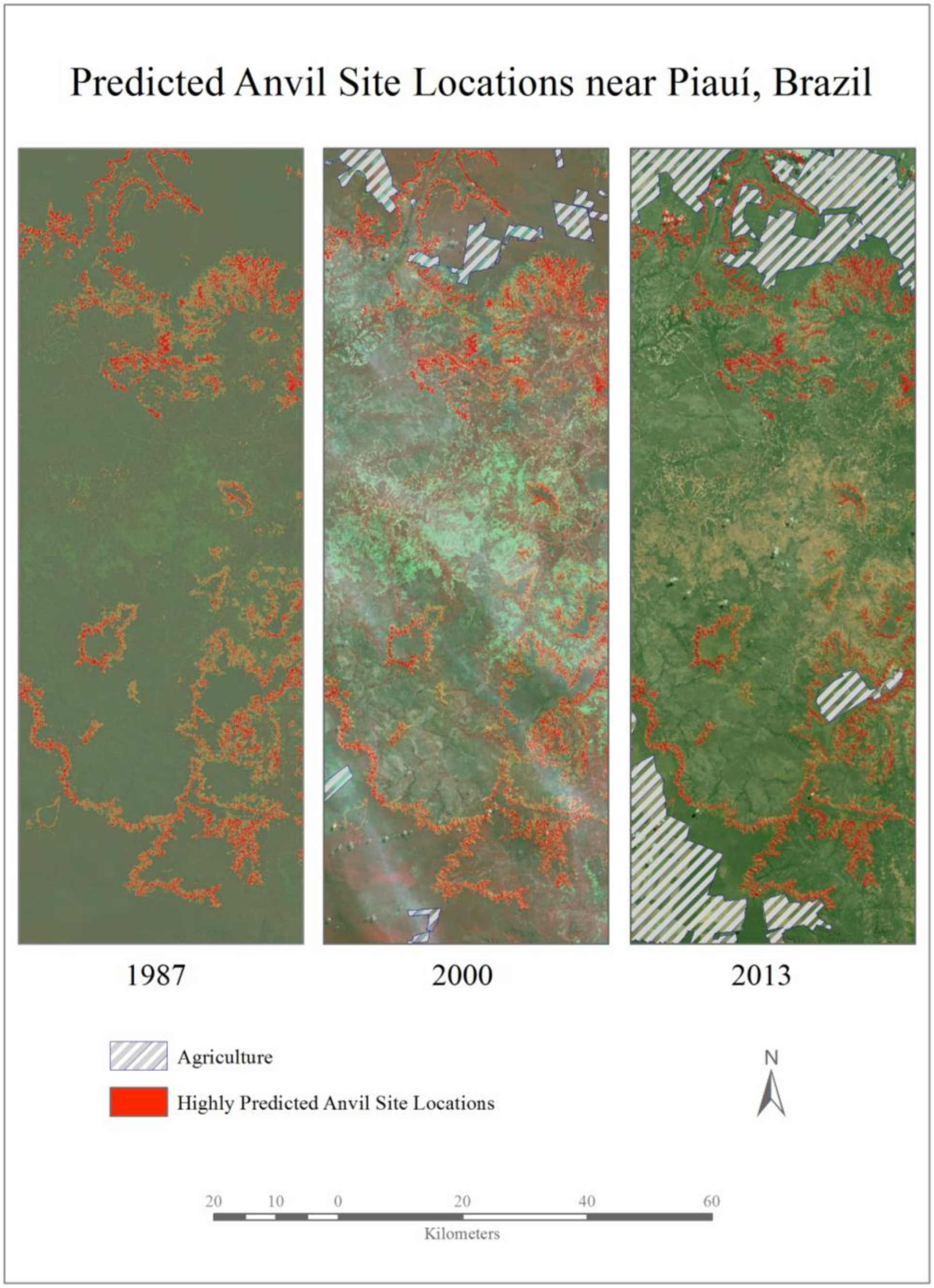

Figure 4.9: Predicted anvil site locations in relation to agricultural areas

The variables included in the model produced by this thesis, land cover and slope, were used to determine likely areas of agricultural development. The historical Landsat imagery provided the basis for the land cover variable. Conversion of individual classes of land cover to agriculture from 1987 to 2000 and 2000 to 2013 showed that all classes increased within the time frames. Between 1987 and 2000, the coversion of land to agriculture from bare soil and Cerradão increased roughly 300 km^2 and 400 km^2, respectively. Between 2000 and 2013, the conversion of land to agriculture from bare soil, Campo limpo, Campo sujo, Cerradão, and riparain increased more than 500 km^2. Between 2000 and 2013, the amount of land that was converted to agriculture in each class increased at least twice as much as it increased during the previous period (Figure 4.10).

