A CAMERA TRAP STUDY OF THE CYPTIC, TERRESTRIAL GUENON *CERCOPITHECUS LOMAMIENSIS* IN CENTRAL DEMOCRATIC REPUBLIC OF THE CONGO

by

Steven G. McPhee

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Kate Detwiler, Department of Anthropology, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the Dorothy F. Schmidt College of Arts and Letters and was accepted in partial fulfillment of the requirements of the degree of Master of Arts.

SUPERVISORY COMMITTEE:

Kate Detwiler
Thesis Advisor, Ph.D.

Douglas Broadfield, Ph.D.

Andrew Halloran, Ph.D.

Michael S. Harris, Ph.D.
Chair, Department of Anthropology

Heather Coltman, DMA
Dean, The Dorothy F. Schmidt College of Arts and Letters

Deborah L. Floyd, Ed.D.
Dean, Graduate College

3/30/2015
Date

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ABSTRACT

Author: Steven G. McPhee

Title: A Camera Trap Study of the Cryptic, Terrestrial Guenon *Cercopithecus lomamiensis* in Central Democratic Republic of the Congo

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Thesis Advisor: Dr. Kate Detwiler

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From October-December 2013, we conducted a study of the newly discovered primate species lesula, *Cercopithecus lomamiensis*, in the DR Congo. We placed 41 camera traps inside a 4 km^2 grid outside the proposed Lomami National Park (LNP). We compared an analysis of 140 lesula events over 1,683 camera trap days from the heavily hunted Okulu area to a pilot study (38 events over 462 camera trap days) at the Losekola study site within the LNP. Our data show an unexpected result: capture probability of lesula (0.08) is the same at both the hunted and non-hunted sites. This is in contrast to the sharp decline in capture probability of all other medium-to-large terrestrial mammals at the Okulu site. These findings suggest lesula's cryptic behavior is an important adaptation buffering the species from the impacts of hunting. This study also expands knowledge on minimum group size, terrestriality, diet, and times of activity.

DEDICATION

To my father and mother, John and Noela McPhee. I promise I will not be a student forever. I will get a real job, someday.

A CAMERA TRAP STUDY OF THE CYPTIC, TERRESTRIAL GUENON *CERCOPITHECUS LOMAMIENSIS* IN CENTRAL DEMOCRATIC REPUBLIC OF THE CONGO

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INTRODUCTION

The use of technology in the study of cryptic species has been a topic of recent focus in the ecological research community (Cutler and Swann 1999; Foster and Harmsen 2011; McCollum 2013). With the increase in the technological capacity of camera traps over the past decade, these devices have proven to be a valuable tool in the systematic survey and monitoring efforts of conservationists all over the world. Large memory cards, long-life batteries, and high-resolution images have enabled scientists to deploy these devices in remote and inaccessible locations, extracting information on the population status of rare and endangered animals via clear pictures that show the interaction of the target species within its natural environment (Kelly and Holub 2008). Biologists have typically used camera trap data to document the absence/presence of species and to conduct systematic surveys of large-scale ecosystems, most notably with tigers, panthers, and other large cat populations (Dillon and Kelly 2007; Hines et al. 2010; Kawanishi and Sunquist 2004; McCallum 2013; Thorn et al. 2011). Camera trap surveys are proving to be a useful method to monitor endangered, cryptic animals, and are now playing an increasingly important role in the conservation of these species (Kays et al. 2011; O‘Brian 2008; Tolber et al. 2008).

The purpose of this research project was to use automatic camera traps to gather information on the new primate species lesula, *Cercopithecus lomamiensis*, in central Democratic Republic of the Congo. All research was conducted in collaboration with Dr. Kate Detwiler of Florida Atlantic University, and Dr. John Hart of the Lukuru Wildlife

Research Foundation, both co-discoverers of lesula. The discovery announcement, which appeared in PLOS ONE in September 2012, expounded upon lesula's unique morphology, genetics, ecology, and behavior, but remains—to date—the sole, peer-reviewed publication available on this species (Hart et al. 2012). Given the limited amount of existing knowledge regarding the behavior of this shy, cryptic species, and the general lack of information on how lesula populations are coping with challenges associated with central African forests, more research was needed to answer key questions about lesula. This research project fills these gaps and expands the base of knowledge on this little-known primate species.

My primary goal was to assess how lesula populations are faring in the face of unregulated bushmeat hunting. The negative effects of hunting on mammal species throughout the central African forests is well-documented, and acts as the basis for real concern for the survivability of primates that inhabit these unique ecosystems (Damania et al. 2005; Foerster et al. 2011; Koenig 2014; Kümpel et al. 2008; Linder and Oats 2011; Wilkie and Carpenter 1999). One of the difficult questions to answer about the new species is an estimate of population size. Lesula's range is restricted to 17,000 km^2 of forest in DRC's eastern central basin, and the current estimate of approximately 64,000 individuals is based on data from dawn vocalization surveys and visual sightings throughout lesula's range (Hart et al. 2012; K. Detwiler, pers comm). These data provide a starting point for modeling lesula's population size and contribute to the rationale behind the current provisional IUCN Red List Assessment of Vulnerable (Hart et al. 2012). However, to improve lesula's population size estimate and conservation status, more data are needed. Although the goal of this project is not to assess the overall population size of lesula, this research does provide data that can be used to refine the original assessment, by looking at how stable lesula populations are in different areas throughout its geographical range, noting that anthropogenic influences can have varying effects on different species (Carter et al. 2012; Griffiths and Van Schaik 1993). This project provides a natural extension to the research presented in the Hart et al. (2012) announcement paper, and provides strong evidence that can be used in updating lesula's IUCN Red List status from provisional to a status that is empirically verified.

My secondary goal with this research project was to assess if camera traps are a useful tool in gathering behavioral data on lesula, and if so, to create a preliminary methodology for cataloging captured behavioral traits, ultimately leading to an increased understanding of this species. At the start of this project in 2012, very few published studies used camera traps to assess behavior, with most studies focusing on occupancy, abundance, and density assessments (McCallum 2013). Recently, however, several key studies have been done looking at the effectiveness of camera traps in capturing specific behaviors (Hariyadi et al. 2010; Loken et al. 2013). The dramatic increase in the use of camera traps shows definitively that these research tools are quickly becoming an invaluable resource in data collection (McCallum 2013).

The overall impact on the field will be to add new knowledge on this little-known primate species, and to provide a methodology that can be used to study both the behavior and the anthropogenic impact on shy, cryptic species living in difficult-to-reach ecosystems. This thesis is organized into five chapters. Chapter 1 provides a brief history in the use of camera traps, gives an overview of the target species and study area, and ends with the research questions this thesis sought to answer. Chapter 2 provides all methodologies used for the camera trap surveys within this research project. Chapters 3 and 4 outline the results for both the hunting comparison and the behavioral survey, respectively. Chapter 5 provides a discussion on the implications of the results, and discusses the future of lesula in a heavily hunted environment.

CHAPTER 1: BACKGROUND AND RESEARCH QUESTIONS

Background

Although the use of remotely triggered photography extends back to the late 1800s, and was popularized for scientific use in the 1950s, Julie Savidge and Thomas Seibert (1988) conducted one of the earliest modern camera trap studies (Kucera and Barrett 2011; Gysel and Davis 1956). By attaching an infrared trigger to a Kodak disk camera, Savidge and Seibert (1988) attempted to identify predators and predation risk in artificial nest sites for avian species. The addition of an infrared trigger to early camera traps offered an advantage in that it was noninvasive, whereas earlier models relied on trip wires and other manual triggers. However, a major disadvantage of early camera traps was that these devices were not commercially manufactured, so each unit had to be built by the individual researcher at a considerable cost. This changed with the introduction of the Trailmaster 1500. The Trailmaster was the first commercially manufactured camera trap that boasted a portable, rugged design that was weatherproofed for use in rain and snow and housed an internal memory storage for event details that could be exported to a computer for analysis (Kucera and Barrett 1993, 2011).

Camera traps have undergone dramatic transformations since their first use, diversifying in both function, species studied, and scope of questions asked (Kays 2008; Kelly 2008; McCallum 2013). Since the 1990s, there has been a substantial increase in the use of camera traps for scientific purposes, with 73% of published camera trap studies between 1994 and 2011 occurring after 2005 (McCallum 2013). Camera traps in wildlife studies have focused heavily on mammalian species—particularly the order Carnivora—in forested ecosystems, with density estimation being the most prolific topic in camera trap literature (McCallum 2013). The order Primates has been underrepresented in camera trap literature, with less than 20 published papers on this group as of 2011 (McCallum 2013). This is likely due to the fact that most primate species are arboreal and the logistical difficulties of placing and maintaining camera traps in the high canopy are formidable.

Camera traps have also undergone a transformation in size, durability and technological specifications. Over the past decade, these devices have gotten smaller and more weather resistant, with increased battery efficiency and memory capacities. Because of these technological advancements, camera traps can now be placed in the field and left for more than a year, in some cases (Jenks et al. 2011; Liu et al. 2013). As the technological specifications have increased, the cost of purchasing these devices has inversely decreased. Many of the high-quality, durable, research-grade camera traps now cost in the range of $100 – $200, placing these tools within the grasp of small-budget research labs (Trolliet et al. 2014).

Looking at camera trap studies by topic, most published research in the 1990s centered on nesting behavior and predation, feeding ecology, and equipment assessments (Kucera and Barrett 2011). Less common topics, such as activity patterns, population studies, and the detection of rare species, were also present during this decade, but played a minor role in early camera trap studies (Kucera and Barrett 2011). With the refinement of methodologies pushing research toward novel applications, the momentum of the early 2000s began to swing toward the use of camera traps for ecological monitoring, population estimation, and behavioral descriptions. In a review of camera trap literature, Jamie McCallum (2011), subdivided study types into six categories: population, occupancy, richness, behavior, impacts, and technical. For the purposes of this study, I will look specifically at studies focusing on population and the use of camera traps in estimating relative abundance, as well as research into the use of camera traps to study behavior.

Estimating abundance by assessing how often a species is captured by photo or video has a long history in the scientific literature. Despite accounting for only 7% of camera trap studies before 1999, these population studies presently account for 67% of all camera trap literature published, clearly showing this to be a topic of major importance in the field (Cutler and Swann 1999; McCallum 2013). These studies have their roots in the seminal research conducted by K. Ullas Karanth (1995). In this study, the authors used camera traps to individually identify tigers in Nagarahole, India, ultimately expanding the study to four field sites (Karanth and Nichols 1998; Karanth and Sunquist 1995). Using identification stripe patterns unique to each individual, capture-mark-recapture statistics were performed to estimate the tiger density in each of the four study areas. This eventually led to a 9-year study that focused not only on density estimation, but also "estimated survival, recruitment, temporary emigration, transience, and rates of population change…" (Kucera and Barrett 2011). This methodology became the baseline approach to density estimation, and was replicated by scientists studying other carnivore populations across the globe (Kucera and Barrett 2011).

Using camera traps to study relative abundance—how common a species is in relation to other species—has had a rather less straightforward progression. When individuals of a target species are not recognizable, due to uniform coat color and non-distinctive markings, for example, capture-mark-recapture becomes very difficult. This appears to be the case in most target species in studies today, particularly in surveys where the primary goal is to create a species inventory (Manley et al. 2004; Rowcliffe et al. 2008). In order to overcome this limitation, researchers have used the *frequency* of camera trap captures for these species, called capture rate, as a measure of relative abundance, with the implicit assumption that there is a strong correlation between high capture rates and how abundant a species is in a study area (Jenks et al. 2011; Liu et al. 2013). When camera traps are placed in areas that are not known congregation sites for the target species (i.e. fruiting trees, human paths, baited sites), and instead are randomly placed, an individual or group encountering a camera trap is observed as a random event. Thus, the more individuals inside the study area, the greater the statistical odds of being captured by the camera traps, even if they are randomly placed (Jenks et al. 2011; Liu et al. 2013). Although the implied correlation between a species' capture rate and its relative abundance is not considered an ideal or a definitive method for determining actual density, this method has been used frequently by researchers as a reliable proxy for abundance in situations where the use of traditional population assessment methodologies are either extremely difficult or not possible (Jenks et al. 2011; Kelly 2008; Liu et al. 2013; O'Brian et al. 2003).

Despite the limitations of using capture rate as a proxy for relative abundance when targets cannot be individually identified, it is still useful to investigate the patterns in camera trap data that these surveys provide. While in-depth statistical analysis is not always possible in these situations, evaluating capture rates can provide key insights into the population status of targeted species, and is a good starting point that allows for more informed decisions regarding conservation and threat assessment (Kelly and Holub 2008). Also, a qualitative assessment can be made in regards to the status of target populations by examining additional data on group size, group composition, and demographics, and comparing it to the calculated index of relative abundance.

Like population assessment studies, camera trap usage specifically for studying behavior has also become increasingly important since the 1990s (Hariyadi et al. 2010; Loken et al. 2013, McCollum 2013). With rare, elusive, or difficult-to-reach species, traditional ecological monitoring methods (i.e. behavioral follows) can be challenging to conduct, especially considering the long timeframes and sometimes dangerous conditions that are necessary to adequately assess and quantify behavioral traits (Moruzzi et al. 2002; Ehlers Smith and Ehlers Smith 2013; Thoisy et al. 2008). Camera traps have also proven to be effective across a wide range of species (Khorozyan et. al 2014; O'Brian et al. 2003; Oliveira-Santos et al. 2008; Schaik and Griffiths 1996; Tan et al. 2013). In the case of these species, even the addition of small amounts of behavioral data collected by camera traps can drastically change our understanding of the behavioral ecology of these species. Newly described nocturnal/diurnal activity patterns, food inventories, intergroup social dynamics, and polyspecific associations can lead to a more thorough and representative description of difficult-to-study species and their interactions with the surrounding ecosystem.

Activity patterns were some of the first behavioral traits explored with camera traps (Griffiths and Schaik 1993; Schaik and Griffiths 1996). Activity pattern niche-division has been described as one of the most relevant descriptors of species coexistence, and can be useful in assessing human-induced behavioral change (Oliveira-Santos et al. 2008; Schoener 1974). Within this context, camera traps may have an advantage over traditional behavioral follows in that they are not restricted to times of good behavioral observation due to human limitations. Functioning 24 hours a day, these devices can capture activity day or night. Likewise, data can be collected even in situations where direct observation is not possible or it disturbs the natural behavior of the target species.

Other studies have focused on different applications in the use of camera traps to study behavior. Loken, Spehar, and Rayadin (2013) used camera trap data to assess the relative frequency of terrestrial behavior in orangutans in Borneo; orangutans are a relatively well-studied species, for which terrestriality is anecdotally known to be quite common. Using camera trap data, the authors assigned an index of terrestriality by combining ground level camera trap captures and known frequency of orangutans inside the study area, ultimately establishing data-driven confirmation of this behavior. Hariyadi et al. (2010) used a video-based ethogram to study the behavior of the Javan Rhinoceros. In this study, the authors concluded that video functions in camera traps were very promising for studying many aspects of behavior (Hariyadi et al. 2010). In addition to these studies, many claim that camera traps are effective for studying social interaction, migration phenology, infant care, food-storing behavior, and many other aspects of animal behavior (Trolliet et al. 2013).

The research questions in this thesis—and the methodologies developed in order to answer them—are derived from these existing works on population estimation and behavioral assessment via camera traps. Although the methods used for this project can be found in other camera trap studies, modifications in survey design must be made to target each species' unique behavioral traits. Previous research has been a useful guide in formulating the research questions; however, lesula is a newly discovered species for which very little is known, so the basic framework of this thesis is simply the need to collect more data.

Cercopithecus lomamiensis and the Hamlyni group

In June of 2007, working in a remote location in the DR Congo, Dr. John Hart (2012) of the Lukuru Wildlife Research Foundation, henceforth simply the Lukuru Foundation, discovered a previously undescribed species of *Cercopithecus* monkey while conducting initial surveys in an area known as TL2, which was being considered as a future conservation site. This primate was well-known to the local population as lesula, but unknown to the scientific community. Lesula was subsequently revealed as a member of the previously monophyletic *Cercopithecus hamlyni* taxonomic group, with a divergence date between 1.7 and 2.8 million years ago (Hart et al. 2012).

Very little is known about *C. hamlyni*, as there are no published studies of this species in the wild; there is evidence to suggest that two subspecies exist, but a more detailed study is needed to resolve this issue (Grubb et al. 2003). The geographical range of *C. hamlyni* begins on the northeastern bank of the Congo River, and extends outward toward DR Congo's eastern political border, encompassing an area of roughly 180,000 km^2 (see Figure 3)(Hart et al. 2012). Outside of the DR Congo, only one small population exists at Nyungwe Forest National Park, Rwanda (Easton et al. 2011). Within the DR Congo, *C. hamlyni* is found in mature terra firma and secondary forests, and it inhabits a range of elevations from lowland to mountain (Hart et al. 2012). General group composition is single male/multi-female and offspring, and group size can range from one to 15 individuals per group, with individuals utilizing strata from the ground to the canopy (Hart et al. 2012; Young 1998).

In contrast to *C. Hamlyni*, Hart et al. (2012) described lesula's geographic range as starting on the west bank of the Lomami River and extending in a westward direction encompassing approximately 17,000 Km^2—more than 10 times smaller than the geographical range of *C. hamlyni* (see Figure 3). Lesula can be found in mature terra firma forests, including mixed and monodominate, *Gilbertiondedron dewevrei* forests (Hart et al. 2012). Group composition was estimated as single male/multi-female and offspring, and group size was reported as up to five individuals based on 19 separate observations (Hart et al. 2012).

A full physical description of lesula can be found in the announcement paper published by Hart et al. (2012), but in general, lesula is described as a medium-sized, long-limbed monkey (see Figure 7, 8, and 9). Distinctive features include an off-white nose stripe in adults that is reduced and/or absent in juveniles, as well as a variable aquamarine perineal patch that ranges in intensity from bright blue to almost white (Hart et al. 2012). Like *C. hamlyni*, lesula is described as semi-terrestrial, although the extent of ground dwelling behavior in lesula is more pronounced (J. Hart, pers. comm.). Lesula feeds on a variety of terrestrial plant species, including the family Marantaceae; they also feed on leaves, shoots, and fruit dropped from foraging arboreal primate species (Hart et al. 2012).

Study areas

The TL2 region is a 20,000 km^2 conservation area located in the center of the DR Congo (see Figures 1 and 2). Three major rivers form the boundaries of TL2: the Tshuapa, the Lomami, and the Lualaba. The three rivers, from which the region derives its name, surround a continuous stretch of forest, which supports a diverse and little-studied ecosystem that includes the bonobo, forest elephant, okapi, and 12 species of primate. Despite its low human population density, the TL2 region is under threat of being emptied of its mammalian fauna due to uncontrolled bushmeat hunting (Hart and Hart 2011). Other factors that have lead to the decline of animal populations in the DR Congo, such as logging and mining activities, are not present in TL2, implicating unregulated bushmeat hunting as the major cause of decline throughout the region (Hicks et al. 2010; Hart and Hart 2011).

As a means to protect the new *Cercopithecus* monkey and the other species endemic to this block of forest in the DR Congo, Dr. John Hart, scientific director of the Lukuru Foundation, has proposed the 9,000 km^2 Lomami National Park within the TL2 region (see Figure 4). Surrounding the proposed Lomami National Park is an 11,000 km^2 community conservation area, which acts as a buffer zone to the park. The proposed national park has been supported at the local, regional, and national levels, and has officially been accepted and protected by the Orientale and Maniema provinces. Steps are underway for its national gazettement (Hart et al. 2012).

