A SURVEY OF INDOCHINESE SILVERED LANGURS (*TRACHYPITHECUS GERMAINI*)

IN PHU QUOC NATIONAL PARK, VIETNAM

by

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

ABSTRACT

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A Survey of Indochinese Silvered Langurs (*Trachypithecus germaini*) in

Phu Quoc National Park, Vietnam

Thesis directed by Professor Herbert H. Covert

A survey of Indochinese silvered langurs (*Trachypithecus germaini*) in Phu Quoc National Park, Vietnam, conducted during the wet season, using eleven line transects over fourteen field days, obtained an estimate of 1,249.37 to 1,498.89 total animals in the strictly protected area. Other estimates of population were found for comparison. This population has the potential to be a stronghold for the species in Vietnam and globally. The degree of fragmentation within the population and the population size trends are unknown. More information is needed for the conservation of the population on Phu Quoc Island and the species as a whole.

DEDICATION

This work is dedicated to Duncan.

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INTRODUCTION

Of the twenty-five species of primates inhabiting Vietnam, seventeen are listed as endangered or critically endangered by the International Union for the Conservation of Nature (IUCN) (Roos et al., 2013). This sad reality has prompted new research on Vietnamese primates in recent years. The rough terrain found throughout significant portions of Vietnam means that this work progresses slowly. With the numbers of most Vietnamese primates declining at unknown rates, all information on their situation is important.

This thesis details a survey conducted from July 15th 2014 to August 2nd 2014 (fourteen field days) on Indochinese silvered langurs (*Trachypithecus germaini*) in Phu Quoc National Park, located on Phu Quoc Island, Kien Giang Province, Vietnam. This brief study was intended to gain a better assessment of possible silvered langur numbers within this national park. Silvered langurs were first reported in Phu Quoc National Park in 2004 by Ngo Van Tri. Forty-five animals were reported at that time. Prior to this, the presence of silvered langurs was confirmed in Phu Quoc National Park in 2003 during a general mammal survey by Abromov et al. (2007). At that time, a single group of animals was observed in high canopy. The group consisted of four or five adults with one golden infant; no estimation of total population size within the national park was made.

The first estimation of population size was made by Le Khac Quyet and Nguyen Vu Khoi (2010) based on fifteen field days during 2008 and 2009 during which twenty-two animals in seven groups were observed. An estimation was made of thirty-one to forty-four total animals in the area surveyed. This study was intended to add to the information gathered by Le Khac Quyet and Nguyen Vu Khoi and increase the precision of the total population estimate.

Other than the investigations into the presence or absence and possible number of silvered langurs in the national park, there has been no research done on their behavior or feeding ecology. This study was conducted to gain a better understanding of the number and distribution of the animals, thus leading to future inquiry. The first crucial step toward the understanding of this population is to establish number and distribution of animals.

Due to the status of Indochinese silvered langurs as endangered, a primary goal of an accurate census of silvered langurs in Phu Quoc National Park is conservation—a major objective in many primate census projects (Nadler et al., 2008). Plumptre and Cox discuss four reasons that census data is essential for conserving primates (2006: 65).

1. Census provides a baseline density or total number of animals to help monitor population changes.
2. A census can provide information on the relative importance of different habitats in the area.
3. A census can be compared to previous (or later) censuses to assess how the population size or density is changing.
4. Frequent censuses can show population trends.

This short list gives only some of the reasons why census data is essential for developing effective conservation strategies. There are others, including using the census to determine the socioecological differences between populations (Fashing and Cords, 2000). Understanding factors limiting populations and impacts of disease are also made possible with census data (Sterling et al., 2013). In the case of this study, the differences between the populations on Phu Quoc Island and on the mainland of Vietnam are of interest. The population of *T. germaini* in the Kien Luong Karst Area is currently threatened by mining activities. The possible translocation of these animals from their dwindling habitat into the protected Phu Quoc National Park has been discussed. This particular census was aimed at determining a baseline number of animals that can be monitored in the future, thus providing decision support for those considering the translocation of animals from threatened habitats into Phu Quoc National Park.