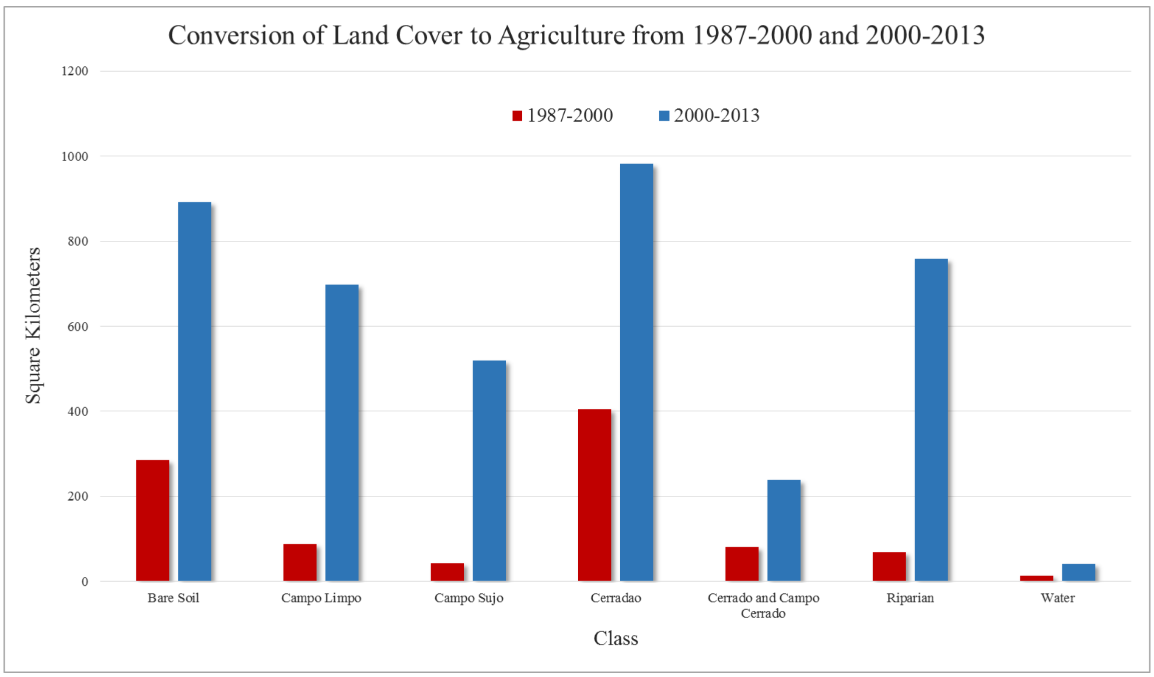

Figure 4.10: Conversion of land cover to agriculture from 1987 – 2000 and 2000 – 2013

Slope information was derived from ASTER imagery. Pixels with a slope from zero to eight degrees represented 90.86 percent of land that was converted into agriculture by 2013 (Figure 4.11). This threshold was used in combination with the land cover conversion values to model potential areas for agricultual expansion within the study area.