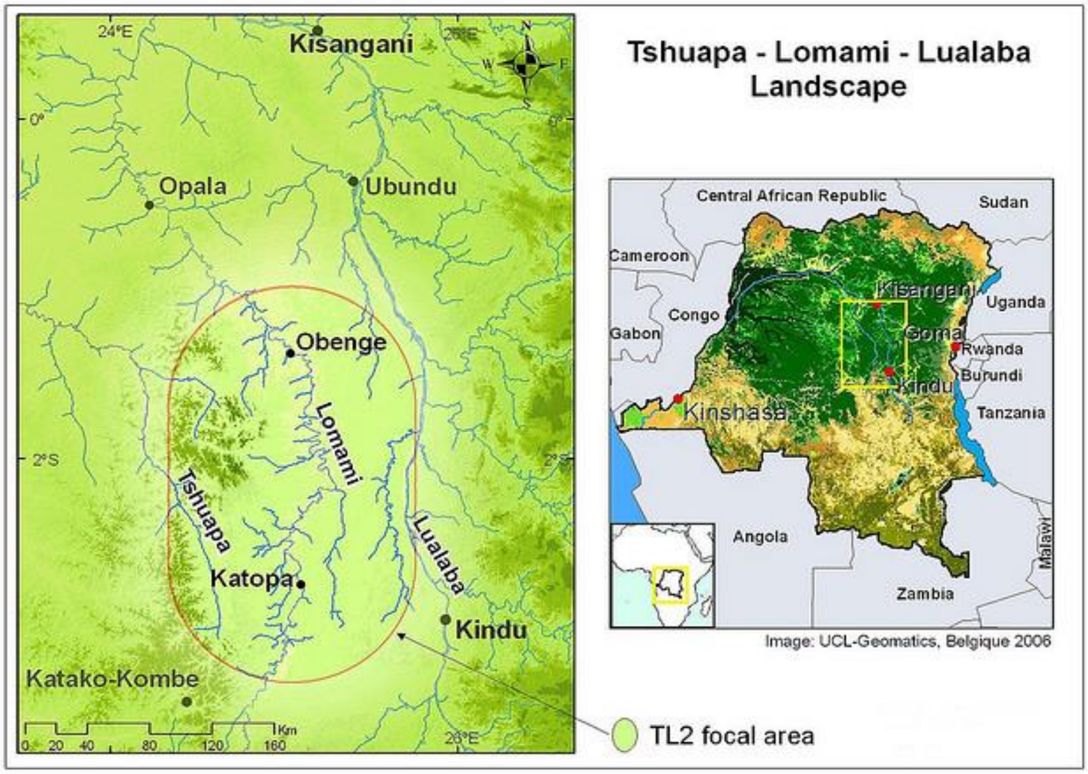

Figure 1: Map of the TL2 region in central DR Congo. Map by Lukuru Foundation, TL2 project.

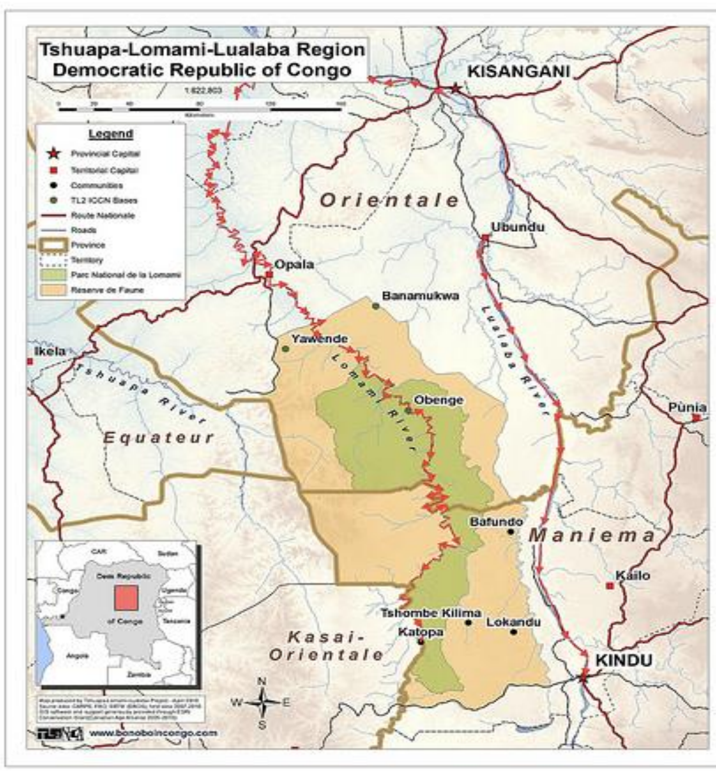

Figure 2: 9,000 km^2 proposed Lomami National Park (Green) surrounded by 11, 000 km^2 community conservation zone (Brown). Map by Lukuru Foundation, TL2 project.

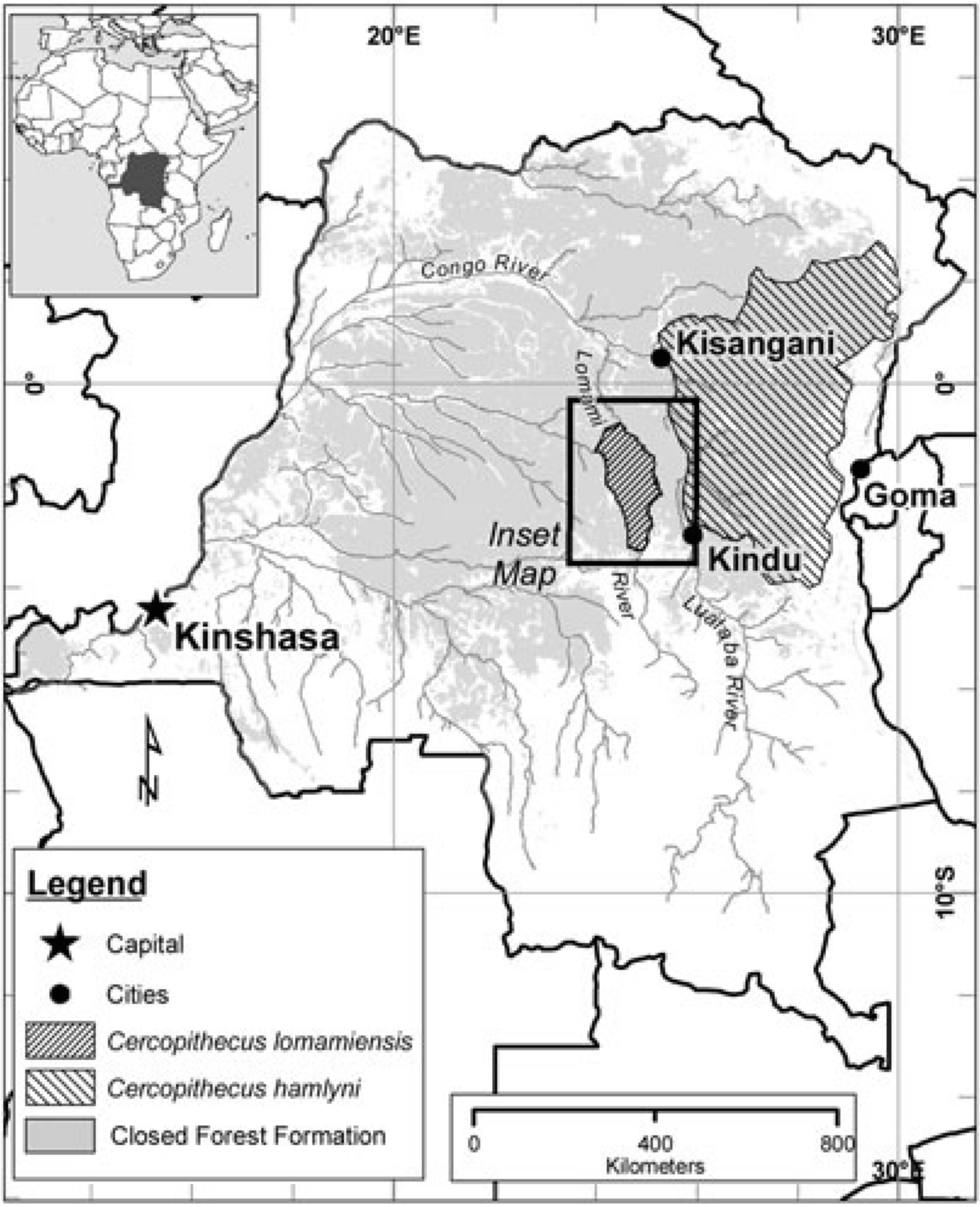

Figure 3: Geographical range of lesula and sister species *C. hamlyni*. Lesula's range is bounded by the western bank of the Lomami River and extends to the west, and *C. hamlyni's* range begins on the east bank of the Lualaba (upper arm of the Congo) River and extends eastward. Map by Lukuru Foundation, TL2 project.

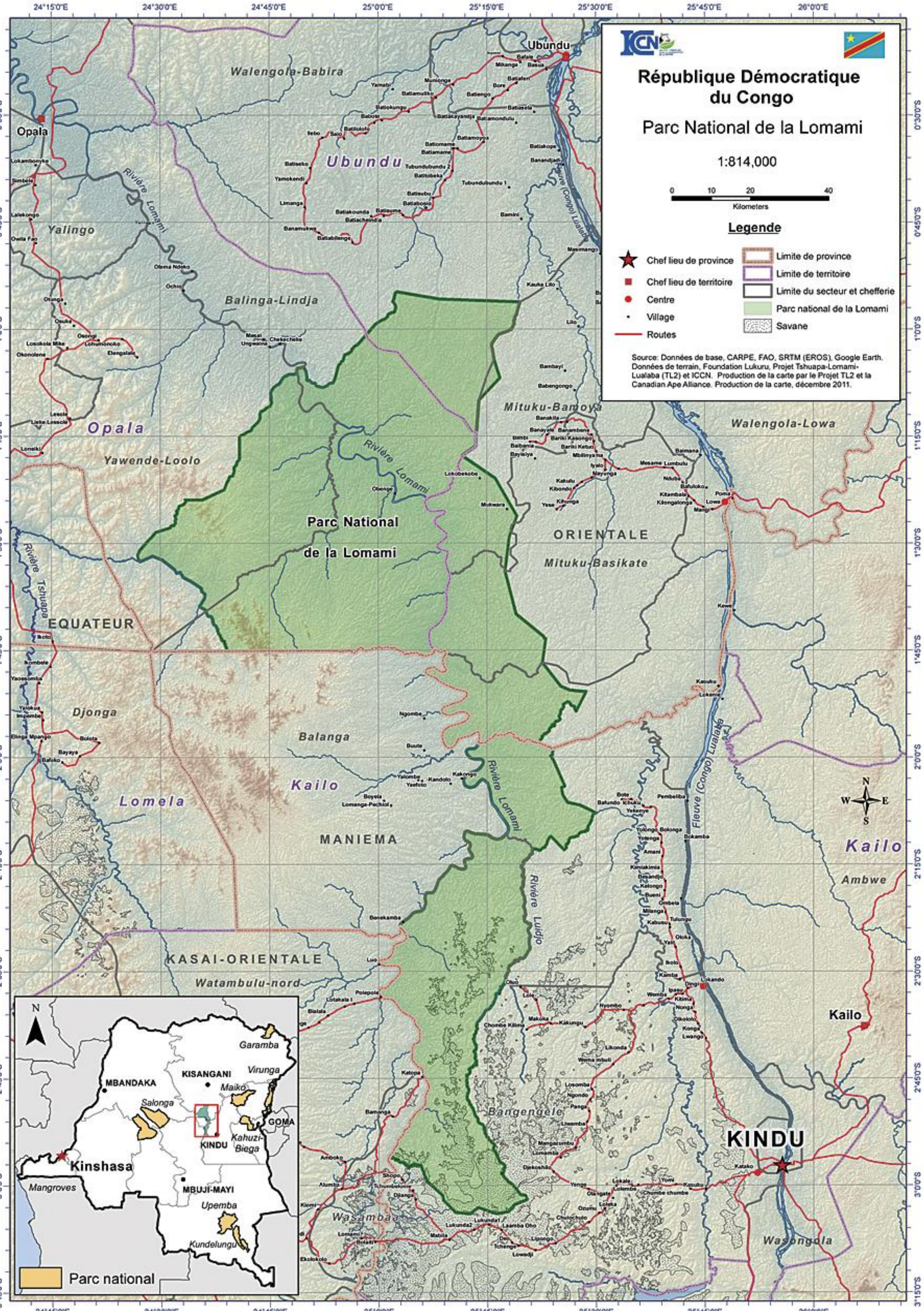

Figure 4: Map of the proposed Lomami National Park. Orientale and Maniema Provinces have accepted Park borders. Ratification of the new park is awaiting government approval. Map by Lukuru Foundation, TL2 project.

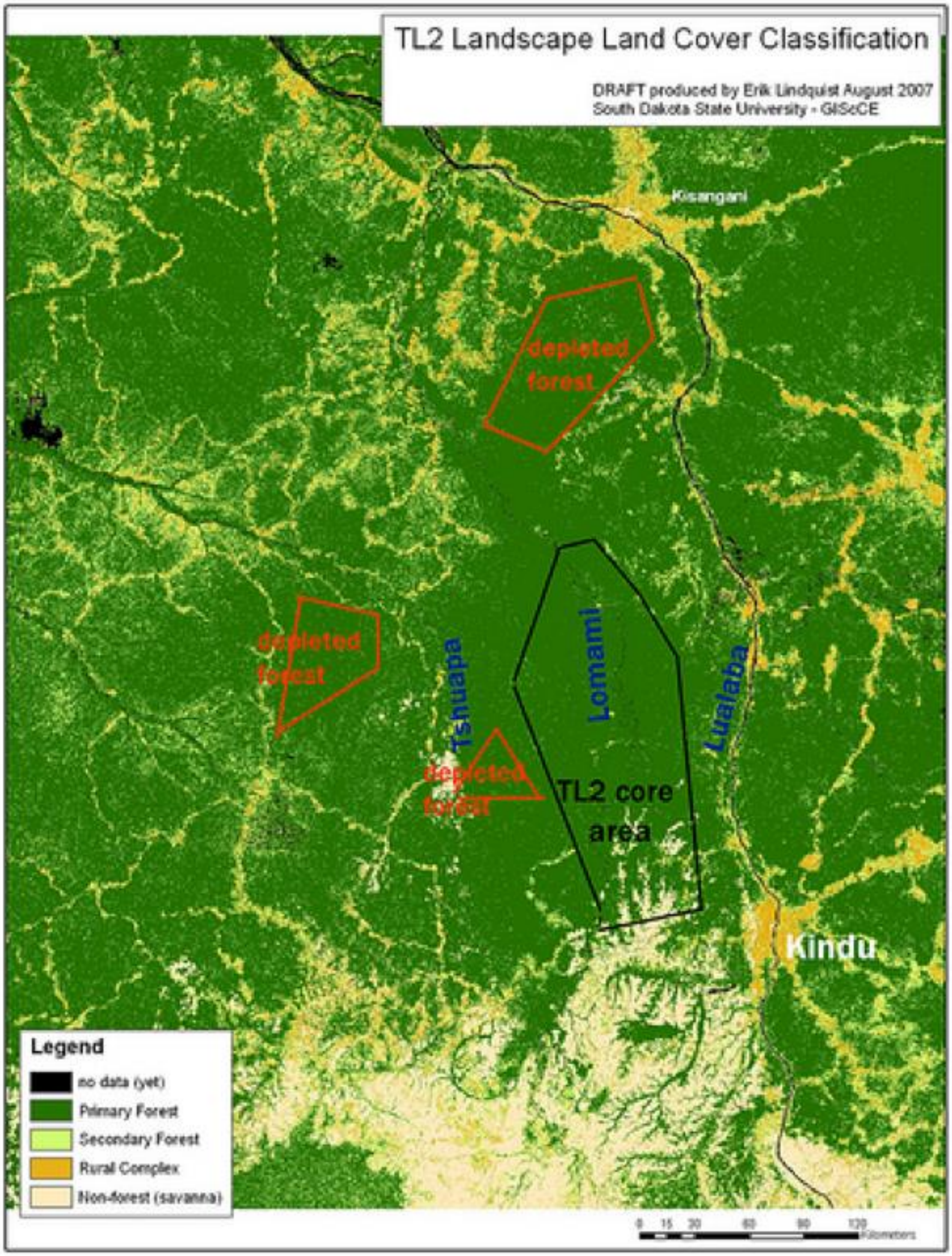

Figure 5: Early surveys by Dr. John Hart and team revealed the distribution of wildlife in relation to the TL2 core area. Forest areas near human population centers were found to have little remaining wildlife present. Map by Lukuru Foundation, TL2 project.

The Lukuru Foundation's TL2 Project has established two research areas to study lesula: the lightly hunted Losekola research area, established in 2008, and the heavily hunted Okulu research area, established in 2013 (see Figure 6). The Losekola study area is a remote, lightly hunted research site deep within the national park that has been protected since 2008, suffering only brief and infrequent incursions. By contrast, the second site, Okulu, is a community conservation area outside the park, where there is high hunting and human activity. A small cluster of villages is situated 13 km west of the Okulu study area, and the local population frequently uses the surrounding forest—including the Okulu research area—to hunt and gather forest materials. These two study sites are separated by approximately 60 km of contiguous, close-canopy, tropical rainforest, with no major geographical barriers separating them. The Losekola and Okulu research areas are also of similar elevation, are made up of comparable fauna and flora, and there is no logging or mining in the region (Hart and Hart 2011; J. Hart, pers. comm.).

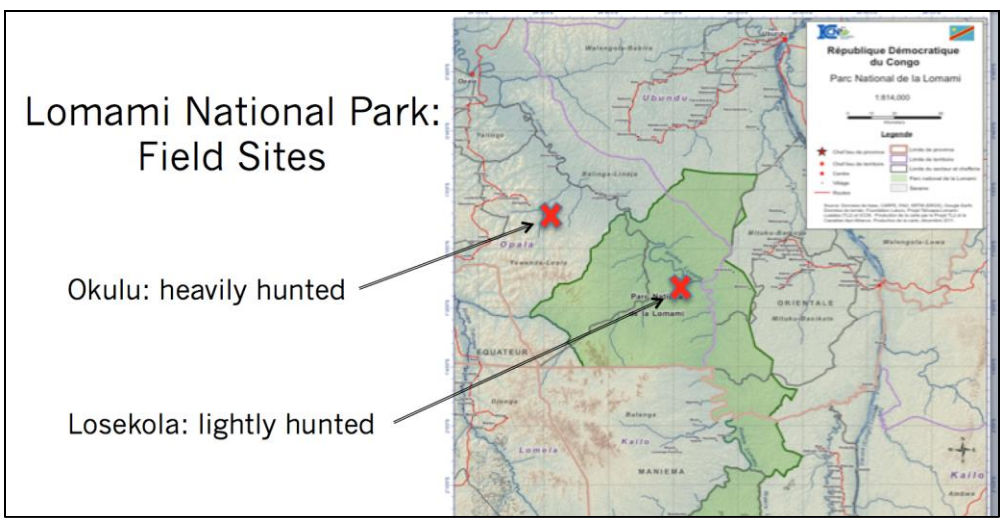

Figure 6: The Losekola and Okulu research areas were established to study lesula and other species present. Losekola is located deep inside the protected park and has had little hunting or incursions since 2008. Okulu is situated 13 km west of a small cluster of villages known as Yawende, and is threatened by heavy hunting. Map modified from original version by Lukuru Foundation, TL2 project.

In order to determine the survivability of lesula, it is important to know which areas of TL2 have abundant numbers of lesula with stable populations, and which areas do not (and are thus likely declining due to overhunting). Our current understanding of lesula's abundance and distribution throughout its range is based on data collected during listening point surveys inside the TL2 region (Hart et al. 2012). Listening point surveys are an effective way of collecting absence/presence data on primate species that give distinctive calls, and have been used to determine abundance in difficult-to-study species (Aldrich et al. 2008; Dacier et al. 2011; Papworth et al. 2013; Press et al. 1998) These surveys documented where lesula was heard giving what became known as the dawn morning chorus—a period of high vocal activity.

At the Losekola study area, lesula was heard at 84% of the listening posts, suggesting a relatively high density of lesula in this part of the TL2 forest (Hart et al. 2012; J. Hart, pers. comm.). This study site is a protected closed evergreen forest. Thus, two factors are likely to contribute to lesula's high numbers at Losekola: no hunting and good habitat for this species. Listening point surveys are an effective way of collecting absence/presence data on primate species that give distinctive calls; however, in areas where human hunting occurs, this method may not be appropriate as primates are known to change their calling behavior to become more cryptic to hunters, for example they stop or reduce calling (Papworth et al. 2013). Therefore, it is important to develop additional methodologies, such as camera trap surveys, to accurately monitor lesula's absence/presence.