Due to pressures from tourism and poaching, an accurate census is both vital and urgent for the conservation of this population. Though Phu Quoc National Park is officially a protected area, poaching exists. In August 2013, the poaching of three silvered langurs was highly publicized (Pham Duc Hai, 2013). The effects of poaching—and the development of a prevention plan—are impossible to assess without an accurate census. Tourism development on the island and within the park is also of concern, as these activities could have unintended consequences for the monkeys. Opening up the park for tourism has the potential to fragment the habitat. An accurate census now will allow the effect of this to be measured in the future and ensure we are able to alter tourism and conservation plans to fit the changing needs of the monkeys.

Possible Translocation

The possible translocation of threatened animals from the Kien Luong Karst Area to Phu Quoc National Park mentioned above is a major motivation for gaining accurate census and behavioral data on *T. germaini* in Phu Quoc NP. Translocation, the human mediated release of animals from one area into another, is an extreme conservation measure and sometimes comes with excessive risks to animals, environment, and people (IUCN/SSC, 2013). Though translocation of animals has the potential to save threatened animals and increase the genetic diversity of the protected population on Phu Quoc, successful primate translocation is a difficult and delicate process. It is not always successful and a translocation of silvered langurs to Phu Quoc requires much more information than is currently available. Informed risk assessment and models must show that the benefits to the animals and the overall ecological system will outweigh the risks—before a translocation can be considered over alternative conservation measures (IUCN/SSC, 2013).

Bright and Morris (1994), using dormice, assert that translocation is a viable conservation strategy because translocated animals have higher performance and survival than captive bred animals. There is reason to believe this may hold true for primates as well, as some translocations (like the baboon example discussed below) have been successful, while very few captive breeding programs with reintroductions have any success. They also point out that translocations are especially important as habitat fragmentation increases. Fragmentation is a major issue in Vietnam, as the plight of many isolated langur populations shows.

A critical issue in successful translocation is avoiding translocation induced chronic stress, which decreases the animals' ability to form a self-sustaining population in the new location (Dickens et al., 2010). Major contributions to chronic stress include the process of translocation itself, which must be done carefully. Another source of chronic stress—assessable before translocation begins—is the novelty of the new site (Dickens et al., 2010). Though not done during this study, future work on Phu Quoc must carefully determine the differences between Phu Quoc National Park and the Kien Luong area where the animals currently live. Too many differences in forest type or plant species composition could cause chronic stress and failure of the translocation. Overcrowding of animals can also cause extreme stress. Census data is therefore critical to ensure animals are not introduced into an area that is already at or near carrying capacity.

Translocations of wild primates are still relatively rare. One example comes from baboons in Kenya (Strum, 2005). This famously successful 1984 primate translocation saved two baboon troops from extirpation and followed twelve years of pre-translocation study of the animals. Fortunately, there is ample time for planning a translocation of monkeys from Kien Luong. Translocation is a viable conservation strategy and has the potential to save both the threatened animals from extirpation and the Phu Quoc population from dwindling genetic diversity—but only if done correctly and based on accurate data.

Thus, we must gain an accurate understanding of current numbers, density, and distribution in Phu Quoc National Park, as well as a general comparison of forest type and plant composition, before translocation is attempted. Moving animals into an overly novel or crowded area will result in chronic stress and death. This study represents the first census during the wet season and adds—modestly—to our knowledge of the Phu Quoc population.

Successful translocation requires careful analysis of risks to translocated animals, native animals, and the overall environment. Extent of fragmentation, resource availability, cross species interactions, parasite loads, and effects on the human community must be assessed before a translocation can be considered (IUCN/SSC, 2013). These factors will be examined further in the discussion section.

Since this census was conducted over only fourteen days during the rainy season, its accuracy is necessarily limited. Further investigation and survey will be needed in the near future to obtain a more exact population estimate.

Current Primate Census Methods

There are many different ways to census animals; including direct methods (mark-recapture), point methods (counting all animals seen from a fixed point), and strip transects (counting all animals in a belt through the habitat). There is currently general agreement that the use of line transects is the best way to census forest living primates like silvered langurs (Plumptre and Cox, 2006). With line transects all animals seen from a line walked through the forest can be counted and included in the data analysis. This relaxes any assumption that all animals in a certain area on either side of the transect were counted (an assumption made by strip transects). The only assumption made by line transects is that animals directly above the line are counted. Though this is not always possible, the assumption of this method is met far more often than the more stringent assumptions imposed by point methods or strip transects (Buckland et al., 2010).