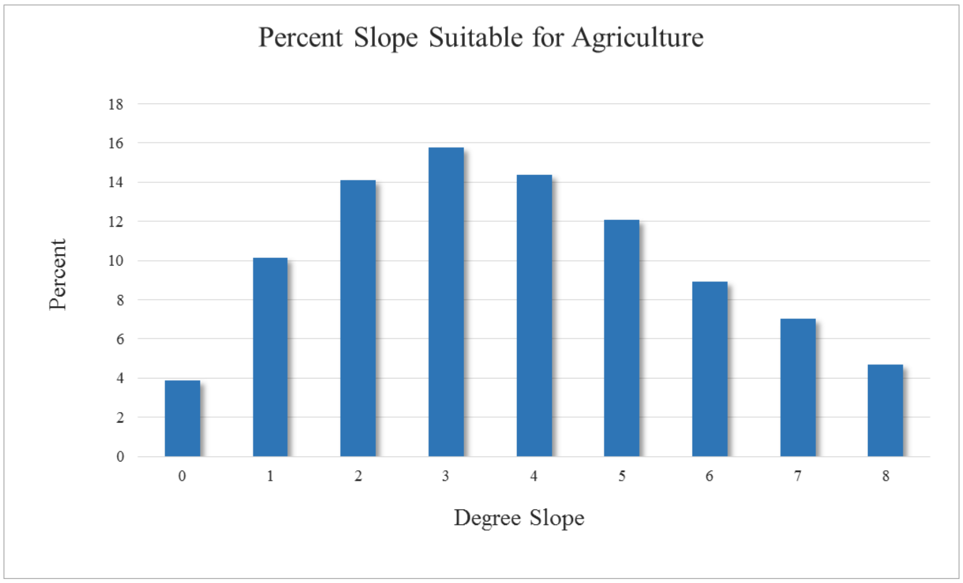

Figure 4.11: Percent slope suitable for agricultural development

Approximately 40 percent of the land in the study area was determined to be either Highly Likely or Likely areas for agricultural use. A roughly equal percentage of land was considered Highly Unlikely and Highly Likely (30 percent). Highly Likely and Likely areas of agricultural use that were not already being used for agriculture in 2013 are concentrated in the central and northwest regions. These areas exist directly between two large agricultural regions. Large tracks of land that are considered either Highly Unlikely or Unlikely for agricultural use occur throughout the study area but are most prevalent in the southeast and northeast regions.

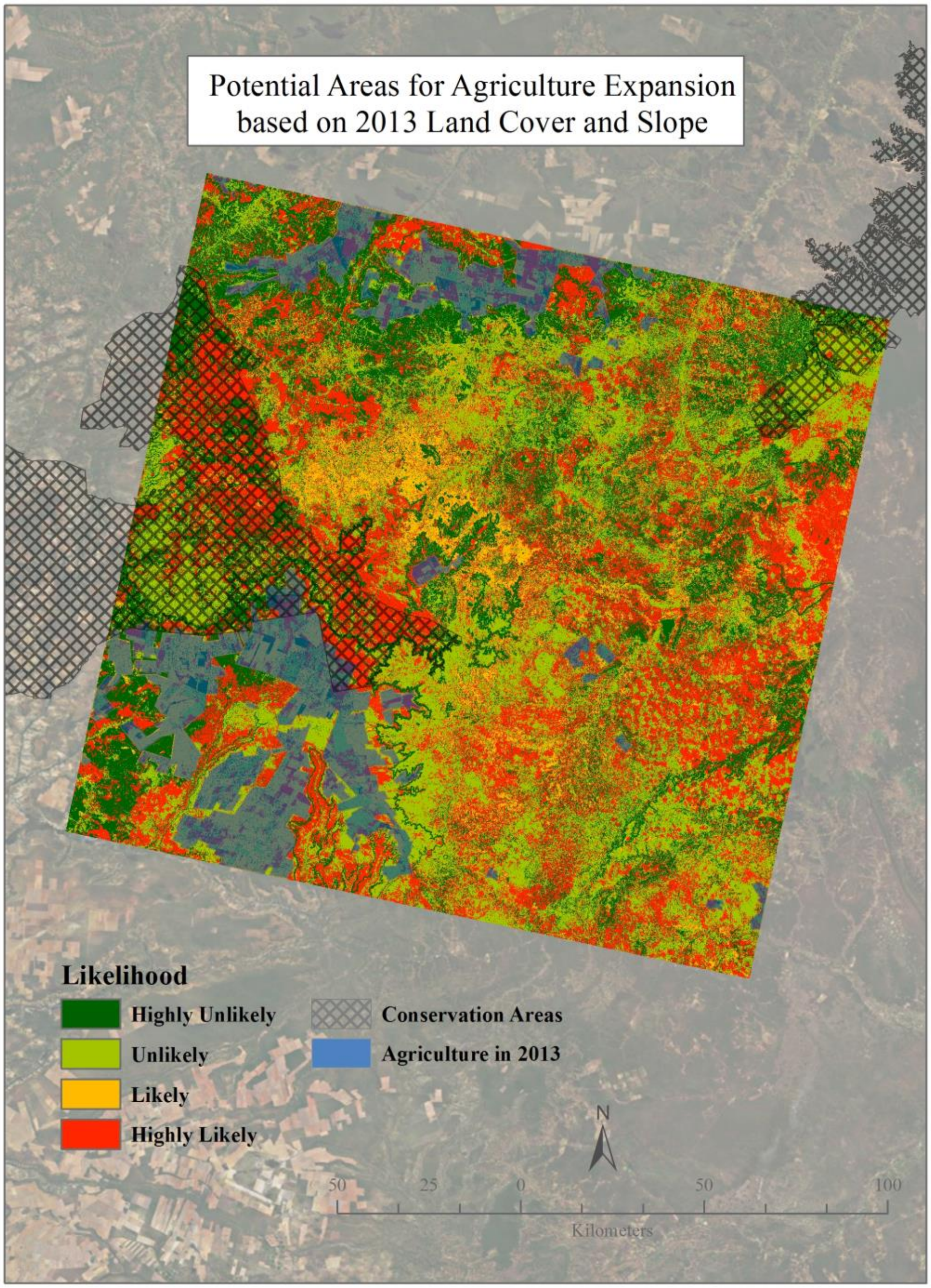

Figure 4.12: Potential areas for agriculture expansion based on 2013 land cover and slope