Measuring the impact of hunting on animal populations in various areas is problematic and complicated by naturally occurring factors that can affect the abundance and distribution of species at any given location (Linder and Oates 2011). To effectively measure the direct impact of hunting on lesula at the Losekola and Okulu sites, a full study of habitat structure, geographic variables, temporal changes in habitat use, and bushmeat surveys would be needed (Linder and Oates 2011). These variables are outside the scope of this research project. However, we can begin to address the impact of hunting on lesula by looking at the relative abundance of this species under two varying, clear-cut situations: a known heavily hunted site, and a known non-hunted site. By studying the behavior, occupancy, and abundance of lesula at the Losekola and Okulu research areas, we can gather baseline data and generate key questions to inform future research within the TL2 region. This work will significantly impact conservation approaches and policies specifically in TL2, and perhaps influence surrounding communities and other conservation areas.

Figure 7: Camera trap photos of lesula. Left) Lesula male showing variable blue perina and scrota. Center) Lesula female with infant. Right) Lesula juvenile shown eating a new food source: mushrooms.

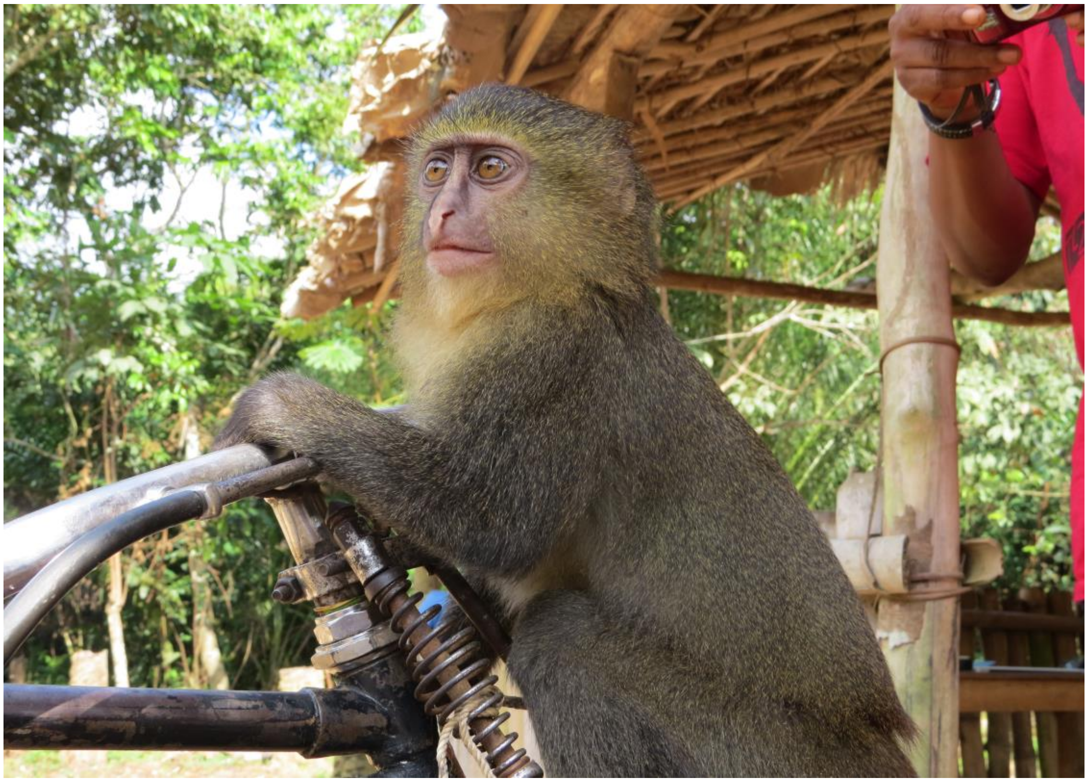

Figure 8: Captive lesula juvenile. Note: light skin around face and ears, buff, golden diadem, and unusually large eyes.

Figure 9: Captive lesula juvenile.

Research questions

The research questions that I chose to examine in this thesis fall under two broad categories: how is lesula faring under the threat of unregulated bushmeat hunting, and are camera traps useful tools for studying the behavior of lesula. In order to answer these two overarching questions, I examined data from two different camera trap surveys. The first survey was a pilot camera trap study conducted by John Hart in the Losekola research area in 2012, and the second was a full-scale camera trap study conducted by myself in collaboration with the Lukuru Foundation at the Okulu research area in the DR Congo in 2013.

Although these surveys were conducted independently, I ensured that comparable methodologies were used—both for data collection and for data analysis—so I was ultimately able to compare data sets. I first examined all data pertaining to the 2012 Losekola pilot camera trap study, and I then analyzed all data from the 2013 Okulu survey. Some analyses were completed with the intent of contrasting categories of data—such as species present and frequency of encounters—*between* the two sites. In addition to these between-site comparisons, the data from both sites were pooled in order to assess behavior. My specific research questions were:

I. Initial pilot study questions

1) Are camera traps effective tools for studying lesula?

2) Can individuals be recognized in camera trap photos, enabling capture-recapture methods for estimating population density?

II. Generalized Losekola and Okulu questions

3) What species are present in the research areas?

4) How often are these species captured by the camera traps?

5) How often are lesula captured by the camera traps?

III. Hunting comparison between Losekola and Okulu

6) Are all species captures lower at the Okulu hunted site than at the lightly hunted Losekola site?

7) Are lesula captures lower at the Okulu hunted site than at the lightly hunted Losekola site?

IV. Behavioral study

8) Are the photos and videos recorded of high enough quality to enable behavioral assessments?

9) Can lesula's sex and age be determined from camera trap data?

10) Can lesula's group size be determined from camera trap data?

11) Can lesula's terrestriality be quantified using camera trap data?

12) Can home range and diet be determined from camera trap data?

13) Can lesula's activity pattern be determined from camera trap data?

Although it was outside the scope of this study to measure the direct effect of hunting on lesula populations at the two study areas within the TL2 region, we gathered preliminary data in order to investigate if unregulated hunting is having adverse effects on the lesula population within the heavily hunted Okulu area. We posit that differences in the occupancy and abundance of lesula between the two sites, Losekola and Okulu, are reliable ways of measuring the effects of bushmeat hunting. Further research into habitat structure, geographic variables, temporal changes in habitat use, and bushmeat surveys can be conducted in future projects. All data gathered on the behavior, occupancy, and abundance of lesula at these two sites will be available as baseline data for further studies and could prove pivotal in directing the future conservation efforts in the TL2 region. Details of how I collected and analyzed the camera trap data are outlined in the next chapter.

CHAPTER 2: METHODS

Pilot camera trap survey – Losekola 2012

In 2012, John Hart conducted a small-scale exploratory camera trap survey in the Losekola Research Area inside the proposed Lomami National Park. Losekola was chosen for the pilot study due to the area's remote location and well-known, stable population of lesula (J. Hart, pers. comm.). The lesula population of the Losekola research site has encountered little-to-no hunting pressure due to the area's location deep inside the proposed national park, as well as the protective measures that have been in place since 2008.

Hart began his survey on May 8th, 2012 and continued through December 8th, 2012 for a total survey period of seven months. Due to the remote location of the field site and logistical factors involved in data collection from various camera trap stations (locations), deployment of a spatially and temporally continuous survey was not possible. Fifteen separate surveys were conducted over the course of seven months, ranging in duration from 10 to 83 days. Over the course of all conducted surveys, 462 camera trap days of data were collected, with a camera trap day defined as the number of 24-hour periods that each camera was operational and capable of recording species encounters.

Eight camera traps of two different makes were deployed in a 2 km^2 grid at 10 stations (two of the eight camera traps were relocated to different stations) within the Losekola research site (see Figure 10). The first infrared remote camera model was a Bushnell Trophy Cam, and the second was a Moultrie M100. Both models were equipped with a 6-mega pixel (mp) resolution camera. Nine camera trap stations were placed at locations along previously established transects within the 2 km^2 grid, as well as along active game trails. The 10th camera trap station was located 1 km east of the 2 km^2 grid, but was included in this survey due to the similarity of habitat type with all other stations. Longitude, latitude, and elevation were recorded at each camera trap station, along with the start and end date of each survey period.

Along with a time and date stamp, all photos from the Moultrie camera models included information on temperature, barometric pressure, and moon phase. The distance between each camera trap station varied from 500 m to 1,750 m with most of the camera trap stations falling between 500 m and 1,000 m apart. After the survey period, all camera trap data were collected and compiled for analysis.

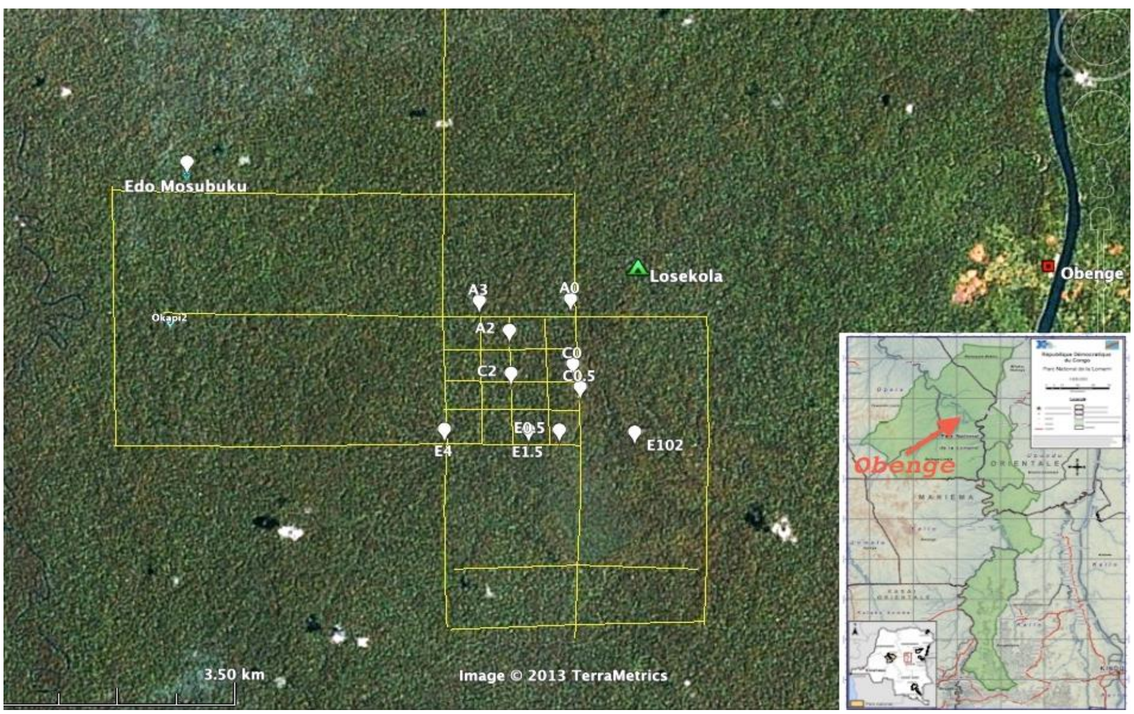

Figure 10: Google earth view of the Losekola research area and camera trap placement. A camera trap was place at Edo Mosubuku—a small, natural clearing—but was not included in the survey. Map by Lukuru Foundation, TL2 project.

The goal of this pilot survey was to assess the effectiveness of camera traps for studying lesula (see subsets I and II of our specific research questions in Chapter 1). With the majority of camera trap research being conducted on large cat populations with easily-identifiable individuals and broad species inventories, several generalized assumptions needed to be clarified before a costly, full-scale research project was initiated on this species. Based on a preliminary, informal visual examination of the photos obtained from this pilot study, Hart found that the camera traps appeared to be a highly efficient and cost-effective means for indirect observation of lesula. Despite lesula's highly cryptic nature, the number of photographic records for this species appeared to be equivocal to other common terrestrial mammals, leading Hart to expect a full-scale survey would yield significant data returns (J. Hart, pers. comm.)

Hart's preliminary methodology was pivotal in assessing the practical usage of camera traps and in refining our assumptions and informing the research questions that I could ask (see subsets III and IV in of our specific research questions in Chapter 1). Upon inspection, I concluded that the Losekola pilot survey was of sufficient quality to be used in conjunction with a future comparative survey. We chose to conduct a second camera trap survey in a heavily hunted forest in order to gain insight on how lesula is faring under the threat of unregulated bushmeat hunting. My goal was to take the opportunistic methodology introduced by Hart and refine it into a more systematic camera trap survey technique that could then be used as the basis of regional camera trap studies in the future. In the next section, I outline the specific methodology that I developed for this thesis, based on Hart's unpublished Losekola pilot survey and other published camera trap studies.

Full camera trap survey – Okulu 2013

In September of 2013, I traveled to the DR Congo to begin collecting data for the Okulu survey. The Lukuru Foundation team members were assembled at Lohumonoko, a small village in the Yawande district, on the 5th of October. Our team consisted of four research assistants: Pablo Ayali, Ephrem Mpoka, Bravo Bofenda and Louison Bokatunga, and eight field assistants. During our week-long stay there, the surrounding forest was surveyed and a suitable prospective study area was located due east of the village. The prospective study area was chosen due to its mixed forest, varied topographical features, and semi-isolation from the local villages. A small team was sent to the east bank of the Okulu River to conduct preliminary pre-dawn vocalization surveys and determine if lesula were calling, and thus, present in the area. Upon confirming that lesula was calling in significant numbers, the team returned to the basecamp, and on the 13th of October, all team members departed from Lohumonoko and began the 13 km trek to the study area where Camp Okulu (-1.10431, 24.50209) was officially established.

At the Okulu site, twenty kilometers of transects were cut between October 14th and 19th in a 4 km^2 area (see Figure 11). The transects were cut in a grid, with five 2 km transects extending west-to-east, and five 2 km transects extending north-to-south. East-west transects were named A, B, C, D, and E, respectively, starting at the northern most transect heading in a southerly direction. North-south transects were named 0, 1, 2, 3, and 4, respectively, starting at the most eastward transect heading in a westward direction. The east-west and north-south transects intersected every 500 meters. The labeling system was consistent with the nomenclature used by Hart in the 2012 Losekola pilot survey, and allowed each 500 m transect intersection to have a unique designation (i.e.

A4 represents the most northwestern corner of the study area, and E0 represents the most southeastern corner).

During the transect-cutting process, recce notes (opportunistic observations) were recorded, looking specifically at vegetation type, wildlife signs, and presence of hunting apparatus. The local forest environment was made up of *Gilbertiondedron dewevrei* forest and mixed forest, with lower-elevation flooded rainforest occurring on the western border of the study area, near the Okulu River. Signs of wildlife were sparse inside the area, but included feces from several species of duiker, aardvark burrows, and buffalo tracks/feces. Wildlife sightings were also rare. Although vocalizations from *C. mitis*, *C. mona wolfi*, *C. ascanius*, and *L. aterrimus* were heard, visual confirmation was seldom achieved. It became very clear after the initial survey that hunting was prevalent throughout the area. We discovered six active snares and one inactive snare alongside active human footpaths inside the study area, and we also encountered an inactive hunting camp situated outside the Northwest corner of the study area.

Following the transect cuts, we began setting camera traps inside the study area. We placed a camera trap at each transect intersection (every 500 m), and in the center of each smaller 500 m x 500 m square, for a total of 41 camera traps inside the study area (see Figure 11). To avoid possible theft and disruption due to travel along the transects, we placed each camera trap slightly off, but within 25 m, of the pre-appointed transect intersection. Once a suitable location was found, camera traps were mounted 50 cm – 60 cm high, and the area within 3 m of the face of the camera was cleared of any small brush that would potentially block the view of the camera. Care was taken to minimally alter the surrounding habitat.

Two models of camera trap were used for this survey: 2013 Moultrie M-880s (n = 21) and 2011 Bushnell Trophy Cam (n = 26). The first Moultrie model cameras were new and had an 8-megapixel (MP) camera and the capacity to shoot 1280x720p HD video. The detection range was 12.2 meters with an angle of view of 50 degrees yielding a potential detection area of 7.9 m^2 per camera trap, under ideal conditions. The 2011 Bushnell Trophy Cams had previously been deployed in an unrelated survey in the Bili region of DRC. The Bushnell models had an 8-megapixel (MP) camera and the capacity to shoot 720x480p video. The detection range was 13.7 meters with an angle of view of 45 degrees, yielding a potential detection area of 7.36 m^2 per camera trap under ideal conditions. For the Bushnell models, angle of view was not published on the manufacturer's website, so measurements were taken in-field using compass, and represent an approximate estimate of the angle of field of view.

Duracell Ultra and Energizer Lithium batteries were used in all camera traps. Both battery types worked very well for the survey and lasted for the duration of the camera trap study. We chose high-quality Scandisk memory cards, 30 of which were 32 GB with the remainder being 8 GB in size. The larger 32 GB memory cards proved to be unnecessary, as the maximum amount of space used on any camera trap was only 1.2 GB.

Fieldwork at Okulu: camera trap locations, malfunctions, and corrections

In addition to the 41 camera traps set in the 4 km^2 study area, six additional "experimental" camera traps were set that were not included in the survey results. On October 14th, two camera traps were set 50 m and 100 m south of the E3 camera trap station. These locations were ideal for testing the quantity/quality of video data, and they also helped us gauge which species were present in the area, if any. The areas chosen, E3-50m and E3-100m, were predominately *Gilbertiondedron dewevrei* forest with a high canopy and very little scrub brush present. The two camera trap stations were placed on a connecting, wide, well-traveled animal path.

On the 16th of October, two more experimental camera traps were set east of the B0 camera trap station at 50 m and 100 m. In contrast to the previously described E0 camera trap station, the B0 experimental stations were placed in dense, thicketed forest. The habitat was predominately mixed forest that was closely patched with briars and heavy underbrush. Getting in and out of this location of the study area was difficult, and provided a sharp contrast to the open, the easily traversable E0 experimental study area.

On the 23rd of October, two more experimental camera trap stations were set up along an active buffalo trail. The first, B0.5-buffalo was located inside the study area just south of the B0.5 camera trap station, and the second, D5.4-buffalo, was located between the D0 and D0.5 camera trap stations. This camera trap was placed where we had previously recorded buffalo tracks and feces, and was situated in flooded rainforest surrounded by standing swamp.