By censusing along lines and estimating how far from the line animals can be seen, a subset of the total habitat is surveyed. The number of animals in this subset of the habitat can be used to estimate total animals. The statistics program DISTANCE is often used to analyze the data resulting from line transect surveys. This program calculates the detection function (the probability that an animal a certain distance from the line will be spotted) and uses it and the length of the transects to estimate the area surveyed. However, DISTANCE requires twenty independent sightings to work, fewer sightings do now allow for calculation of an accurate detection function (Buckland et al., 2010).

Leca et al. (2013) used line transect sampling to measure the population of ebony leaf monkeys (*Trachypithecus auratus*) in West Bali National Park, Indonesia. Line transects were used because they are robust, rapid, cost effective, need little labor, and can be done often. This makes them ideal for providing information to conservation organizations and governments. The effectiveness of conservation strategies can be rapidly and frequently assessed at a low cost. Leca et al. (2013) also found that line transect sampling is particularly effective for forest-dwelling, group-living primates, such as most *Trachypithecus* species. Leca et al. (2013) used the generally accepted method of calculating the distance of all encountered animals from the line. Using these data, they calculated the detection function (the probability that an animal is detected at a certain distance from the line) which allows the calculation of animal density. This is a simple and effective way to indirectly measure density from a small sample size and does not assume that all animals are seen at any distance—an extremely problematic assumption with primates living in dense forest and high canopy.

Plumptre and Cox (2006) used line transects to census chimpanzees (*Pan troglodytes*) in Uganda. This line transect survey gave a different estimate than other surveys in the same area that used different methods. Plumptre and Cox state that there is a need for consistency in census methods so population trends can be monitored for changes. Line transects are less accurate than direct counts (counting all individuals), but direct counts are almost never feasible. Therefore line transects should be the standard method so population size data over time, and between sites, can be compared.

Hassel-Finnegan et al. (2008) compared population estimates of Phayre's leaf monkey (*Trachypithecus phayrei crepusculus*) derived from line transect walks and long-term group follows. They found that line transects overestimated population density of Phayre's leaf monkey. They attributed their error to the monkeys' tendency to form subgroups that travel alone during the day. These subgroups were counted as whole groups. This error demonstrates the need to understand the behavior of the primates being studied in order to increase the accuracy of line transect surveys.

Despite the problems inherent in estimating population size and density from a subset of the population with line transects, this is the generally accepted method of surveying and the one used in this study. Almost all authors agree that the benefits of line transects (namely their rapidity and low cost) outweigh the losses in accuracy from direct counts.

METHODS

Study Site

Abromov et al. (2007) provide an admirably comprehensive overview of the general conditions on Phu Quoc Island and in the national park. Phu Quoc Island is the largest offshore island belonging to Vietnam and is part of Kien Giang province. The island itself is in the Gulf of Thailand, forty-five kilometers west of Ha Tien, Vietnam, and fifteen kilometers south of the coast of Cambodia. The island is sixty-two kilometers long, from three to twenty-eight kilometers wide, and 562 square kilometers in area. A series of sandstone ridges run north to south along the length of the island. The highest peak is Mount Chua at 603 meters. Phu Quoc Island is in the monsoon sub-equatorial climate zone and has two seasons. Based on weather data collected at the Rach Gia Meteorological Station in the Kien Giang Province, the rainy season is from April or May through November. The average annual rainfall on the island is 2,879 millimeters. The average annual temperature is twenty-seven degrees centigrade.

It should be noted that the census reported in this thesis took place during the rainy season—any changes in habitat use during the dry season will not be detected. Census during the dry season is a goal of future research.

Phu Quoc National Park was reorganized from the Phu Quoc Nature Reserve in 2001 to encompass 31,442 hectares of land in the northeast portion of the island, with the northern and eastern borders of the park on coastal lines. The strictly protected area of the national park is 8,786 hectares (Vietnam Administration of Forestry, 2014). Most of the park is forest and consists of predominantly primary tropical forest. Coastal and mangrove communities are also included in the park (Abromov et al., 2007). Studies have indicated the presence of at least 1,164 higher plants species and 208 animal species. Twenty-eight species of mammals have been recorded on the island, of which six are considered endangered—including the silvered langur (Discover Phu Quoc, 2012).