Several capuchin monkey tool use sites are surrounded by areas that are considered Highly Likely for agriculture use but the majority are located within areas where the expansion of agriculture is considered Highly Unlikely or Unlikely. A large concentration of areas that are considered Highly Likely for agriculture use is located south and southeast of the capuchin tool use sites. These results can be used to target future conservation efforts to protect land in closest proximity to capuchin habitat at the highest risk.

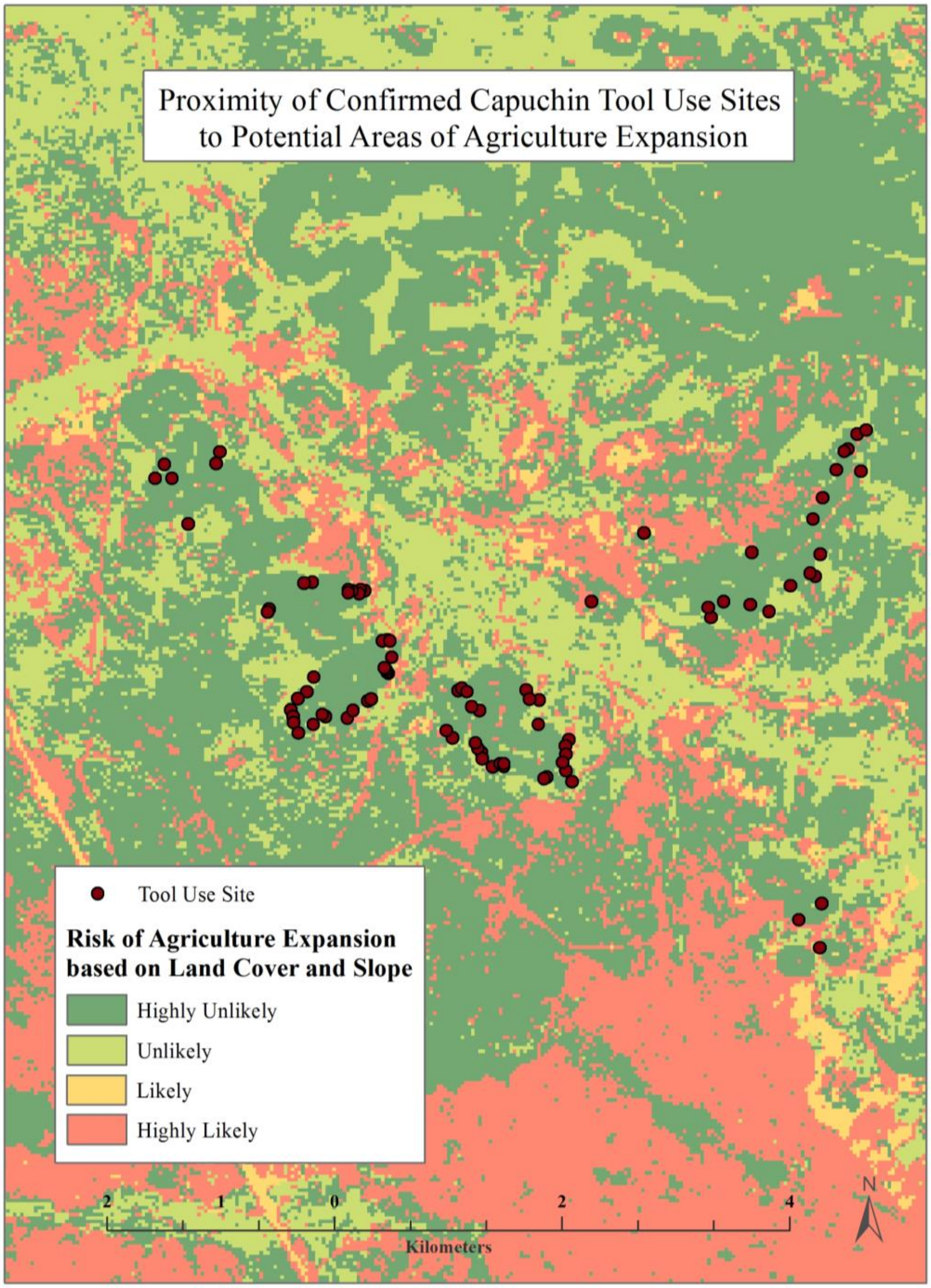

Figure 4.13: Proximity of confirmed capuchin tool use sites to potential areas of agriculture expansion

Costa Rica

The point density analysis calculation and thiessen polygons generated in ArcGIS defined an area of influence around points representing capuchin observations, so that any location inside a polygon was closer to that point than any of the other sample points. The thiessen polygons and their centroids were overlaid on the classification map and provided a clear picture of what types of land the monkeys were using (Figures 4.14 and 4.15).