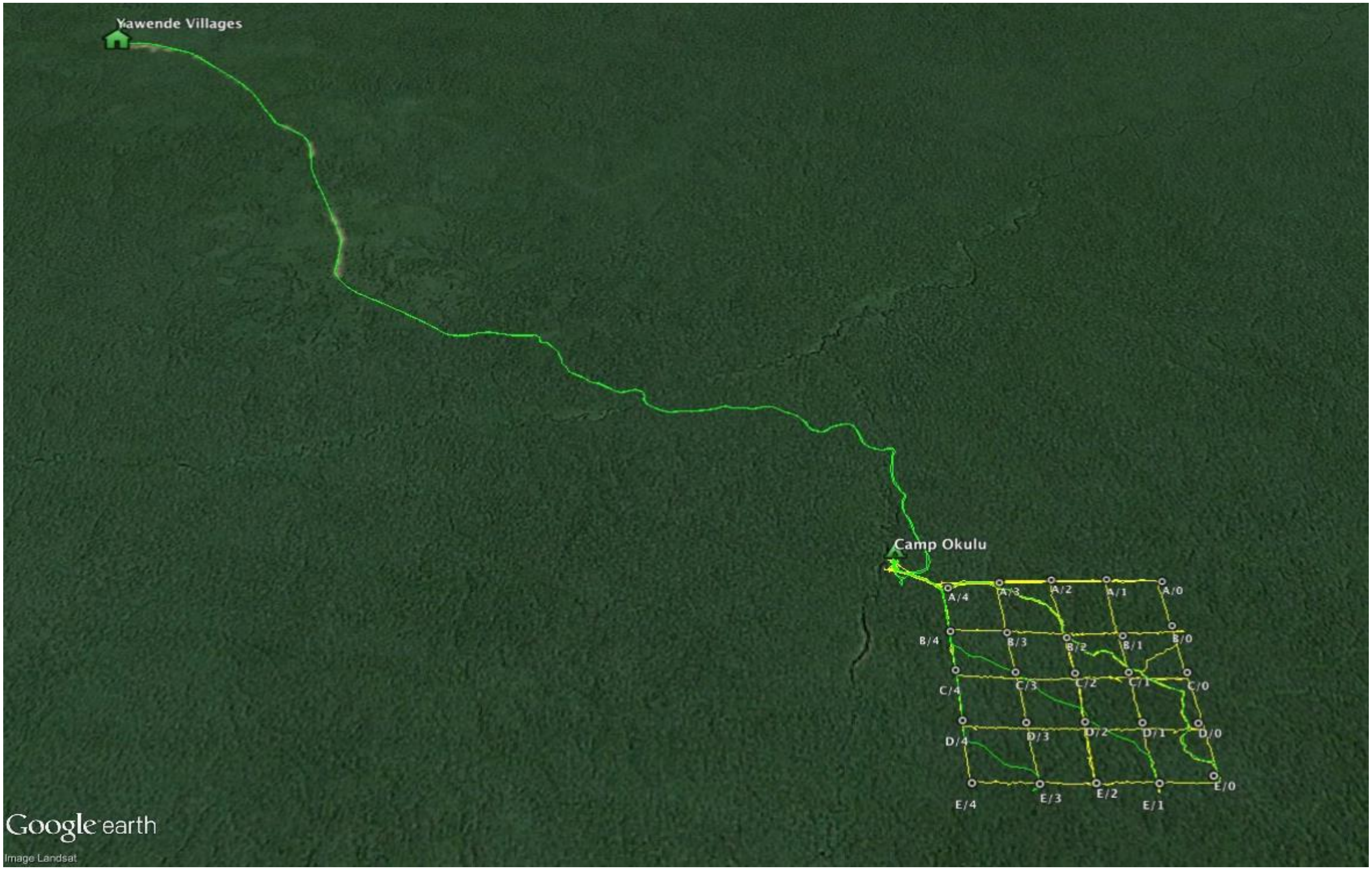

Figure 11: Google Earth map of the Okulu study area and camera placement. The path (highlighted in green) from the nearest village to the study area is a frequently used hunter trail. Map modified from original version by Pablo Ayali.

During the course of the survey period, we had multiple equipment failures. A total of 10 camera traps malfunctioned: eight Bushnell models and two Moultrie models. The camera trap stations that had faulty equipment were A1, A3, A3.5, B3, B0.5, C2.5, D3, D2.5, D3.5, and E4. Camera traps A1, A3, A3.5, C2.5, and D3.5 all malfunctioned from the start of the survey. However, we did not know if the camera traps were malfunctioning or if there were no species present at these locations. It was eventually assessed through testing (manually triggering the camera traps) that they were not functioning properly.

An experimental camera trap outside the study area replaced the faulty camera trap at B3, while the camera trap at A4 replaced D2.5. The decision to remove the A4 camera station permanently from the study area was deemed acceptable due to the undesirable nature of the A4 camera station location. This location was considerably lower in elevation in relation to the rest of the study area and was surrounded by low, swampy conditions in flooded rain forest, with no recording of any species by the camera trap.

The camera trap stations B0.5 and D3 were not replaced. Since both camera traps recorded species captures up until failure, the initial survey time was included in the overall survey. We also had significant issues with the E4 camera trap station. Upon initially checking the camera trap on the 8th of November, it was discovered that although the camera trap was still there, the memory card had been stolen. While performing a second check on the 18th of November, it was discovered that the E4 camera trap had malfunctioned. Thus, no species captures were recorded at this camera trap station.

Finally, on the 2nd of November, we assessed all camera trap data that we had collected to date. It became apparent that 1/3 of the camera traps in the study area were not set up in a way that would maximize quality video recording. The camera traps were angled too far down, which resulted in videos that recorded only the immediate three to four meters of the ground in front of the camera. In order to correct this issue, we returned to those camera stations and angled the camera traps up higher. The result was that all camera traps in the study area captured not only the ground in front of them, but also gave a view of the low understory to approximately 6 m in height.

On the 22nd of November, the team departed Camp Okulu, and returned to the Lohumonoko base camp. During the five-day stay there, a rest period was given to the team while final preparations were made for my departure home. All data gathered were consolidated and entered into an Excel spreadsheet by Pablo Ayali and myself. The finalized data set was copied and secured in four separate hard drives, two of which I brought with me, and two of which remained with the team. Instruction was given to the RA's on the protocol and methodology to complete the survey in my absence. On the 26th of November, I transferred all project responsibility to Mr. Ayali and began the journey home, eventually arriving back in the United States eight days later on the 5th of December, 2013.

Mr. Ayali and the field team returned to the study area on the 27th of November and continued monitoring the survey. They remained there for three weeks, finally pulling all camera traps on the 15th of December, and officially ending the Okulu camera trap study. After the completion of the survey, all camera traps were eventually moved back to the Losekola research area where Dr. Hart and Mr. Ayali initiated a comparative survey beginning in early 2014, following the design and methodology of the Okulu survey.

Post fieldwork: initial data cataloging, research effort, and sampling units

Analysis of the camera trap data took place in several stages between 2013 and 2014. I analyzed the Losekola pilot study photo data in May 2013, prior to conducting the full-scale Okulu survey. The Okulu video data were analyzed in two major phases. I examined all data collected from October 20th to November 24th, 2013 in January of 2014 and compiled preliminary survey results (842 CT days) based on the data that I was able to bring back with me from the field. The second stage began after the data collected during the survey extension (November 24th – December 15th, 2013) arrived via DHL in late March of 2014. Analysis of all Okulu data began in May and continued on through August 2014.

All camera trap photos and videos were organized by survey and systematically cataloged in a modified spreadsheet based on an original Excel file created by John Hart and Kate Detwiler (see Appendix B). Additional categories of information were later added to the spreadsheet to better quantify time and date statistics, event quality, and interobserver reliability. The finalized spreadsheet was used for both the Losekola pilot study and the Okulu camera trap survey, and was designed to allow cross-comparisons to be made between photo data and video data. The main goal of the spreadsheet was to separate hundreds of photos and videos collected across both surveys into discrete sampling units. Each sampling unit consisted of: the camera trap model it came from, quality of the event recording, date and time of occurrence, number of photos or videos recorded for each encounter, identification of species present, number of individuals per encounter and age and sex of all individuals present. Organizing the data into sampling units allowed for quantification of the survey's measure of effort, and transformed continuously collected data into discrete, non-overlapping, independent captures of all species recorded (Jenks et al. 2011; Loken et al. 2013; Tolber et al. 2008). The measure of effort and sampling units were generally defined as:

I. Units of effort: camera trap days

The total number of 24-hour periods that all camera traps in the survey area were on and functional.

II. Sampling unit: events

The total number of photos or videos recorded of each species captured within a one-hour period of time, and separated by at least one hour.

Effort in camera trap days (CT/days) is a commonly used metric, and is similarly defined in almost all camera trap studies represented in literature (Gerber et al. 2010; Karanth and Nichols 1998; Kelly and Holub 2008; Munari et al. 2011; Tobler et al. 2008). This number provides a total survey length that accommodates comparison between discrete surveys, even if the number of camera traps used, or even the duration of the studies, differs. An event, also a commonly used metric to define discrete, independent species captures takes into account multiple triggers of a camera trap by the same individual (Loken et al. 2013; Tolber et al. 2008). The one-hour cut-off period of an event is an arbitrary timeframe, but it takes into account the typical duration the target species is likely to linger in in front of a camera trap before dispersing onward. Although the length of an event can vary, they commonly range from 30 minutes to one hour in the literature (Loken et al. 2013; Tolber et al. 2008). All events are assumed to be different individuals, instead of a single animal triggering the camera multiple times. This assumption likely holds true of our data; for example, in the Losekola pilot study, all successive events involving a single species were separated by a minimum of four hours, with a majority of events having a separation greater than 24 hours.

Data analysis for the hunting comparison study

To address the question of how lesula is faring in heavily hunted forests, I examined all photos and videos from both the 2012 Losekola pilot study and the 2013 Okulu survey. I totaled all days the camera traps were in-field and functional for each survey and determined the total effort in camera trap days. For the Losekola pilot study, field notes provided by John Hart were used for start and end dates for each camera. All dates provided in the field notes were cross-referenced with the first and last photo taken at the associated camera station. In cases where no dates were included, I assigned the start date as one day before the first photo was taken, and end date as one day after the last photo was taken.

For the 2013 Okulu survey, all start and end dates were recorded in-field and used for assessment of survey length. Due to the significant number of malfunctions and movement of camera traps within the study area, I tracked all recorded data for the length of the survey, and cross-referenced the written data with the start and end dates of each station’s video records. This assured fidelity between the written dates and the video dates.

All photos and videos were then organized and broken down into individual events for all species present. Each photo or video capture was examined closely by camera trap station, and all applicable information was recorded in the master database. Individuals that were clearly visible and could be identified at the species level were recorded by the species common and scientific name, and non-identifiable individuals—considered as those who were impossible to identify at the species level due to obscuring foliage, partial capture, etc.—were catalogued as unknown. During this process, only photos or videos that contained a visible specimen, identifiable or unknown, were entered into the database. All photos or videos that contained no visible targets, due to camera misfire, individuals not being present in the field of view, or due to underexposure or overexposure of the film, were excluded from the database.

After events were recorded by camera trap station, a compiled list of all species across the total survey was created and then organized. All birds, unknowns, and mammals less than 1 kg in weight were excluded from the survey analysis. The 1 kg weight was determined by overall visible size of the individual captured, and eliminated rats, shrews, squirrels, and other small rodents from the survey. From this point, I calculated the number of events per species and the proportion each species represented in the camera trap record. In addition to the number of camera trap days and the number of events for each species, I broke down the information into 2 categories:

I. Capture Rate (CR)

The total number of events of a particular species divided by the total number of all species events, multiplied by 100.

II. Capture Probability (CP)

The total number of events of each species divided by the total number of camera trap days.

Capture rate represents how often one species is recorded in relation to all other species, and is independent of the total survey length in camera trap days. This allows us to look at how commonly a species is captured as a percentage inside the study area, and is useful in ranking species by number of events. This should not be confused with capture probability. Capture probability is used in this survey as an index of relative abundance. Dividing the total number species events by the number of camera trap days in the survey provides the average frequency that a particular species will be recorded on any given day during the survey period. Since the camera traps were placed in the survey area along a transect grid, regardless of microhabitat surrounding each camera station, placement is assumed to be evenly and systematically dispersed with the likelihood of a species encountering a particular camera trap being randomly distributed.

While the placement of each camera trap was not completely random (i.e. stations were set along animal trails to maximize capture rates), each camera station location inside the study area was chosen in the same way to avoid disparities in capture rates between stations. Although capture probability does not tell us about absolute density (because it does not provide a minimum or maximum number of individuals), it does indicate how commonly occurring a species is inside the study area. This is based on the assumption that more capture rates indicate more individuals present in the study area (MacKenzie et al. 2002).

An attempt was made to identify all species present in both the Okulu Survey and the Losekola pilot study; however in certain cases, positive confirmed identification was not possible at the species level. In cases where positive identification was not certain, the best possible attempt was made to correctly identify the species using *The Kingdon Pocket Guide to African Mammals* (Kingdon 2004). Most of the species that fell into this category were rare small cat species. Although positive identification was not always possible, physical differences between difficult-to-identify species (size, color, etc.) could lead to the conclusion that the species in question were not the same. For example, if two videos showed two difficult-to-identify individuals, I could conclude that they were not the same species due to first individual's large size and tan coat color, and the second individual's small size and black coat with spots. Also, I could determine that those two difficult-to-identify individuals were not the same species as any of the identifiable species captured. Thus, I can say that we captured X-number of species per survey without the need to positively identify all individuals.

One notable exception to this was with the duikers (genus *Cephalophus*). Physical differences could be used to identify some of the individuals present, like the blue duiker (very small) and the yellowback duiker (very large), but there was a large overlap in size for two medium-sized duikers: Peter's duiker, and Weyne's duiker. Due to the inability to distinguish certainly between large members of one species and small members of another, all duikers were lumped into one overarching category by genus.

Data analysis for the behavior and ecology study

For the behavioral and ecology study, a separate Excel sheet was created to track behavioral occurrences from video captures of lesula in the 2013 Okulu survey. The purpose of this study was to conduct a preliminary assessment of lesula's demographics, terrestriality, group size, times of activity, and also to assess the quality of video events recorded. No in-depth behavioral studies have been published using camera trap data on lesula, and few behavioral analyses using only camera trap data currently exist. Thus, I developed a novel scoring system for the particular behaviors we encountered, which was derived from the standard literature on primate ethograms, but modified to suit the needs of this study (Eisenberg 1981; Martin and Bateson 2007; Hariyadi et al. 2010).

The scoring methodology was refined with the help of Dr. Kate Detwiler. Two undergraduate assistants, Meghan O'Connor and Sarah Dempsey, assisted me in logging all behavioral data into the spreadsheet. I used individual focal surveys to describe five overarching categories of behavior:

I. Focal definition.

Observation started at the first sighting of the individual, and ended at either the end of the video, or when the individual left the view of the camera.

II. Behavioral categories

1) Video quality

2) Logistical information

3) Sex, age, and individual information

4) Substrate use and location information

5) Time of activity

The importance of assessing video quality was pivotal to the success of the behavioral study. Low-quality videos, for example, inherently limit analysis and interpretations, and a predominance of low-quality videos could ultimately undermine the conclusions of our study. Video quality was categorized as: high, medium, or low. An assessment of video quality was given to each focal individual present. If a focal individual was in full view of the camera, not obscured by foliage, and the video was sharp and clear, then the video quality was ranked as high. If a focal individual was in full view of the camera, but far away, partially obscured by foliage, or the video was blurry or unfocused, then the video quality was ranked as medium. Finally, if the focal individual was partially out of view of the camera's field of view, or almost completely obscured by foliage, then the video quality was ranked as low.

The first issue that needed to be resolved was how to track multiple individuals across each event. Since some events contained not only multiple individuals, but also multiple videos per event, a numbering system was created to identify each lesula present, and assign every individual an identification number. Since most of the events contained only one lesula and one video per event, assigning an identification number was often a straightforward process. However, in cases were multiple lesula were present, the following procedure was used: at the start of an event, we located all lesula present in the video, and numbered each individual starting in the order they appeared scanning from right to left of the screen. After all lesula present were accounted for at the opening frame of the video, each additional lesula that entered the frame of the video—regardless of the direction they entered—was assigned a number in the order that they appeared. For example, if during the first frame of a video, three lesula were visible with one situated on the ground in the right-hand-side of the video frame, one in the center, and one in the left low understory, the individual on the right was assigned number 1, the individual in the center was assigned number 2, and the individual to the left was assigned number 3. If an individual entered the camera view several seconds later, they were given number 4, and so on.

The numbers assigned were cumulative, and did not reset at the end of each event. This way we could tally the total number of all individuals across all video events. In some cases a single individual could be tracked across multiple videos. When this was possible, the original assigned number remained the same throughout all videos. If it was at all unclear if the individual was the same individual in the previous video, a new individual number was assigned. To account for multiple videos across a single event, we assigned an event number to each video. Like the individual numbers assigned, the event numbers were also cumulative, and in sum they represent the total number of events across all videos in the 2013 Okulu survey.

Logistical information also included date, camera trap location, model of camera at that station, and time of event. The video reference number was recorded, and minimum and maximum of individuals per event were logged. We recorded the length of each focal by individual number. All individual focals in a single event were then added together for a total focal time per event, and the total duration of each event. A final category simply noted whether the video was recorded in infrared (black and white) or in full color (see Appendix C).

The demographics and individual information section was created to determine the sex and age of all individuals present. Individuals were scored as male, female, or unknown, and the age of each individual was recorded as adult, juvenile, or infant. For males, we looked size, coat color, and signs of external genitalia, and for females we looked at size, coat color, and lack of testicles. An unknown classification was given to all individuals where these traits could not be visually confirmed. For age, we looked at size and coat coloration. If coat was light in color and the individual was small in size, we classed that individual as a juvenile. All large individuals with mature coat colors were classed as adults.

Any individual that bore any sort of identifiable mark, injury, or odd coloration was described in a column titled 'identifiable marks'. Descriptions of these individuals were ad-lib and the language used was non-standardized to give the most detailed account of what made them visually distinctive. Finally, a binary category for 'face' was added. If, during an event, an individual fully presented a clear, frontal view of their face, this category was marked as 1 for yes. If no clear frontal view of an individual's face was present, then the column was marked 0 for no. Although for the purposes of this thesis, no attempt was made to identify individuals across separate events, this could be a useful tool in future studies.

Substrate use and location information were examined to determine terrestriality in lesula. I assessed positional data by identifying the location of each lesula for the duration of the focal. If the individual was on the ground and remained on the ground for the entire focal, then that individual was marked as ground. If the individual was in the low understory and remained in the low understory for the entire focal, then that individual was marked as above ground. If the individual moved from the ground to the low understory (or vice versa), then a third category, representing both, was used.

One of the morphological details that resulted from the original lesula announcement paper in 2012 was that lesula had significantly larger orbits than its sister species *C. hamlyni* (Hart et al. 2012). Although the reason for lesula's larger eyes was not elaborated on in the publication, one hypothesis that arose was possible pre-dawn or post-dusk activity. In order to determine the time of activity for lesula, we compiled the times of each lesula event from three different surveys: the 2012 Losekola pilot survey, the 2013 Okulu survey, and a 2013 Losekola photo survey that was not used in either the hunting comparison or in other aspects of the behavioral and ecology study presented in this thesis. This 2013 Losekola photo survey was not included in the hunting or behavioral studies due to the low number of camera trap days of the survey and that the placement and locations of the camera traps were unknown. Although I decided not to include this survey in the hunting and behavioral study, the recorded event times were useful in further establishing lesula's time of activity.

Each day was separated into 24, one-hour blocks. Categories started at 12:00 am. The next categories were 1:00 am, 2:00 am, 3:00 am, and continued on until 11:00 pm. The time of each event was then examined and placed into the appropriate category. For example, if an event occurred between 10:00 am and 10:59 am, then that event was placed into the 10:00 am category. Thus, all lesula events were binned by hour to determine the first time of activity, the last time of activity, and general time-use trends for each survey. Time of activity data can, therefore, indicate something as simple as presence of nocturnal behavior, or something more complex, such as trends associated to terrestriality or other aspects of behavior.

Methods summary

All data for the hunting comparison came from both the 2012 Losekola pilot camera trap study and the 2013 Okulu camera trap survey. All data from the behavioral and ecology study came only from the Okulu camera trap survey, with the exception of 'Time of Activity' category noted in the previous section. I used only the Okulu survey because the Okulu video data were more appropriate for analysis of behavior than the photo-only data from the Losekola pilot study. An effect of the Okulu video data was that we were able to capture behavior, and also the *context* to that behavior, leading to more accurate descriptions that were not possible with the photo-only surveys.

CHAPTER 3: HUNTING COMPARISON RESULTS

Losekola camera trap pilot survey results

From May 8th to December 8th of 2012, the pilot survey recorded a total of 794 photos of 16 distinct species over 462 camera trap days, with an average of 1.72 photos per camera trap day. Over 462 camera trap days, 158 independent events were recorded, making the overall capture probability (number of total events/total number of camera trap days) of the pilot survey 0.34 per camera trap day, or one event every 2.92 days, with the overall capture rate of each camera station varying by location. The capture probability by each individual camera station ranged from a minimum of 0.05 for camera station C0.5 to 0.63 at station A2, and the probability for an individual species to be recorded varied by species and location (see Table 1).

Table 1: 2012 Losekola pilot survey results by camera

Camera Location	Camera Trap Days	Number of Photos	Number of Events	Capture Probability (All Species)	Capture Probability (Lesula)	Capture Rate (Lesula)
A0	86	87	21	0.26	0.05	18%
A2	43	190	27	0.63	0.05	7%
A3	20	26	6	0.3	0.1	33%
C0	40	20	7	0.18	0	0%
C0.5	19	3	1	0.05	0	0%
C2	18	4	4	0.22	0.06	25%
E0.5	51	32	10	0.2	0.4	20%
E1.5	76	229	33	0.45	0.2	44%
E4	10	5	3	0.3	0.2	67%
E102	99	198	46	0.47	0.1	21%
Total	**462**	**794**	**158**	**0.35**	**0.08**	**24%**

The species with the highest capture rate (CR) for this survey was the duiker, with 80 independent events (CR = 0.51). The species with the second highest capture probability was lesula, with 38 events (CR = 0.24) followed by the red river hog with 15 events (CR = 0.09) and the bonobo with 6 events (CR = 0.04). The remaining twelve species captured by the camera traps each have between one and five independent events per species and when combined represent 18% of the total species captures.