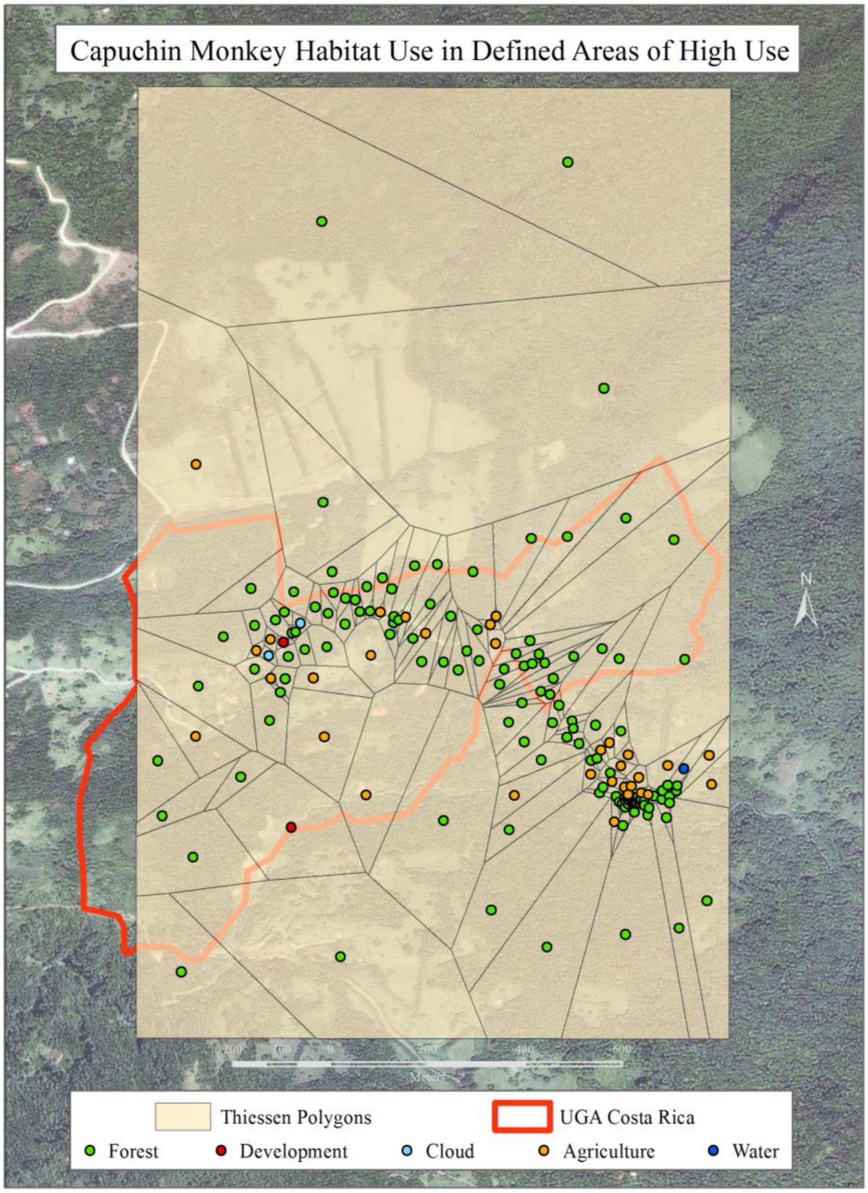

Figure 4.14: Capuchin monkey habitat in defined areas of high use

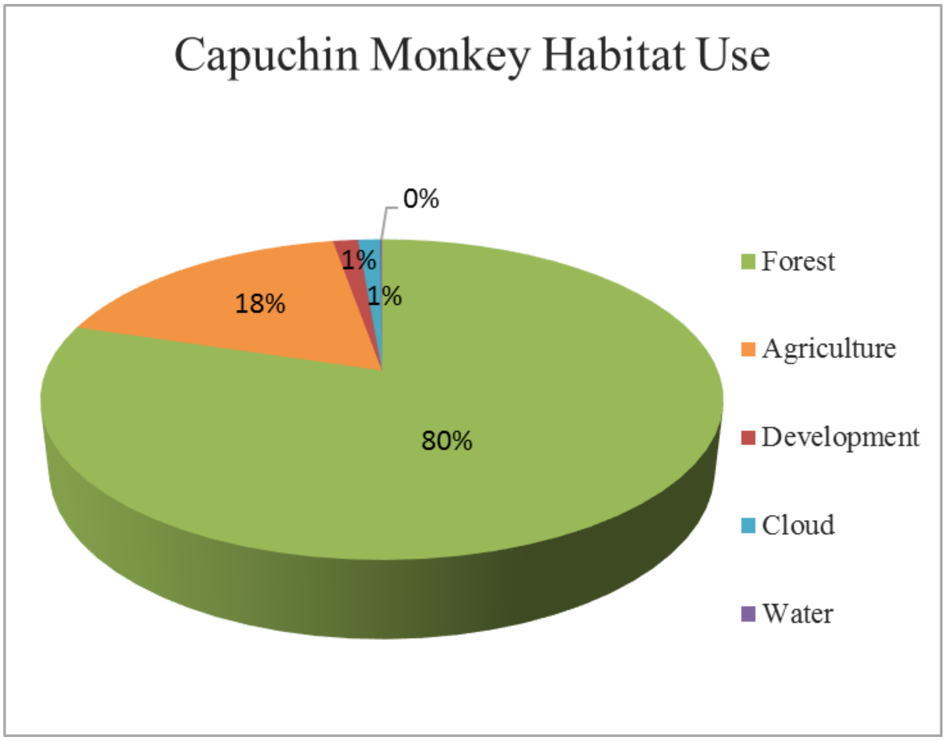

Figure 4.15: Capuchin monkey habitat use based on thiessen polygon analysis

Eight polygons were manually constructed which encompassed the areas of land that were most intensively used by the capuchin monkeys (Figure 4.16). This analysis allowed for the calculation of each land use or land cover class within each polygon of high use (Figure 4.17). Half of the high use polygons were covered by at least 75 percent of forested land. The remaining four polygons were characterized by large amounts of agricultural land, relative to the amount of agriculture in the entire study area.

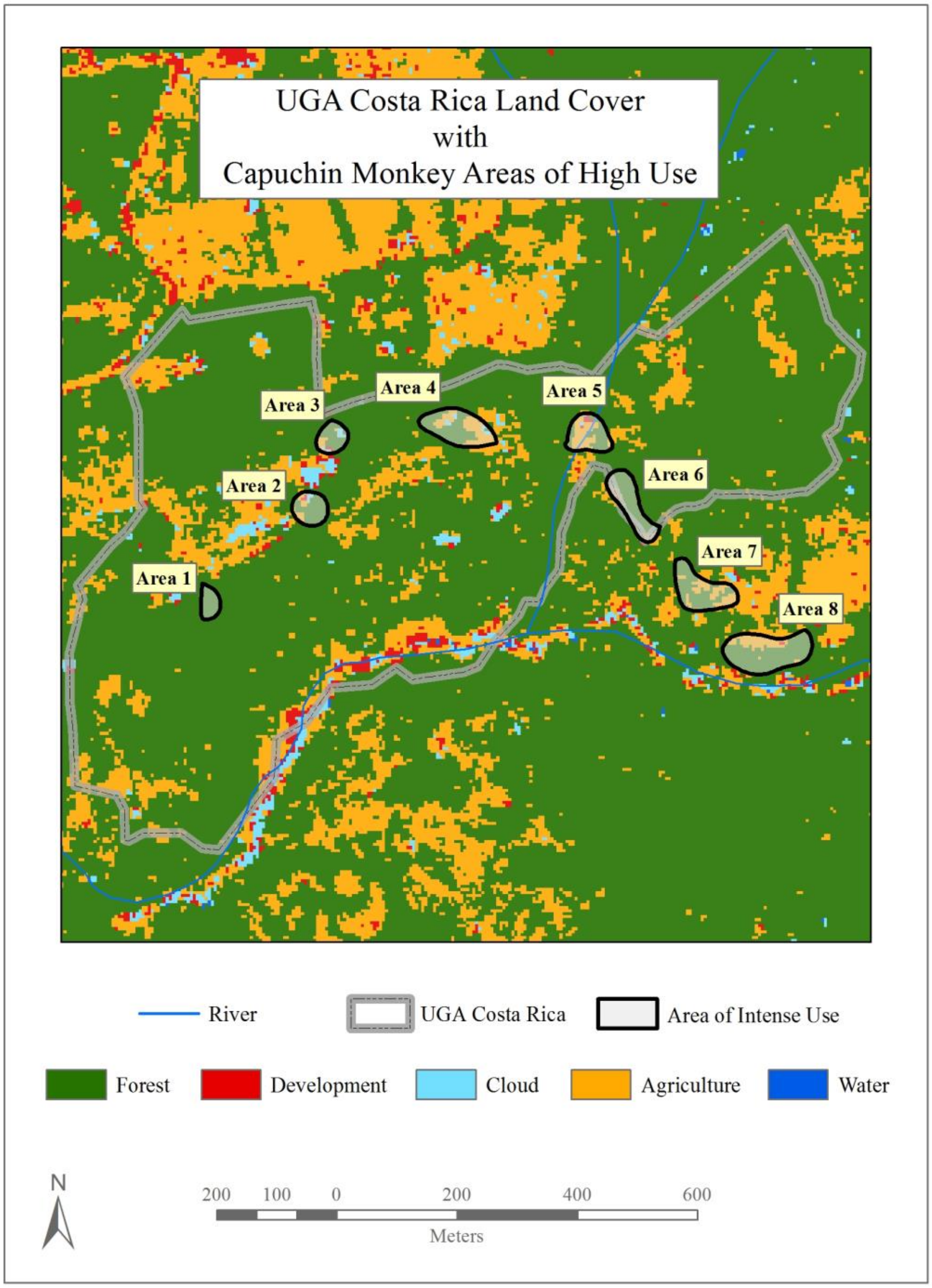

Figure 4.16: UGA Costa Rica land use/land cover with capuchin monkey areas of high use