Capture rates were also compared between the two camera trap models. The Bushnell Trophy Cam recorded 332 camera trap days (72% of the sample) while the Moultrie M100 recorded 130 camera trap days (28% of the sample). The overall number of captured events by the Bushnell Trophy Cam was 121 independent events, while the Moultrie M100 model captured 37 independent events. A *z*-test for a two-sample proportion was conducted with the null hypothesis being the capture rate would be the same between the two camera trap models. There was a significant difference at $\alpha = 0.01$ between the event capture rate of the two camera models ($z = 5.1714$, $p = 0.0000001$). This suggests that the Bushnell Trophy Cam was superior to the Moultrie M100 in capturing events overall.

However, upon further examination of the individual camera stations, it was observed that two of the three low-event-yielding camera trap stations (*C0* and *C2*) were both shot by Moultrie cameras while the third (C0.5), a station rigged with a Bushnell, had an equally low event capture rate. The previous analysis did not take into account the low-event-yielding camera trap stations, and thus, could be skewing the data analysis toward a *false* significant difference. To investigate this matter further, camera station E1.5 was analyzed. This station’s survey period was split between the Bushnell model and the Moultrie model with 34 camera trap days and 31 camera trap days, respectively, between July and September. The Moultrie model recorded 13 independent events, while the Bushnell recorded 21. The same proportions test was run on this camera station, and a *z*-score of 1.3541 was obtained. At this camera station, there was no statistically significant difference between the two models at $\alpha = 0.01$. This suggests that performance of each model varied much more based on the individual station than the average of the field site as a whole, and neither model was better than the other overall.

The capture probability of lesula was the second-highest of all species surveyed at the Losekola research site, comprising 24% of total captured events (see Table 2). The capture probability of lesula, or the probability of any camera capturing a lesula event on any given day, was an average of 0.08 per camera trap day, or one lesula event every 12.5 days. The trap success of lesula varied by location with two stations, C0 and C0.5, capturing no lesula and camera station E4 having the highest trap success for lesula at 0.2 per camera trap day, or one lesula event every five days.

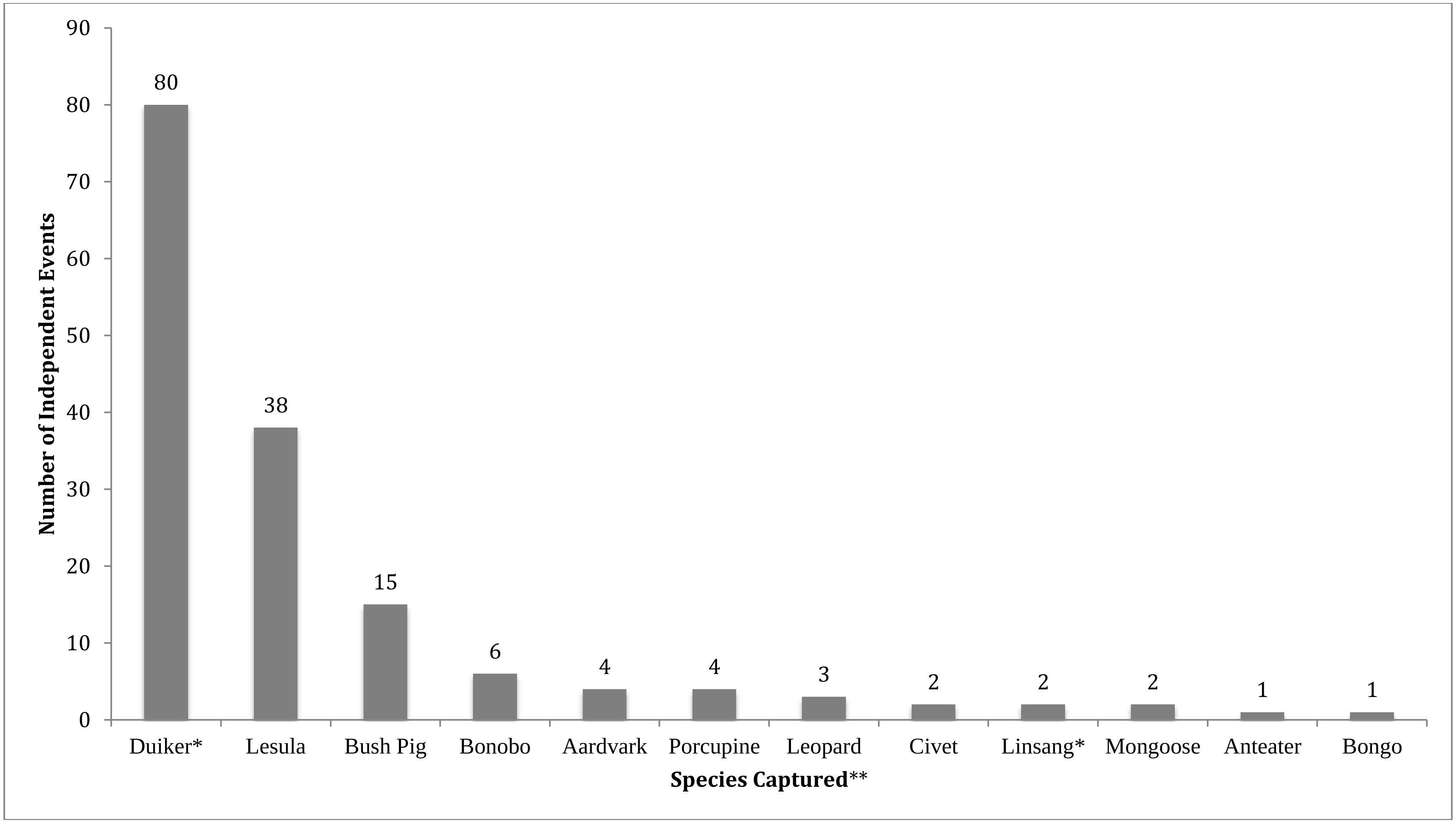

Figure 12: Number of captured events by species recorded during the Losekola camera trap survey.
*Category represents all species of duiker, and one or more species of linsang.
**See Table 6 for full species identification.

Addressing the preliminary research questions

The effectiveness of camera traps in the study of lesula is a simple question that can be reduced to one criteria: are they showing up in the photos and if so, how often? We recorded 16 terrestrial mammals in the Losekola pilot study. Lesula was the second-most-commonly captured species. With 38 events recorded in 462 camera trap days, and a capture probability of 0.08, lesula far exceeds the minimal capture rate from the literature on large cats (Noss et al. 2012). This led us to believe lesula is an ideal candidate for study using this technology. To verify this supposition, I estimated the length of survey required to obtain a similar number of events for two primate species present at Losekola: lesula and the bonobo.

A Poisson distribution probability was calculated to predict minimal and maximal number of expected lesula capture events at $\alpha = 0.05$ for the Losekola pilot study. Using a 462 camera trap day survey, and a rate of occurrence of 0.08 per day, a minimum of 27 events and a maximum of 49 events is predicted. This shows that the maximal capture rate of 49 events would decrease the needed survey time by 29% while the minimal number of 27 captures would increase the survey time by 36%. This equates into an estimated camera trap survey length of 328 to 628 camera trap days.

In comparison, the bonobo, the only other terrestrial primate that inhabits the Losekola research area, had a rate of occurrence of 0.01 per day. Using the same Poisson probability calculation, a 462 camera trap day survey would yield at $\alpha = 0.05$ a minimum of two and maximum of 10 independent bonobo events, requiring a survey between 305 and 1,386 camera trap days. This has strong implications for future study using camera traps in the region: a bonobo camera trap survey would require approximately 3,000 camera trap days to reach the same number of capture events as lesula did in only 462 days. Consequently, lesula requires far less effort to study than other species present at the study site—translating into less cost and labor—which makes this species an ideal candidate for using this technology.

One of the primary uses of camera traps by scientists to date has been to estimate the density of cryptic species (Noss et al. 2011). Accurate density estimates have been achieved using mark-capture-recapture statistics and have been the driving force of these studies. However, the mark-capture-recapture method requires that a minimum number of animals can be individually recognized. The Losekola pilot study confirms the original prediction that individual recognition of lesula is not possible using the technology that is available at this time, mostly due to the lack of distinctive markings. This could change in the future with the use of specialized software programs.

The Losekola pilot study sought to assess the effectiveness of camera traps in answering key questions concerning basic ecological requirements such as diet and intragroup dynamics, home range, and group size. Keeping in mind that the portion of the landscape that is captured in the photo only represents a small fraction of the total activity that is occurring at that particular moment, camera traps can still be effective in setting minimum standards for such questions. Without the ability to recognize individuals for mark-capture-recapture studies, home range proves to be the most difficult question for camera traps to answer. It cannot be determined from this pilot study whether lesula captured at each location represent a single group or multiple groups inhabiting the study area; however, on one occasion, two lesula were captured within three hours of each other with a spatial separation of over two miles. Given our initial estimate home range of

1—2.5 groups per 1 km^2 that is typical of terrestrial forest guenons, this indicates that we are capturing at least two lesula groups within the Losekola study area (Hart et al. 2012; K. Detwiler, pers. comm.).

Concerning diet, camera traps in the pilot study did capture fruit and vegetation being eaten by lesula. Of the 219 individual photos of lesula, four clear photos of a food source were recorded and were found to fit with the diet assessment by John Hart (2012) that was recently published. Minimum group size could also be assessed from the camera trap data. While most photos included between one and four individuals, one photo series recorded five individuals in one picture with a likely sixth that was obscured from sight, but clearly shaking a tree in the center of the group. This sets maximum group size at five, and quite possibly six per group, using a photograph-only camera trap survey.

Okulu camera trap survey results

The Okulu survey yielded 1,683 total camera trap days, or 3.64 times more effort than the Losekola pilot study, between the 20th of October and the 15th of December 2013. Seventeen species of large mammal (>1kg) were recorded over 1,683 camera trap days, with 303 total species events. The overall capture probability of all species was 0.18 per camera trap day, or one event per 5.54 days. Capture rate varied by camera trap station and ranged from 0.04 at station B0 and B2 to 0.64 at station A0, similar to the Losekola pilot study, the probability for an individual species varied by species and location (see Table 4).

The species with the highest capture rate was lesula, which comprised 46% of all species events. The second highest capture rate recorded was the duiker at 33%, and the third highest capture rate was human at 4%. The other 14 inventoried species comprised the remaining 17% of all species captures (see Figures 13 and 14). Capture probability for all species followed a similar trend with lesula having a capture probability of 0.08, duikers 0.06 and humans recorded at 0.01 (see Table 4). The presence of humans inside the study area was not surprising due to the numerous signs of activity present during the initial transect cuts, and supports the claim that hunting was occurring during the time of the survey (see Figure 12).

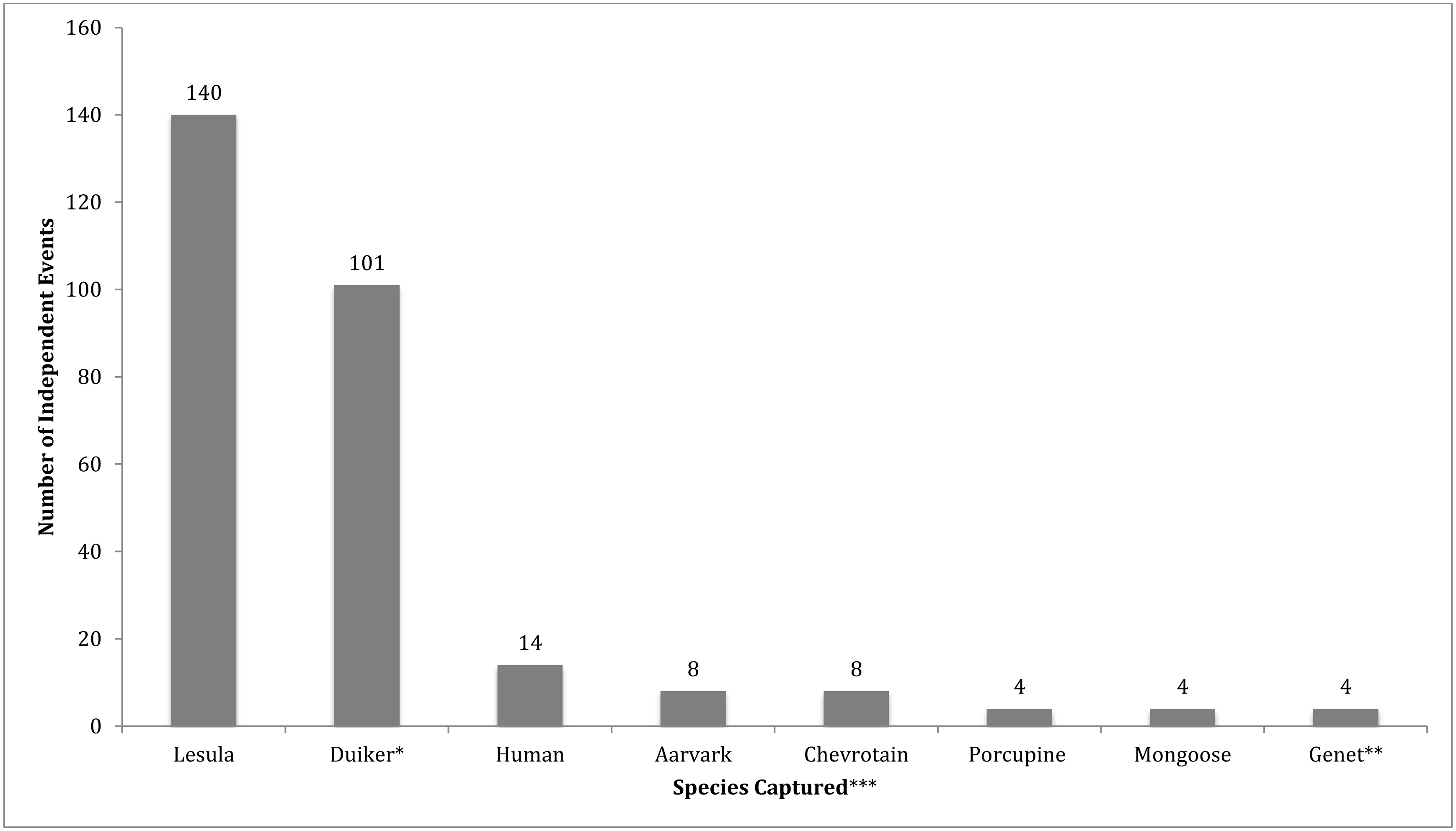

Figure 13: (Graph 1 of 2) Number of captured events by species recorded during the Okulu camera trap survey.
*Category represents all species of duiker.
**Category represents possibly one or more species of genet.
***See Table 6 for full species identification.

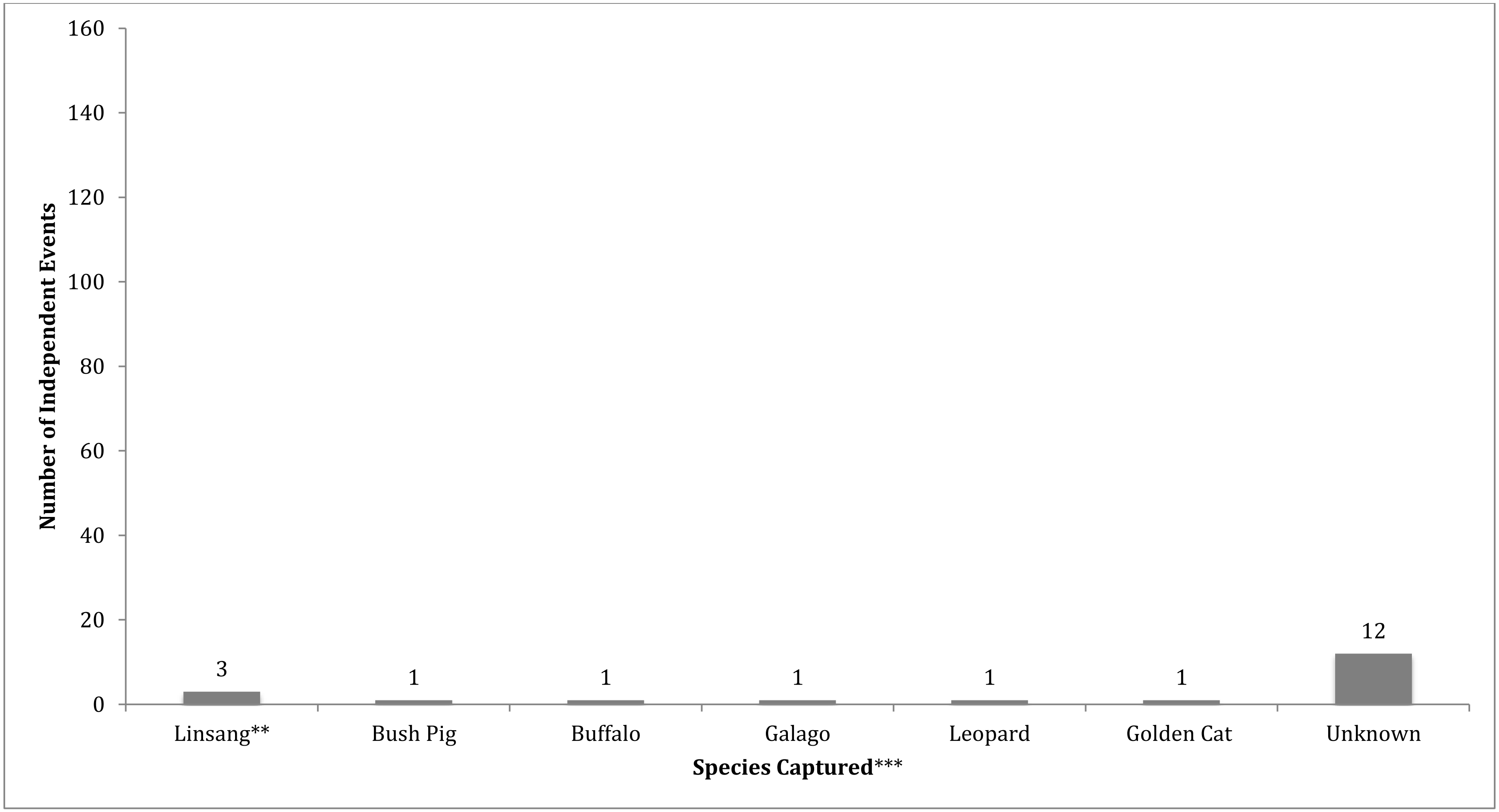

Figure 14: (Graph 2 of 2) Number of captured events by species recorded during the Okulu camera trap survey.
**Category represents possibly one or more species of linsang.
***See Table 6 for full species identification.

Table 2: 2013 Okulu survey results by camera trap station.
X indicates malfunction of camera trap.