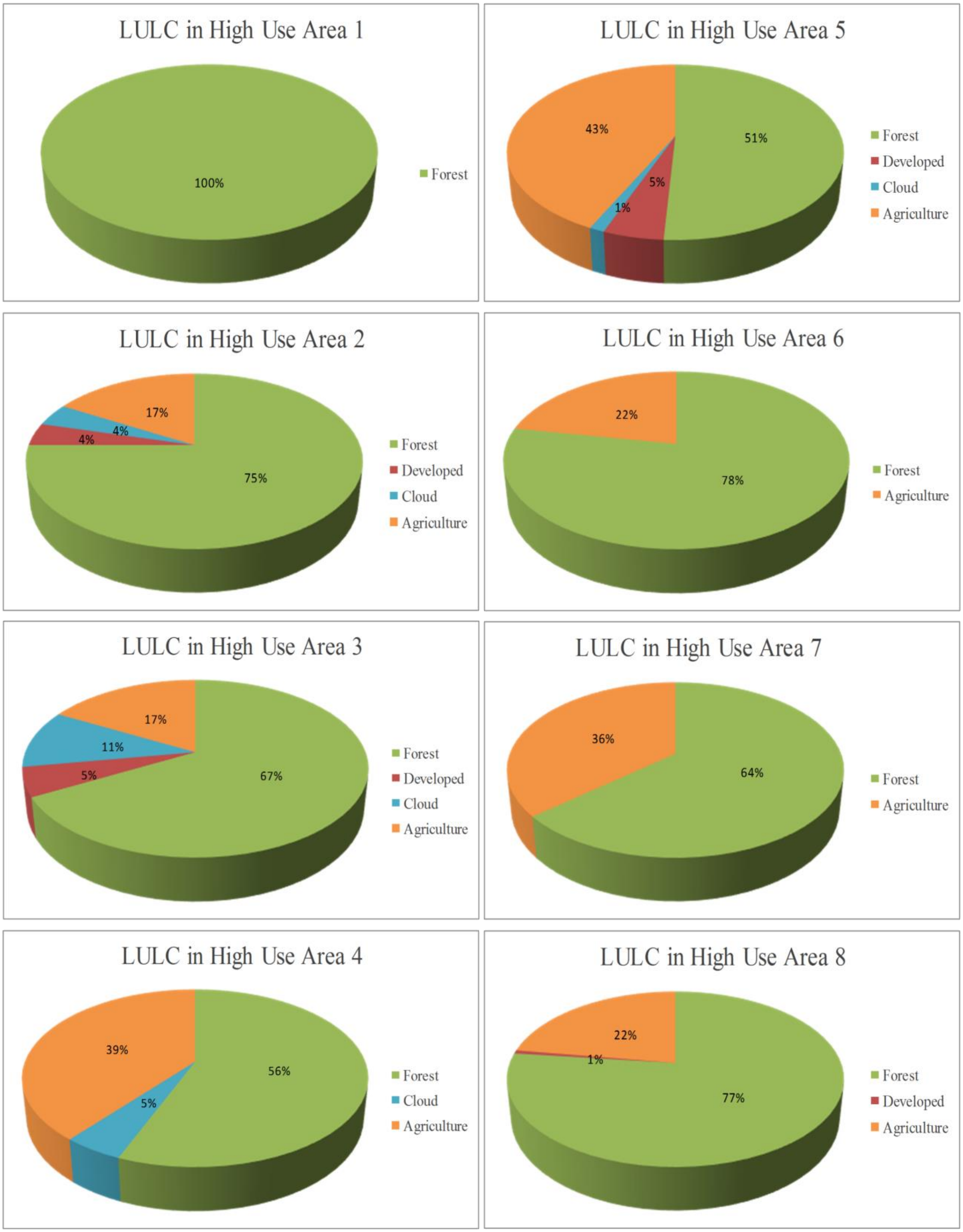

Figure 4.17: Land use/land cover within individual capuchin monkey areas of high use

CHAPTER 5

CONCLUSIONS

The objectives of this study to complete a LULC classification and spatial assessment of capuchin monkey habitat in Brazil and Costa Rica to be used to inform conservation efforts and awareness were accomplished. The LULC maps created for Brazil and Costa Rica provided a clear illustration of the land use and land cover within the study areas and highlighted potential risks of agricultural expansion on capuchin habitat. A pixel based classification method was used for characterizing LULC from medium (30 m) and high resolution (5 m) satellite imagery, and in the case of the Brazilian study area, changes in LULC over time.

The time series of Landsat images for Brazil revealed agricultural expansion and encroachment on capuchin monkey habitat. The agricultural areas in the 2000 and 2013 images were manually defined and transformed into polygon shape files. This was a feasible way to identify agriculture because it was clearly demarcated in the study area.

Incorporating an accurate habitat suitability model that predicted locations where bearded capuchin monkey tool use behavior occurs enhanced the analysis by allowing the visualization of suitable habitat for capuchin tool use. This model was developed from freely available, medium resolution satellite imagery. It was applied to the classified Landsat imagery and illustrated predicted tool use sites in relation to agricultural land. Not only did this confirm the utility of this model, it also demonstrated how multiple data sets derived from freely available, medium resolution NASA imagery can be combined to improve habitat assessments.

The final end products for the Brazil study consisted of two maps. The first map illustrated potential areas for agriculture expansion based on 2013 land cover and slope data. It combined slope data derived from a digital elevation model and land cover data derived from the initial supervised classification into a single raster dataset so that each pixel contained associated slope and land cover values. A simple count of every combination of slope and land cover was made both inside known agricultural areas and across the entire study area. These counts were used to calculate the likelihood of each pixel with its specific