CT Station	Start Date	End Date	Total Camera Trap Days	Events (All Species)	Events (Lesula)	Capture Probability (All Species)	Capture Probability (Lesula)	Capture Rate (Lesula)
A0	10/20/13	12/15/13	56	35	14	0.63	0.25	40%
A0.5	10/26/13	12/15/13	50	11	6	0.22	0.12	55%
A1	X	X	0	0	0	N/A	N/A	N/A
A1.5	10/26/13	12/15/13	50	15	4	0.30	0.08	27%
A2	10/20/13	12/15/13	56	20	8	0.36	0.14	40%
A2.5	10/26/13	12/15/13	50	6	1	0.12	0.02	17%
A3	X	X	0	0	0	N/A	N/A	N/A
A3.5	X	X	0	0	0	N/A	N/A	N/A
A4	10/20/13	11/16/13	27	0	0	0	0.00	N/A
B0	10/20/13	12/15/13	56	2	2	0.04	0.04	100%
B0.5	10/26/13	11/16/13	21	1	1	0.05	0.05	100%
B1	10/20/13	12/15/13	56	6	5	0.11	0.09	83%
B1.5	10/26/13	12/15/13	50	17	12	0.34	0.24	71%
B2	10/20/13	12/15/13	56	2	2	0.04	0.04	100%
B2.5	10/26/13	12/4/13	39	10	4	0.26	0.10	40%
B3	10/23/13	12/15/13	53	4	0	0.08	0.00	0%
B3.5	10/26/13	12/15/13	50	8	4	0.16	0.08	50%
B4	10/23/13	11/18/13	26	4	0	0.15	0.00	0%
C0	10/23/13	12/15/13	53	6	4	0.11	0.08	67%
C0.5	10/26/13	12/15/13	50	12	7	0.24	0.14	58%

Table 2 continued on page 58

Table 2 continued from page 57

CT Station	Start Date	End Date	Total Camera Trap Days	Events (All Species)	Events (Lesula)	Capture Probability (All Species)	Capture Probability (Lesula)	Capture Rate (Lesula)
C1	10/23/13	12/15/13	53	12	8	0.23	0.15	67%
C1.5	10/26/13	12/15/13	50	29	9	0.58	0.18	31%
C2	10/23/13	12/15/13	53	8	4	0.15	0.08	50%
C2.5	X	X	0	0	0	N/A	N/A	N/A
C3	11/16/13	12/15/13	29	5	1	0.17	0.03	20%
C3.5	10/26/13	12/15/13	50	8	4	0.16	0.08	50%
C4	10/23/13	12/15/13	53	5	0	0.09	0.00	0%
D0	10/13/13	12/15/13	63	6	4	0.10	0.06	67%
D0.5	10/25/13	12/15/13	51	4	1	0.08	0.02	25%
D1	10/23/13	12/15/13	53	9	4	0.17	0.08	44%
D1.5	10/25/13	12/15/13	51	4	3	0.08	0.06	75%
D2	10/23/13	12/15/13	53	9	3	0.17	0.06	33%
D2.5	10/25/13	12/15/13	51	2	2	0.04	0.04	100%
D3	10/23/13	11/9/13	17	1	1	0.06	0.06	100%
D3.5	X	X	0	0	0	N/A	N/A	N/A
D4	10/23/13	12/15/13	53	2	2	0.04	0.04	100%
E0	10/25/13	12/15/13	51	8	5	0.16	0.10	63%
E1	10/25/13	12/15/13	51	15	3	0.29	0.06	20%
E2	10/25/13	12/15/13	51	11	7	0.22	0.14	64%
E3	10/25/13	12/15/13	51	6	5	0.12	0.10	83%
E4	X	X	0	0	0	N/A	N/A	N/A
Total			**1683**	**303**	**140**	**0.18**	**0.08**	**0.46**

Species present in research areas

Of the 17 species recorded in the Okulu study area, and the 15 species recorded in the Losekola study area, 12 species were present at both field sites. Again, due to issues with positive species identification of certain genera, *Cephalophus* (duiker) and *Poiana* (linsang) were each conflated into their own respective category for analysis. In the case of the duikers, it should be noted that the placement of these four species into a single category for comparison does not affect the overall determination of how this genera is faring in the face of heavy hunting conditions, but does represent a slight overestimation of relative abundance in each study area. Because of this, the relative abundance of the category duikers, in relation to the relative abundance of other species categories, is not a direct comparison, but can still be compared effectively to answer the research questions. This is due to the use of the same classification system at both study sites.

Table 3: Captured events by species during the Losekola camera traps survey.
*Category represents all species of duiker.
**Category represents possibly one or more species of Linsang.
***Unknowns were not counted or included in Losekola survey results.

Species Captured – Losekola	Number of Events
Duiker*	80
Lesula	38
Red River Hog	15
Bonobo	6
Aardvark	4
Brush-Tailed Porcupine	4
Leopard	3
African Civet	2
Linsang**	2
Marsh Mongoose	2
Scaly Anteater	1
Bongo	1
Unknown	N/A***
Total	**158**

Table 4: Captured events by species during the Okulu camera traps survey.
*Category represents all species of duiker.
**Categories represent possibly one or more species of linsang and genet.

Species Captured – Okulu	**Number of Events**
Lesula	140
Duiker*	101
Human	14
Aardvark	8
Water Chevrotain	8
Brush-Tailed Porcupine	4
Marsh Mongoose	4
Genet**	4
Linsang**	3
Red River Hog	1
Water Buffalo	1
Galago	1
Leopard	1
Golden Cat	1
Unknown	12
Total	**303**

Statistical analysis of species between research areas

After the completion of both the Losekola pilot camera trap study analysis (April 2013) and the Okulu camera trap survey (August 2014), I examined all data, specifically looking for categories that overlapped between the two studies. Categories examined were: species present in the study areas, relative abundance of commonly occurring species between the study areas, and lesula captures and distribution in the study areas. This comparative approach shed light on the occupancy and relative abundance of all species present throughout the surveys, and allowed me to draw conclusions about the effect of unregulated bushmeat hunting on the species present.

Although there were 12 common species present at both Losekola and Okulu sites, I examined only the top three most commonly captured species: duikers, lesula, and bushpigs. I excluded the other 9 species based on their low capture rate and small sample sizes. I calculated a Poisson distribution to estimate the range of expected events. Using the Losekola capture rate for each of the 3 species, an ‘expected’ number of events were estimated for each species and compared to the actual number of events recorded (see Figure 15; Table 5). I then used the expected versus the actual number of events at the Okulu site to calculate the percent change in capture probability. We found a radical reduction in capture probability in both duikers and bushpigs. Lesula showed no reduction in capture probability between the heavily hunted and the lightly hunted site, with the actual number of events recorded falling within the expected Poisson range.

Table 5: Statistical comparison between field sites.
*Poisson range represents minimum and maximum expected capture events.
**Expected values are based on the capture rate recorded at the lightly hunted Losekola site.
***Percent change is the difference in capture rate of lesula between field sites.

Species Count	**Poisson Range* (α = 0.05)**	**Expected Okulu****	**Actual Okulu**	**Percent Change*****
All Duikers	262 - 318	289	101	-66.10%
Red River Hog	41 - 65	55	1	-98.18%
Lesula	119 - 165	138	140	1.45%

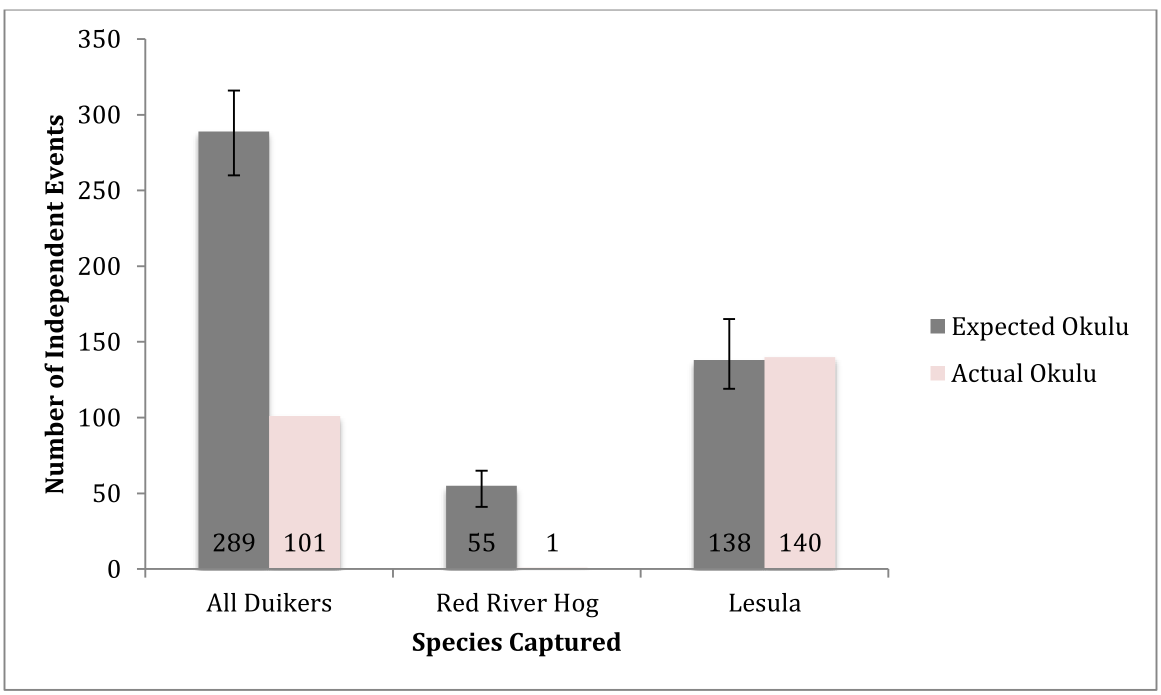

Figure 15: Graph of top 3 species at Losekola compared to Okulu. Expected numbers are based on capture rate at Losekola. Error bars represent the minimum and maximum expected capture events at α = 0.05.

CHAPTER 4: BEHAVIOR AND ECOLOGY RESULTS

Overall results

For the behavior and ecology study, I addressed the question: are camera traps a good method to study behavior in lesula? For a total of 1,638 camera trap days, we examined 135 events and conducted 341 total individual focals using the Okulu survey video data. Examining all 341 individual focals resulted in one hour, 36 minutes, and 27 seconds of direct observation time. Although some individual focals were very short (<1 sec), the average time of observation for all focals was 17 seconds, which is a tremendous amount of behavioral data on this little-known species. It should be noted that this behavior and ecology study was not designed to be a comprehensive analysis, but a preliminary investigation into using camera traps to study behavior in lesula. All results presented below are preliminary and serve to address the research questions using a broad approach (see Table 6).

Table 6: Overall behavioral study effort.

Video CT Survey Length (CT Days)	Total Lesula Events	Total Individual Lesula Focals	Total Focal Duration (h:m:s)	Average Focal Duration (Seconds)
1683	135	341	1:36:27	17

Video quality

Video quality is an important observation, and has broad implications to the overall effectiveness of using camera traps to study behavior. Twenty-six percent (*n* = 88) of all individual focals rated high in quality, and 35% (*n* = 118) were rated medium. This translates into 61% (n = 206) of focals that yielded average or better than average behavioral observation conditions. For the remaining 39% (n = 135) of video that was rated poor, behavioral observations were still made, but the classification of these traits were more conservative and yielded less data (see Table 7).

Table 7: Assessment of Video quality.

Video Quality	Number of Focals	Percent
High	88	26%
Medium	118	35%
Low	135	39%
Total	**341**	**100%**

Demographics: sex and age identification

For 341 individual focals, we attempted to determine sex and age based on size and coat coloration. Due to the uniformity in coat color between male and female lesula, and the difficulty in determining the absolute size of an individual present in a focal, assessing the sex of individuals via video was difficult. However, sex could be positively distinguished when an adult male was positioned in such a way that external genitalia could be viewed. Sex determination was not possible in juveniles, and problematic for females. We determined sex and age for several individuals, but upon chose to not include the results in this thesis, as there was low interobserver reliability for scoring adult females.

Group size

Hart et al. (2012) recorded 19 observations of lesula, with only a single lesula observed in 8 encounters. Of the remaining 11 encounters, between two and five individuals were recorded, making a minimum groups size assessment for lesula at five individuals (Hart et al. 2012). Based on the Okulu survey data, 48% of all events (n =

140) recorded only a single individual, 20% of events recovered two individuals, and 12% of events recorded three individuals. Between four and six lesula individuals were observed in 12% of the video events, between seven and 10 individuals in 4% of events, and in two events (0.01%), 11 individuals were recorded (see Table 11; Figure 17).

Table 8: Recorded group size by event.

Group Size	Number of Events
1	67
2	28
3	17
4	8
5	6
6	2
7	2
8	1
9	1
10	1
11	2
Total	**135**

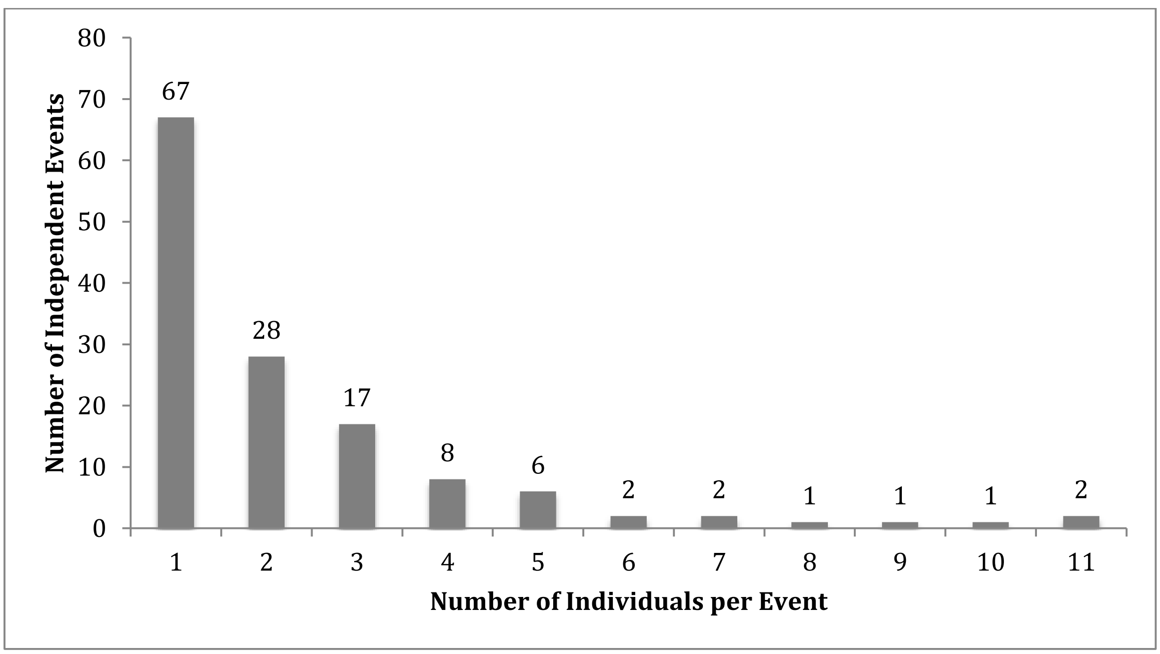

Figure 16: Group size by event. Although capturing multiple individuals in one event is rare, these data contain information on minimum group size.

Terrestriality

Assessing the percent of time lesula devotes to ground activities is challenging due to one complicating factor: the camera traps are biased to terrestrial activities due to their placement at ground level. Since there was no control set of camera traps placed in the canopy, we can only make assumptions about non-ground level activities (>3 m) based on limited direct observation. However, looking at several supporting pieces of information, inferences can be made about the role of ground-based activities in this species.

Upon examining the camera trap data, the number of lesula events recorded is in line with the number of other species events that are known to be 1) wholly terrestrial, and 2) common within the study area. For example, looking at the top three species in the lightly hunted Losekola research area—duikers, red river hogs, and lesula—this primate species ranks as the second most-commonly captured species at 38 independent events. Duikers rank as the number one species at 80 events, and the red river hog is the number three most common species at 15 events. This high capture rate of a primate in ground-positioned camera traps is very unusual. Combining camera trap data from the 2012 Losekola pilot study, the 2013 Okulu study, and a smaller 3rd survey conducted at Losekola in 2013 (n = 262 camera trap days), only one photo event of a fully arboreal monkey species, *Cercopithecus ascanius*, was recorded on ground level. This is compared to lesula's total recorded 216 ground level events over all three surveys.

From the Okulu camera trap survey, an assessment was made for ground use by examining the positional location of all focal individuals. Of all 341 individual focals, 88.6% (n = 302) of all lesula observed were positioned on the ground and remained on the ground for the entirety of the focal. In 3.8% (n = 13) of the individual focals, lesula was found to be positioned in the low understory, and remained there for the duration of the focal. Finally, 7.6% (n = 26) of all individual focals observed lesula either moving from the ground to the low understory or from the low understory to the ground. This data corroborates the 2012 announcement paper's claim that lesula is predominately a terrestrial species (see Table 9).

Table 9: Positional data by strata use.

Substrate Use	**Number of Focals**	**Percent Frequency**
Ground	302	88.6%
Low Understory (off ground - 3 m)	13	3.8%
Both Ground and Low Understory	26	7.6%
Total	**341**	**100.0%**

Diurnal activity

By examining the time of first and last camera trap capture, I have addressed the question of possible nocturnal or crepuscular activity. Out of 216 total lesula events, 100% occurred between 6 am and 7 pm, and only one lesula event was recorded in the 6 – 7 pm timeframe, occurring at 6:14 pm (see Table 10). Likewise, only one lesula event was recorded during the dawn chorus, which occurs between 5:30 am and 6:30 am. This event occurred at 6:29 am, during the end of peak vocalization activity. It can be concluded that during the dawn chorus, lesula's activity is very low or is confined to the canopy, outside the detection zone of the camera traps.

A secondary question relating to the activity pattern of lesula is if there is variation in the quantity of captured camera trap events per hour during lesula's known diurnal motion. In order to assess this, I calculated a polynomial coefficient of determination to assess how well the distributed activity data fit a predicted curve (R^2 = 0.91). This shows that there is a strong correlation between time of day and amount of activity. Figure 18 shows a distinct bimodal form with peak activity occurring at 7 – 9 am and 3 – 5 pm.

Table 10: Time of activity by event.

Time of Activity	Number of Events
6 - 7 AM	6
7 - 8 AM	20
8 - 9 AM	24
9 - 10 AM	15
10 - 11 AM	15
11 - 12 PM	17
12 - 1 PM	14
1 - 2 PM	19
2 - 3 PM	23
3 - 4 PM	23
4 - 5 PM	27
5 - 6 PM	12
6 - 7 PM	1
Total	**216**

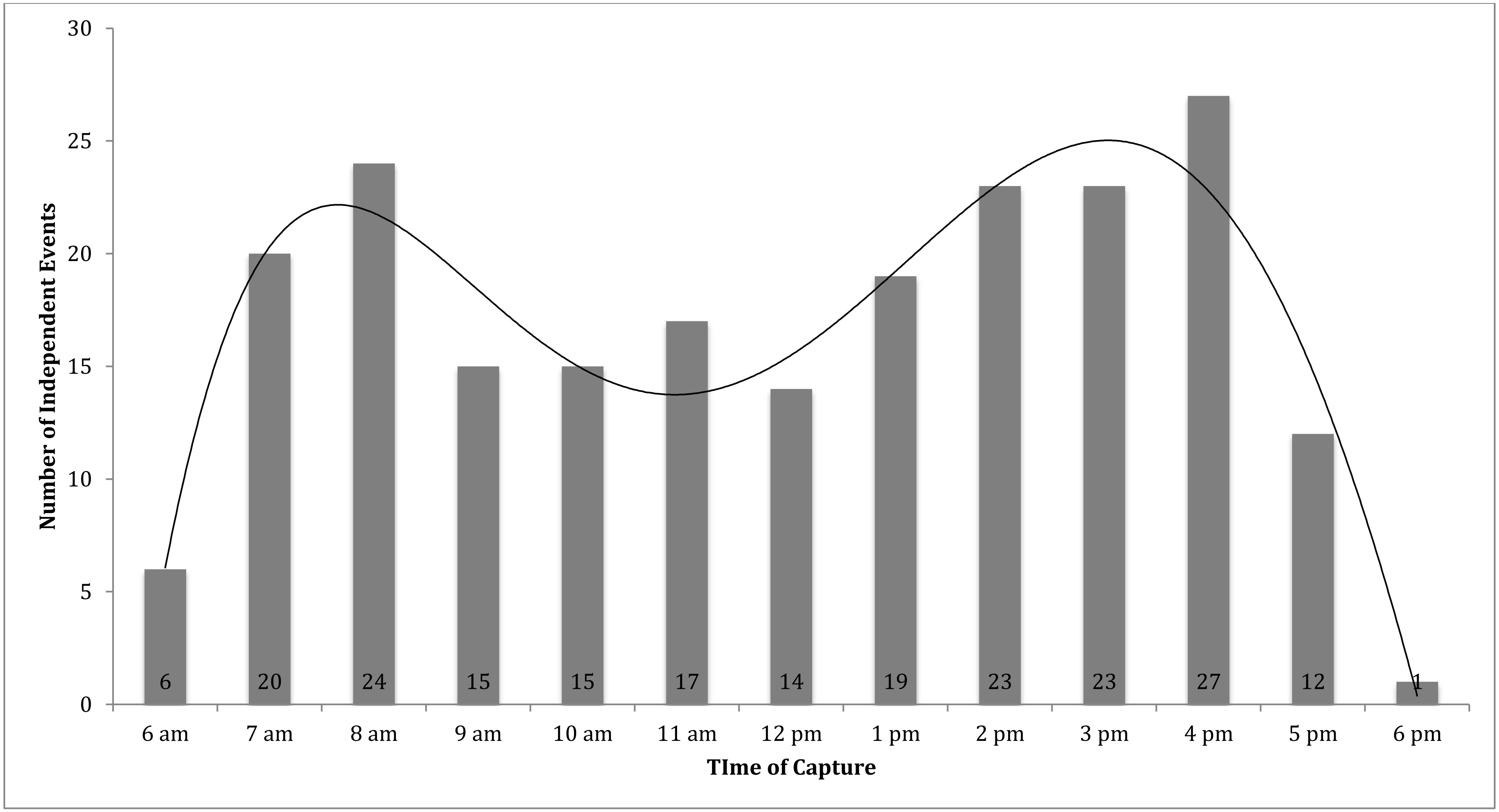

Figure 17: Times of captured events. Best-fit curve shows a bimodal distribution in peak activity time. Time of capture categories represent one-hour intervals.

CHAPTER 5: DISCUSSION

Overview of research questions

The purpose of this discussion is to take the data I presented in Chapters 3 and 4 and expound on the effects and implications of the research. Since lesula is a little-studied species, much of the data presented in this thesis are new. However, in many cases, I obtained results that confirmed either material covered in the 2012 PLOS ONE announcement paper, or in-field observations made by Hart and his field teams since this species was discovered in 2007. It is important to note that both new and confirming data are essential to the continued study of lesula. New findings add to the existing body of knowledge on this recently discovered primate species and confirming data strengthen our confidence in previously published observations—some of which were obtained from small sample sizes and minimal observation. In these early research efforts, *all* data gathered on lesula are important, as they provide insight that will lead to our eventual understanding of the behavior, ecology, and survivability of this species.

In regards to the specific research questions I addressed in this thesis, I have shown that camera traps are an effective tool for studying both lesula's behavior and determining the effect of unregulated bushmeat hunting on this species. This is evidenced by the capture rate of lesula in both the Losekola research area and the Okulu research area. In Losekola, lesula was the second-most captured species next to the duikers. In Okulu, lesula was by far the most frequently captured species. What is profound about the capture rate of lesula is not just the percentage of photos and videos in relation to other species, but also the number of total events recorded. At 38 lesula events in Losekola and 140 lesula events in Okulu, using camera traps to study this species is a highly cost-effective means of gathering large amounts of data in very short timeframes. We recorded over 96 minutes of direct observation time in a 1,638 camera-trap-day survey, which proves that future camera trap surveys examining the abundance of lesula can also be used for behavioral studies.

Individual recognition for capture-mark-recapture surveys proved to be more challenging. As originally suspected, lesula's uniform size and coat color made individual recognition almost impossible. Although the video was clear enough to address the behavioral categories, the 720p video quality, coupled with low light conditions, blurred any small unique markings that could be used to identify individuals. Notably, there were two lesula spotted in the Okulu video survey that had very prominent tail kinks, and two lesula who had amputated arms—presumably from hunter snares. Although I was not able to identify these individuals at separate camera trap stations, it does show that with more video data or specialized software, individual recognition could be possible.

Table 11: Evaluation of pilot research questions.

I. Preliminary pilot study questions	**Yes**	**No**	**Partially**
Are camera traps an effective tool to study lesula?	X		
Can individuals be recognized in camera trap photos for capture-recapture surveys for the purpose of estimating density?			X

For the Losekola pilot study and the Okulu survey's initial research questions, the methodology was based in existing literature and was adapted to the needs of TL2's field sites. Species captured in photos were generally easy to identify using visual inspection. Some complications arose when individuals were partially in view of the camera or obscured by foliage; however, in most of the photo records, we were able to identify almost all individuals down to the species level (see page 36 for exceptions). The Okulu video camera trap survey greatly increased our ability to identify captures by adding a longer time frame to observe species present. Lesula was very easily spotted in both the photos and videos. Although they do not have distinctive markings that allow for individual identification, lesula are distinctive from all other terrestrial mammals in the survey sites. In some cases, all that was needed was a partial view of a tail for determining a lesula event. This was advantageous, especially in the Losekola photo survey.

Table 12: Evaluation of initial research questions.

II. Losekola pilot study and the Okulu survey initial questions	**Yes**	**No**	**Partially**
Can we assess what species are present in the research areas?	X		
Can we assess how often are these species are captured by the camera traps?	X		
Can we assess how often lesula is captured by the camera traps?	X		

For the hunting comparison, I examined species captures in two ways: each species in relation to all other species events (capture rate), and each species in relation to the overall length of the camera trap survey (capture probability). For capture rate, Tables 2 and 3 clearly show a change in the overall proportions of the number of total events, as well as which species were captured more frequently. The generalized trend shows a radical reduction in population size for species inhabiting the heavily hunted Okulu forest in comparison to the lightly hunted Losekola site. For the most commonly hunted species—the duikers and the bushpigs—percent decrease in capture probability between sites was 65% and 99.8%, respectively. For lesula, we saw no decrease in capture rate between the hunted and lightly hunted sites, which suggests that the lesula population is abundant at Okulu despite heavy hunting pressures.

The only mammal species to precipitously increase in number at the Okulu research area was humans; this is not surprising in light of the substantial activity of villagers in and around the study site. Despite this increased activity and pressures from hunting, lesula appears to be buffered from the deleterious effects of bushmeat hunting, likely due to their cryptic, terrestrial behavioral adaptations.

Table 13: Evaluation of hunting comparison research questions.

III. Hunting comparison	**Yes**	**No**	**Partially**
Are all species captures lower at the Okulu site (hunted) than at the Losekola site (lightly hunted)?	X		
Are lesula captures lower at the Okulu site (hunted) than at the Losekola site (lightly hunted)?		X	

Studying rare, elusive species in difficult-to-reach ecosystems can be costly in terms of both time and money. Because of this, studying behavior remotely via camera trap data is a desirable alternative to traditional primatological techniques. With just over 96 minutes of lesula observation time, we have shown that even small video camera trap surveys can yield a relatively large amount of behavioral data. Although the length of direct observation is relatively short, camera trap data contain valuable information—especially when very little is known about the target species. This thesis has shown that video quality of captured events is sufficiently high enough to conduct a behavioral study on lesula.

As part of the behavioral study, sex and age identification were attempted. Although a preliminary assessment was conducted for this thesis, it became clear that the methodology and definitions used to determine both sex and age were not defined well enough during analysis to produce reliable results; this was particularly evident in determining sex in suspected females. Because of this, I have not included the results in this thesis. Nevertheless, sex determination in some adults is possible, as long as an unambiguously defined methodology is used.

We had remarkable success with assessing group size in this study. In the original announcement paper, minimum group size for lesula was five individuals (Hart et al. 2012). This determination stemmed from 19 visual sightings at the Losekola research area between 2008 and 2010 (Hart et al. 2012). For the 2012 Losekola pilot study, group size was again assessed at five to (possibly) six individuals. This minimum group size came from examining two photos taken approximately one second apart. Five individuals were clearly seen in both photos with a possible sixth individual obscured by foliage, but moving a small sapling tree.

In the Okulu video camera trap survey, we were able to double our estimate of minimum group size in lesula. This large leap in minimum group size estimation was a direct effect of using video as opposed to photos or visual sightings. For example, in one event we saw 11 individuals move into—and then out of—the frame of the camera over the course of a single 20-second video. This minimum group size would not have been observed with either a photo survey or with direct observation of unhabituated animals. The video, therefore, creates a period of pseudo-habituation where groups can be observed without disrupting natural behavior. We expect minimum group size to increase in subsequent camera trap studies. Although observing large groups is rare in camera trap data, these encounters contain important information on lesula's group size.

This thesis provided evidence for lesula's terrestriality, which is also confirmed by direct observations of this species (Hart et al. 2012). Although we were not able to place control camera traps in the canopy for this survey, the camera trap data recorded, along with corroborating information, support the conclusion that lesula is a predominately terrestrial species. Although this mode of locomotion is common in lesula's sister species, *C. hamlyni,* it is an unusual adaptation in the guenon clade (Gebo and Sargis 1994).

Home range could not be determined using the analysis that I employed for this thesis. This is naturally a difficult topic to study. Although home range could not be determined for this study, there is promise in estimating the number of groups per kilometer squared, if in the future, individual recognition is achieved.

We were also able to add two items to lesula's list of dietary items. Although most of the food items eaten were from familiar sources listed in the announcement paper, we recorded lesula feeding on mushrooms and found evidence for insect consumption. Lesula's diet appears to be very broad and generalized. For example, in leaf consumption, lesula was observed eating both young shoots and mature leaves that had naturally fallen from the canopy. One issue with using camera traps to determine diet is video quality. Like with individual recognition, although we could easily determine that lesula was foraging and feeding, identifying the food source down to the species level was difficult. The 720p video quality, coupled with low light conditions made it problematic to identify a food source that generally occupied only a small area of the camera view. Clear, non-pixelated photos and videos of dietary items were rare; however, like group size, these rare videos were exceptionally informative. More camera trap data from future research will likely add to lesula's diet item inventory.

Finally, this thesis successfully described lesula's time of activity. Lesula is a solidly diurnal primate that does not exhibit nocturnal or crepuscular behavior. Lesula has also shown little terrestrial movement (one out of 216 observations) during their pre-dawn period of high vocal activity. The question of why lesula's eye orbits are considerably larger than *C. hamlyni* is yet to be resolved; however, lesula's terrestriality, coupled with low light conditions that occur at lower strata could be a contributing factor.

Table 14: Evaluation of behavioral study research questions.

IV. Behavioral Study	**Yes**	**No**	**Partially**
Are the photos and videos recorded of high enough quality to assess behavior	X		
Can sex and age identification be determined from camera trap data?			X
Can group size be determined from camera trap data?	X		
Can lesula's terrestriality be determined from camera trap data?	X		
Can home range be determined from camera trap data?		X	
Can diet be determined from camera trap data?			X
Can lesula's activity pattern be determined from camera trap data	X		

The future of lesula in a heavily hunted forest

This thesis has shown that lesula appear to be highly resilient against the threat of unregulated bushmeat hunting, but despite evidently stable populations, we are still unsure of the future of lesula in these heavily hunted forests. Unregulated bushmeat hunting that exceeds sustainability produces far-reaching consequences for seed dispersal, forest composition, predator/prey relationships, species richness, and primate diversity (Rovero et al. 2012; Wright et al. 2000). Despite being a very heavily hunted group, primates show different responses—some positive, some negative—when overhunting occurs (Kümpel et al. 2008; Wilkie and Carpenter 1999). Josh Linder and John Oats' (2011) research on the differential impact of hunting on primate groups in Korup National Park, Cameroon, serves as a striking reminder. While resilience to hunting in certain primate populations can be observed, this apparent stability can be temporary; as preferential and easier-to-catch prey populations decrease, hunting effort on less preferential and harder-to-catch prey can increase (Linder and Oats 2011; Rist et al. 2008). In these situations, sustained overhunting can cause a decrease in *all* species over time, ultimately leading to 'empty forest syndrome'—an intact forest that has been emptied of all fauna (Wilkie et al. 2011). Signs of empty forest syndrome have been observed in forests on the peripheral edges of the TL2 region, and there is concern that this trend will continue inward toward the proposed national park (see Figure 5) (J. Hart, pers. comm.). In order to uncover the long-term effects of unregulated bushmeat consumption in the TL2 region, more research is needed.

This thesis has shown that lesula appear to be highly resilient against the threat of unregulated bushmeat hunting; however, we are still unsure of the future of lesula in these heavily hunted forests (see Figures 10 and 20). Furthermore, lesula populations could be in decline presently, but a slow reduction in numbers due to their shy, cryptic behavior could mask an actual decreasing trend. While lesula appear to be buffered from the effects of unregulated bushmeat hunting, the results of this thesis should be considered provisional.

Figure 18: Hunter with kill (probably *C. mitis)* taken inside the study area during the Okulu survey.

Figure 19: Lesula kill obtained in Yawende.

Figure 20: Lesula adult male in the Losekola research area.

Figure 21: Lesula perching on a termite mound.

CONCLUSION

The results presented in this thesis have several important implications. First, in light of our findings, the camera trap surveys have shown that the lesula population appears highly resilient against the threat of unregulated bushmeat hunting; this is likely due to their cryptic, terrestrial behavior. Second, these findings also support the original IUCN Red List Status of lesula as Vulnerable, and although more research is needed to fully update lesula's status, a preliminary assessment can be made on needed conservation efforts for the future. The capture rate of lesula in both hunted and non-hunted sites is the same, so the relative abundance of lesula at both the Losekola research area and the Okulu research area is likely very similar. This is in stark contrast to duikers, bushpigs, and other large mammals—all of which have shown a radical reduction in population size at the heavily hunted Okulu site. In addition to using camera trap capture rates as a proxy to relative abundance, examination of the behavior and ecology of this species via video show what appear to be a healthy population of lesula at the heavily hunted Okulu site. This assessment is independently confirmed by the 'group size' results that reveal large groups of lesula—up to 11 individuals per group—occupying the Okulu research area.

In addition to determining the population status of lesula, this research also shows that camera traps are highly useful tools in studying the behavior and ecology of this little-known primate species. New information was added on lesula's minimum group size, diet, and activity pattern, and this research confirmed previous findings on lesula's terrestriality and group composition. We also determined that even in small-to-medium sized camera trap surveys, valuable behavioral data can be organized and catalogued revealing otherwise hidden behavior.

The research that I conducted in the TL2 region is not simply an isolated expedition to investigate one species, but was part of a broader international partnership between Florida Atlantic University and the Lukuru Foundation based in the Democratic Republic of the Congo. Since the inception of this project I have been working closely under the supervision of Dr. Kate Detwiler and her collaborators in the DR Congo, Drs. John and Terese Hart. The goal was to jointly create a project that would not only increase our understanding of lesula and its specific ecology, but to also create a project that will enhance the conservation goals of the Lukuru Foundation in the TL2 region and the surrounding community conservation areas. While my project does not directly address the issue of conservation, this project has been designed to support the mission statement of the Lukuru Foundation. Their conservation goals are to monitor animal populations, provide much needed information for dissemination to local communities by the foundation's staff, and train the local people and students to protect, monitor, and promote conservation in the TL2 region.

In order to strengthen the broader impacts of this research project, the deployment, use, and maintenance of the camera traps were taught to local personnel during the Okulu survey, and camera traps are presently being used in continued research in the region. These camera traps are crucial in the future monitoring of primate and other mammal populations, such as the forest elephant, okapi, and bonobo, all of which reside within the TL2 region (Hart and Hart, 2011). All data gathered on the behavior, occupancy, and abundance of lesula at these two sites is now available as baseline data for the ongoing studies inside the proposed Lomami National Park, and could prove pivotal in directing the future conservation efforts of lesula, and all fauna that reside in this unique ecosystem.

APPENDICES

Appendix A—IACUC approval

FLORIDA ATLANTIC UNIVERSITY

Division of Research
Institutional Animal Care and Use Committee
777 Glades Road
Boca Raton, FL 33431
Tel: 561.297.0777
Fax: 561.297.2319
http://www.fau.edu/research/rcs/

DATE: October 1, 2013

TO: Kate Detwiler
Anthropology, College of Arts and Letters

FROM: Janet Blanks, Chair *Janet Blanks*

RE: A13-20"A Camera Trap Study of a Cryptic and Threatened Primate Species, *Cercopithecus lomamiensis*"

The Institutional Animal Care and Use Committee (IACUC) has reviewed the above-referenced protocol and approves the proposed research as meeting the ethical and legal standards for the protection of the rights and welfare of the animal subjects involved.

This approval expires September 30, 2016 however annual renewals are required. Please note that actual numbers of animals used in the study should be reported to the IACUC upon return from field research. It is your responsibility to renew this approval or the study must be halted. Additionally, any changes in the approved personnel or procedures must be approved by the IACUC prior to implementation.

Florida Atlantic University's Animal Assurance number is A-3883-01. Should you have any questions, or require additional clarification, please contact Elisa Gaucher at 7-2318, Kristen Ware at 7-0961 or me at 7-4310.

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Appendix B—Example of camera trap notebook records: camera station C1

Event Date	Event Start	Event End	Event Duration (hour:minute)	No. Videos
10/23/13	16:34	16:34	0:00	1
10/26/13	23:19	23:19	0:00	1
10/28/13	6:25	6:25	0:00	1
10/31/13	8:55	8:55	0:00	1
11/3/13	8:22	8:22	0:00	1
11/8/13	6:20	6:20	0:00	1
11/12/13	14:04	14:04	0:00	1
11/12/13	16:56	16:56	0:00	1
11/17/13	13:30	13:30	0:00	1
11/25/13	8:07	8:08	0:01	1
11/30/13	16:39	16:40	0:01	1
12/1/13	6:52	6:56	0:04	2
12/5/13	3:31	3:32	0:01	1
12/6/13	23:14	23:15	0:01	1
12/10/13	0:38	0:39	0:01	1
12/10/13	3:07	3:08	0:01	1
12/13/13	15:59	16:00	0:01	1

Common Name	Scientific Name	Sex	Age
Unknown Bird	Unknown	U	U
Water Chevrotain	Hyemoschus aquaticus	F	A
Unknown Bird	Unknown	U	U
Unknown Bird	Unknown	U	U
Lesula	Cercopithecus lomamiensis	U/U	U/A
Unknown Bird	Unknown	U	U
Lesula	Cercopithecus lomamiensis	M	A
Lesula	Cercopithecus lomamiensis	F	A
Lesula	Cercopithecus lomamiensis	U	SA
Lesula	Cercopithecus lomamiensis	U/U	U/U
Lesula	Cercopithecus lomamiensis	F	A
Lesula	Cercopithecus lomamiensis	U/U/U/U	A/SA/SA/U
Unknown	Unknown	U	U
Unknown Rodent	Unknown	U	U
Aardvark	Orycteropus afer	M	A
Aardvark	Orycteropus afer	M/F?	A/A
Lesula	Cercopithecus lomamiensis	U	J

Max. No. Animals	Observer One	Observer Two	Camera Station	Start Picture
2	Steven McPhee		C1	11
1	Steven McPhee		C1	21
2	Steven McPhee		C1	22
2	Steven McPhee		C1	24
2	Steven McPhee		C1	27
2	Steven McPhee		C1	28
1	Steven McPhee		C1	18
1	Steven McPhee		C1	7
1	Meghan O'Connor	Sara Dempsey	C1	4
2	Meghan O'Connor	Sara Dempsey	C1	5
1	Meghan O'Connor	Sara Dempsey	C1	6
3	Meghan O'Connor	Sara Dempsey	C1	7
1	Meghan O'Connor	Sara Dempsey	C1	11
1	Meghan O'Connor	Sara Dempsey	C1	12
1	Meghan O'Connor	Sara Dempsey	C1	13
1	Meghan O'Connor	Sara Dempsey	C1	14
1	Meghan O'Connor	Sara Dempsey	C1	15

End Picture	Event Quality	Camera Model	Notes	Great Video
11	3	Bushnell		
21	3	Bushnell		
22	3	Bushnell		
24	3	Bushnell		
27	3	Bushnell		
28	2	Bushnell		
18	5	Bushnell	Clear Blue Bottom	
7	3	Bushnell		
4	5	Bushnell		4
5	2	Bushnell		
6	3	Bushnell		
9	3	Bushnell		
11	2	Bushnell	Possible mongoose	
12	3	Bushnell		
13	3	Bushnell		
14	5	Bushnell	Aardvark Mating	14
15	3	Bushnell		