combination of attributes existing within an agricultural area. This allowed for potential areas of agriculture expansion to be identified for modeling future habitat risk. The second map displayed the proximity of confirmed capuchin tool use sites to potential areas of agricultural expansion. Adam Hinely's predicted anvil sites were overlaid on this map so that areas suitable for capuchin habitat could be visualized with high risk areas throughout the study area. This model and the maps developed from it will be shared with researchers from the Etho*cebus* project and University of São Paulo.

The point density and thiessen polygon analysis of the GPS data collected at the UGA Costa Rica study site allowed areas used by capuchin monkeys to be identified and spatially assessed. These analyses provided the basis for the high use area analysis. Manually constructing the polygons encompassing the land most intensively used by the capuchins was time consuming, but allowed for the visualization and quantification of LULC within the polygons. Most importantly, it made examining and assessing human land use and capuchin land use simultaneously possible.

Future work may include a refinement of the pixel based LULC classification. It is possible that performing an object based classification could improve the accuracy of the classification. In addition, field work should be conducted to collect current ground truth data for a LULC classification accuracy assessment of both the Brazilian and Costa Rican study sites. Areas modeled as high risk for agricultural expansion should also be visited to assess the predictive accuracy of the habitat risk model. Future research could also address improving the habitat risk model with additional geospatial parameters such as soils, land tenure (protected vs. private ownership), proximity to water, and proximity to roads to increase the accuracy of predicted agricultural growth and rank potentially threatened habitat for preservation.

This type of work increases understanding of habitat choice throughout anthropogenic landscapes and develops useful methodologies to monitor these areas. Remotely sensed satellite imagery, GPS data, habitat modelling, and GIS can be combined to produce powerful visualization tools and quantitative information to enhance conservation research.

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