Appendix C—Example of Okulu behavioral notebook records: events 1 to 10

Logistic Info (1 of 2)						
Individual No.	**Event number**	**Date**	**CT Station**	**Model**	**Video Start**	**Video end**
1	1	11/3/13	C.5	Moultrie	16	17
2	1	11/3/13	C.5	Moultrie	16	17
3	1	11/3/13	C.5	Moultrie	16	17
4	1	11/3/13	C.5	Moultrie	16	17
5	1	11/3/13	C.5	Moultrie	16	17
6	2	11/1/13	A.5	Moultrie	12	15
7	2	11/1/13	A.5	Moultrie	12	15
8	2	11/1/13	A.5	Moultrie	12	15
9	3	10/23/13	A.0	Moultrie	25	36
10	3	10/23/13	A.0	Moultrie	25	36
11	3	10/23/13	A.0	Moultrie	25	36
12	3	10/23/13	A.0	Moultrie	25	36
13	4	11/20/13	E3	Moultrie	5	9
14	4	11/20/13	E3	Moultrie	5	9
15	4	11/20/13	E3	Moultrie	5	9
16	4	11/20/13	E3	Moultrie	5	9
17	4	11/20/13	E3	Moultrie	5	9
18	4	11/20/13	E3	Moultrie	5	9
19	4	11/20/13	E3	Moultrie	5	9
20	4	11/20/13	E3	Moultrie	5	9
21	4	11/20/13	E3	Moultrie	5	9
22	4	11/20/13	E3	Moultrie	5	9
22	4	11/20/13	E3	Moultrie	5	9
23	5	10/20/13	A.0	Moultrie	16	16
24	6	10/24/13	A.0	Moultrie	37	38
25	6	10/24/13	A.0	Moultrie	37	38
26	7	11/2/13	A.0	Moultrie	54	55
27	7	11/2/13	A.0	Moultrie	54	55
28	8	11/5/13	A.0	Moultrie	60	62
29	8	11/5/13	A.0	Moultrie	60	62
30	8	11/5/13	A.0	Moultrie	60	62
31	8	11/5/13	A.0	Moultrie	60	62
32	9	11/6/13	A.0	Moultrie	63	63
33	10	11/12/13	A.0	Moultrie	8	9

Logistical Info Cont. (2 of 2)						
Time	**Length of Focal (s)**	**Total cumulative focal length per event (s)**	**Video Duration of event (s)**	**Min**	**Max**	**color (1) B&W (2)**
8:11	34	87	40	5	5	2
8:11	37			5	5	2
8:11	6			5	5	2
8:11	7			5	5	2
8:11	3			5	5	2
9:25	63	80	80	3	3	2
9:25	21			3	3	2
9:25	20			3	3	2
17:00	21	74	240	4	5	2
17:00	22			4	5	2
17:00	25			4	5	2
17:00	19			4	5	2
14:28	2	29	100	10	10	2
14:28	3			10	10	2
14:28	2			10	10	2
14:28	1			10	10	2
14:28	3			10	10	2
14:28	2			10	10	2
14:28	2			10	10	2
14:28	1			10	10	2
14:28	13			10	10	2
14:28	2			10	10	2
14:28	2			10	10	2
15:29	1	1	90	1	1	1
6:29	22	32	40	2	3	2
6:29	10			2	3	2
9:00	9	29	40	1	2	2
9:00	20			1	2	2
17:46	17	44	60	3	4	2
17:46	12			3	4	2
17:46	18			3	4	2
17:46	7			3	4	2
6:39	3	3	20	1	1	2
15:14	3	3	40	1	2	2

Individual Info	
Face	**Identifiable Marks**
0	0
0	0
0	Lighter fur
0	0
0	0
1	0
0	Kinked Tail
1	0
1	Protruding bulge at underside base of tail.
1	Tail darkens further back on tail
1	0
1	Dark fur coloration
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	White mark on tail
0	0
1	0
1	0
1	0
1	0
0	0
0	0

Location Info and Quality				
Quality	Ground	Above Ground	Climbing	Descending
Medium	1	0	0	0
Medium	1	0	0	0
Medium	1	0	0	0
Medium	1	0	0	0
Medium	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Medium	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
Medium	1	0	0	0
Medium	1	0	0	0
Low	1	0	0	0
Low	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
High	1	0	0	0
Medium	1	0	0	0
Low	1	0	0	0

Appendix D—All lesula events by date and camera station

Number of Events	Event Date	Event Start	Common Name	Max. No. Animals	Camera Station
1	10/20/13	15:29	Lesula	1	A0
2	10/23/13	17:00	Lesula	4	A0
3	10/23/13	15:31	Lesula	1	B0
4	10/24/13	6:29	Lesula	2	A0
5	10/25/13	8:17	Lesula	3	A2
6	10/25/13	14:17	Lesula	1	A2
7	10/25/13	13:11	Lesula	11	D0
8	10/27/13	15:08	Lesula	1	D2.5
9	10/27/13	7:35	Lesula	1	D4
10	10/27/13	16:29	Lesula	1	E3
11	10/27/13	6:45	Lesula	2	B1
12	10/28/13	8:17	Lesula	4	A0.5
13	10/28/13	12:10	Lesula	1	B2.5
14	10/28/13	17:37	Lesula	11	C0
15	10/28/13	16:28	Lesula	1	C0.5
16	10/28/13	10:40	Lesula	1	E2
17	10/29/13	14:34	Lesula	2	A1.5
18	10/30/13	16:30	Lesula	4	C1.5
19	10/31/13	8:19	Lesula	2	B1.5
20	10/31/13	12:41	Lesula	3	D2
21	10/31/13	11:31	Lesula	1	D3
22	10/31/13	8:22	Lesula	1	B1
23	11/01/13	9:24	Lesula		A0.5
24	11/01/13	11:24	Lesula	1	B3.5
25	11/01/13	8:43	Lesula	1	D0
26	11/02/13	9:00	Lesula	1	A0
27	11/02/13	14:30	Lesula	3	A2
28	11/02/13	17:08	Lesula	2	B0
29	11/02/13	14:36	Lesula	1	E1
30	11/03/13	8:11	Lesula	5	C0.5
31	11/03/13	8:22	Lesula	2	C1
32	11/03/13	8:21	Lesula	1	C2

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Number of Events	Event Date	Event Start	Common Name	Max. No. Animals	Camera Station
33	11/04/13	12:39	Lesula	2	E2
34	11/05/13	17:46	Lesula	4	A0
35	11/05/13	17:11	Lesula	1	B1.5
36	11/05/13	7:44	Lesula	3	B2
37	11/05/13	16:00	Lesula	1	B1
38	11/06/13	6:39	Lesula	1	A0
39	11/06/13	13:01	Lesula	2	A2
40	11/06/13	11:13	Lesula	2	C3.5
41	11/06/13	10:06	Lesula	2	D2
42	11/06/13	14:27	Lesula	2	E0
43	11/07/13	11:06	Lesula	1	C0
44	11/07/13	15:06	Lesula	1	C0
45	11/07/13	10:53	Lesula	2	D1
46	11/08/13	15:57	Lesula	1	B1.5
47	11/08/13	15:23	Lesula	1	B2
48	11/08/13	13:11	Lesula	8	C2
49	11/08/13	9:34	Lesula	4	E3
50	11/08/13	16:37	Lesula	1	B1
51	11/09/13	7:42	Lesula	2	A1.5
52	11/09/13	7:30	Lesula	2	B1
53	11/10/13	8:26	Lesula	2	A2.5
54	11/10/13	11:52	Lesula	1	C3.5
55	11/10/13	11:52	Lesula	4	E2
56	11/11/13	7:12	Lesula	1	B3.5
57	11/11/13	16:04	Lesula	1	D1.5
58	11/11/13	16:20	Lesula	1	E0
59	11/12/13	15:14	Lesula	1	A0
60	11/12/13	10:44	Lesula	2	A1.5
61	11/12/13	7:22	Lesula	4	A2
62	11/12/13	15:06	Lesula	4	B1.5
63	11/12/13	14:04	Lesula	1	C1
64	11/12/13	16:56	Lesula	1	C1
65	11/12/13	8:01	Lesula	1	C1.5
66	11/12/13	12:53	Lesula	2	C1.5
67	11/13/13	12:00	Lesula	2	E1
68	11/13/13	9:25	Lesula	9	E2

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Table continued from page 91

Number of Events	Event Date	Event Start	Common Name	Max. No. Animals	Camera Station
69	11/13/13	12:03	Lesula	2	E3
70	11/14/13	13:16	Lesula	1	A0
71	11/15/13	13:34	Lesula	1	B0.5
72	11/16/13	15:31	Lesula	2	B2.5
73	11/16/13	7:44	Lesula	3	B3.5
74	11/16/13	15:07	Lesula	1	C1.5
75	11/17/13	13:30	Lesula	1	C1
76	11/17/13	14:29	Lesula	1	C1.5
77	11/17/13	15:57	Lesula	1	D1
78	11/18/13	13:56	Lesula	1	A0.5
79	11/19/13	16:09	Lesula	7	B1.5
80	11/20/13	15:09	Lesula	1	A0
81	11/20/13	8:54	Lesula	2	A2
82	11/20/13	7:35	Lesula	1	B1.5
83	11/20/13	9:23	Lesula	1	C0.5
84	11/20/13	16:43	Lesula	2	C0.5
85	11/20/13	10:25	Lesula	4	D0
86	11/20/13	14:28	Lesula	9	E3
87	11/21/13	14:02	Lesula	3	C3
88	11/22/13	16:57	Lesula	2	A1.5
89	11/22/13	13:41	Lesula	1	C2
90	11/23/13	17:37	Lesula	2	A0
91	11/23/13	9:02	Lesula	5	B1.5
92	11/23/13	11:39	Lesula	1	B2.5
93	11/24/13	15:37	Lesula	1	D0.5
94	11/25/13	11:01	Lesula	1	A0.5
95	11/25/13	9:32	Lesula	5	B1.5
96	11/25/13	8:07	Lesula	2	C1
97	11/26/13	14:26	Lesula	2	B2.5
98	11/26/13	16:18	Lesula	3	C0.5
99	11/27/13	7:35	Lesula	9	A0
100	11/28/13	15:57	Lesula	3	B3.5
101	11/28/13	7:17	Lesula	1	C1.5
102	11/28/13	11:12	Lesula	2	E2
103	11/29/13	14:58	Lesula	1	A0.5
104	11/29/13	17:05	Lesula	1	B1.5
105	11/30/13	11:24	Lesula	3	A0

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Number of Events	Event Date	Event Start	Common Name	Max. No. Animals	Camera Station
106	11/30/13	11:44	Lesula	1	A2
107	11/30/13	14:27	Lesula	2	B1.5
108	11/30/13	16:39	Lesula	1	C1
109	11/30/13	13:05	Lesula	1	C1.5
110	11/30/13	10:47	Lesula	1	D1
111	11/30/13	8:23	Lesula	2	D1.5
112	11/30/13	10:12	Lesula	1	D2
113	11/30/13	13:13	Lesula	5	E3
114	12/01/13	7:37	Lesula	6	A0.5
115	12/01/13	6:52	Lesula	3	C1
116	12/01/13	14:16	Lesula	1	C3.5
117	12/02/13	10:37	Lesula	1	C1.5
118	12/02/13	13:41	Lesula	1	D0
119	12/03/13	13:20	Lesula	2	B1.5
120	12/04/13	10:03	Lesula	5	C3.5
121	12/04/13	13:34	Lesula	5	D2.5
122	12/04/13	8:11	Lesula	1	D4
123	12/04/13	11:31	Lesula	1	E0
124	12/04/13	14:30	Lesula	5	E2
125	12/05/13	16:30	Lesula	2	A0
126	12/05/13	17:01	Lesula	2	C0.5
127	12/07/13	16:35	Lesula	2	E0
128	12/08/13	11:57	Lesula	1	B1.5
129	12/08/13	10:11	Lesula	1	C1.5
130	12/08/13	10:22	Lesula	1	C2
131	12/08/13	8:47	Lesula	1	D1.5
132	12/08/13	8:14	Lesula	1	E1
133	12/09/13	13:48	Lesula	2	E2
134	12/10/13	17:00	Lesula	2	A0
135	12/10/13	9:01	Lesula	2	A2
136	12/10/13	10:43	Lesula	3	C0.5
137	12/10/13	12:54	Lesula	1	D1
138	12/10/13	8:39	Lesula	3	E0
139	12/13/13	16:57	Lesula	3	C0
140	12/13/13	15:59	Lesula	1	C1

Appendix E—Species capture probability by survey

Duiker	Losekola	Okulu
Total Events	80	101
CT Hours	462	1953
Capture Probability	0.173	0.052

Lesula	Losekola	Okulu
Total Events	38	140
CT Hours	462	1683
Capture Probability	0.082	0.083

Red River Hog	Losekola	Okulu
Total Events	15	1
CT Hours	462	1683
Capture Probability	0.032	0.001

Human	Losekola	Okulu
Total Events	0	14
CT Hours	462	1683
Capture Probability	0.000	0.008

Aardvark	Losekola	Okulu
Total Events	4	8
CT Hours	462	1683
Capture Probability	0.009	0.005

Brush-Tailed Porcupine	Losekola	Okulu
Total Events	4	4
CT Hours	462	1683
Capture Probability	0.009	0.002

Leopard	Losekola	Okulu
Total Events	3	1
CT Hours	462	1683
Capture Probability	0.006	0.001

Linsang	Losekola	Okulu
Total Events	2	3
CT Hours	462	1683
Capture Probability	0.004	0.002

Appendix F—Time of lesula capture by hour

Date	Time of Lesula Event (6 am - 7 am)	Number of Events
10/24/13	6:29	1
11/6/13	6:39	2
10/27/13	6:45	3
5/22/12	6:50	4
12/1/13	6:52	5
8/31/12	6:57	6

Date	Time of Lesula Event (7 am - 8am)	Number of Events
11/11/13	7:12	1
8/24/12	7:13	2
11/28/13	7:17	3
8/18/12	7:18	4
11/12/13	7:22	5
6/4/13	7:24	6
8/30/12	7:28	7
11/9/13	7:30	8
8/15/13	7:31	9
10/27/13	7:35	10
11/20/13	7:35	11
11/27/13	7:35	12
12/1/13	7:37	13
7/12/12	7:38	14
7/29/13	7:39	15
11/9/13	7:42	16
11/5/13	7:44	17
11/16/13	7:44	18
8/4/13	7:53	19
8/15/12	7:55	20

Date	Time of Lesula Event (9 am - 10 am)	Number of Events
11/2/13	9:00	1
12/10/13	9:01	2
11/23/13	9:02	3
6/10/13	9:11	4
7/1/12	9:16	5
7/30/12	9:19	6
9/19/12	9:20	7
11/20/13	9:23	8

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Date	Time of Lesula Event (9 am - 10 am)	Number of Events
11/1/13	9:24	9
11/13/13	9:25	10
11/25/13	9:32	11
11/8/13	9:34	12
7/9/12	9:39	13
6/20/13	9:45	14
6/18/13	9:49	15

Date	Time of Lesula Event (10 am - 11 am)	Number of Events
12/4/13	10:03	1
11/6/13	10:06	2
12/8/13	10:11	3
11/30/13	10:12	4
12/8/13	10:22	5
11/20/13	10:25	6
7/7/13	10:32	7
6/5/13	10:36	8
12/2/13	10:37	9
7/28/13	10:39	10
10/28/13	10:40	11
12/10/13	10:43	12
11/12/13	10:44	13
11/30/13	10:47	14
11/7/13	10:53	15

Date	Time of Lesula Event (11 am - 12 pm)	Number of Events
11/25/13	11:01	1
11/7/13	11:06	2
8/7/12	11:09	3
11/28/13	11:12	4
11/6/13	11:13	5
11/1/13	11:24	6
11/30/13	11:24	7
10/31/13	11:31	8
12/4/13	11:31	9

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Date	Time of Lesula Event (11 am - 12 pm)	Number of Events
7/12/13	11:33	10
11/23/13	11:39	11
8/23/12	11:42	12
6/7/13	11:44	13
11/30/13	11:44	14
11/10/13	11:52	15
11/10/13	11:52	16
12/8/13	11:57	17

Date	Time of Lesula Event (12 pm - 1 pm)	Number of Events
11/13/13	12:00	1
11/13/13	12:03	2
8/18/12	12:03	3
9/18/12	12:05	4
10/28/13	12:10	5
8/12/13	12:21	6
7/13/12	12:21	7
7/13/13	12:25	8
11/4/13	12:39	9
10/31/13	12:41	10
11/12/13	12:53	11
12/10/13	12:54	12
6/18/13	12:57	13
12/4/12	12:59	14

Date	Time of Lesula Event (1 pm - 2 pm)	Number of Events
11/6/13	13:01	1
11/28/12	13:01	2
11/30/13	13:05	3
10/25/13	13:11	4
11/8/13	13:11	5
11/30/13	13:13	6
11/14/13	13:16	7
12/3/13	13:20	8
7/16/13	13:29	9
11/17/13	13:30	10

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Date	Time of Lesula Event (1 pm - 2 pm)	Number of Events
11/15/13	13:34	11
12/4/13	13:34	12
6/27/13	13:35	13
6/4/13	13:40	14
11/22/13	13:41	15
12/2/13	13:41	16
12/9/13	13:48	17
7/15/12	13:51	18
11/18/13	13:56	19

Date	Time of Lesula Event (2 pm - 3 pm)	Number of Events
6/14/13	14:02	1
11/21/13	14:02	2
11/12/13	14:04	3
6/9/13	14:13	4
12/1/13	14:16	5
10/25/13	14:17	6
5/29/13	14:23	7
6/8/13	14:23	8
11/26/13	14:26	9
11/6/13	14:27	10
11/30/13	14:27	11
11/20/13	14:28	12
11/17/13	14:29	13
11/2/13	14:30	14
12/4/13	14:30	15
10/29/13	14:34	16
11/2/13	14:36	17
7/8/13	14:37	18
7/1/13	14:41	19
9/2/13	14:46	20
8/29/12	14:51	21
6/6/13	14:55	22
11/29/13	14:58	23

Date	Time of Lesula Event (3 pm - 4 pm)	Number of Events
6/18/13	15:01	1
11/7/13	15:06	2
11/12/13	15:06	3
11/16/13	15:07	4
8/18/12	15:07	5
10/27/13	15:08	6
11/20/13	15:09	7
8/3/12	15:13	8
11/12/13	15:14	9
9/11/12	15:14	10
11/8/13	15:23	11
7/5/12	15:26	12
10/20/13	15:29	13
10/23/13	15:31	14
11/16/13	15:31	15
5/27/13	15:37	16
11/24/13	15:37	17
9/6/12	15:52	18
5/25/12	15:53	19
11/8/13	15:57	20
11/17/13	15:57	21
11/28/13	15:57	22
12/13/13	15:59	23

Date	Time of Lesula Event (4 pm - 5 pm)	Number of Events
11/5/13	16:00	1
11/11/13	16:04	2
8/6/13	16:05	3
7/24/12	16:06	4
11/19/13	16:09	5
9/4/12	16:09	6
11/23/12	16:17	7
11/26/13	16:18	8
11/11/13	16:20	9
8/8/13	16:21	10
8/1/13	16:25	11
8/24/12	16:27	12
10/28/13	16:28	13
10/27/13	16:29	14
6/9/13	16:30	15

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Date	Time of Lesula Event (4 pm - 5 pm)	Number of Events
10/30/13	16:30	16
12/5/13	16:30	17
12/7/13	16:35	18
11/8/13	16:37	19
11/30/13	16:39	20
8/13/13	16:40	21
11/20/13	16:43	22
7/27/13	16:45	23
11/12/13	16:56	24
11/22/13	16:57	25
12/13/13	16:57	26
8/6/12	16:58	27

Date	Time of Lesula Event (5 pm - 6 pm)	Number of Events
10/23/13	17:00	1
12/10/13	17:00	2
12/5/13	17:01	3
8/13/12	17:01	4
8/13/12	17:03	5
11/29/13	17:05	6
11/2/13	17:08	7
11/5/13	17:11	8
11/6/12	17:32	9
10/28/13	17:37	10
11/23/13	17:37	11
11/5/13	17:46	12

Date	Time of Lesula Event (6 pm - 7 pm)	Number of Events
11/2/12	18:14	1

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