Infrastructure in the park is varied. Paved roads do run through some of the park and dirt roads run through much of it. Both the paved and dirt roads are frequented by cars and motorcycles. The noise from the motorcycles, in particular, means that the roads form habitat fragments that may or may not be crossed by *T. germaini*. Trails are few within the national park. In many places that were surveyed the jungle was extremely thick and difficult to move through (see Figure 1). Unfortunately, this difficult terrain, combined with a low canopy— blocking the upper canopy—meant that it was difficult to detect animals.

Figure 1a (left) and 1b (right): Examples of the thickness of the Phu Quoc jungle. Photos by Robin Fiore.

Study Species

The Genus Trachypithecus

The genus *Trachypithecus*, langurs or lutungs, is a group of Old World monkeys inhabiting Southeast Asia as well as southern India and Sri Lanka (Roos et al., 2008).

Langurs are slim monkeys with long tails, commonly weighing from five to fifteen kilograms, with males generally larger than females. All species are diurnal and display mostly quadrupedal locomotion, though some are accomplished leapers (Harding, 2010). Langurs live in forests and are generally considered mainly folivorous, though their true feeding behavior is much more complex than just folivory. They often live in single-male multi-female groups of five to twenty individuals. All members of the genus give birth to bright orange infants, which darken within a few months (Harding, 2010). *Trachypithecus* consists of five species groups and at least twenty species within those groups (Fleagle, 2013).

The phylogeny of *Trachypithecus* is complex and not fully agreed upon. There is evidence that the genus originated on Java and spread throughout Southeast Asia during the Pleistocene (Roos et al., 2008). Mitochondrial DNA evidence suggests a radiation type splitting event 0.95-1.25 million years ago (Roos et al., 2008). Mitochondrial and X-chromosome DNA are often contradictory within the genus, suggesting a possible hybrid source for some species (Ting et al., 2008).

Within the genus *Trachypithecus* there are several ongoing debates concerning phylogeny. The position of the ash grey leaf monkey is still debated. Different genetic studies have placed it in either the *T. obscurus* group or the *T. cristatus* group. All of the species in the *T. francoisi* group have uncertain standing. The *T. francoisi* group may contain four species with sub-species or even six distinct species. This largely depends on the species concept being used. If the biological species concept is used (which holds that any populations that can produce viable offspring are the same population) there may be far fewer species than is generally accepted. The phylogenetic species concept (which recognizes the smallest diagnosable clusters of individuals that share an ancestor as a species) leads to more recognized species. Finally, there is still debate over whether *T. germaini* and *T. margarita* should be full species or sub-species (Blair et al., 2011). Overall, more sampling is required to resolve the taxonomy. The most accepted current taxonomy of the genus *Trachypithecus* is described by Mittermeier et al. (2013) in the *Handbook of Mammals of the World: Primates*. This taxonomy is depicted in Table 1.

Table 1: Scientific name, common name, and conservation status of all twenty species in the genus *Trachypithecus*. Obtained from Mittermeier et al., 2013. Conservation status obtained by Mittermeier et al. from IUCN.

Scientific Name	Common Name	Conservation Status
Trachypithecus geei	Golden Langur	Endangered
Trachypithecus pileatus	Capped Langur	Vulnerable
Trachypithecus shortridgei	Shortridge's Langur	Endangered
Trachypithecus auratus	East Javan Langur	Vulnerable
Trachypithecus mauritius	West Javan Langur	Vulnerable
Trachypithecus cristatus	Silvered Langur	Near Threatened
Trachypithecus selangorensis	Selangor Silvery Langur	Not Assessed
Trachypithecus germaini	Germain's Langur	Endangered
Trachypithecus margarita	Annamese Langur	Endangered
Trachypithecus barbei	Tenasserim Langur	Data Deficient
Trachypithecus obscurus	Dusky Langur	Near Threatened
Trachypithecus phayrei	Phayre's Langur	Endangered
Trachypithecus crepusculus	Indochinese Gray Langur	Endangered
Trachypithecus poliocephalus	Cat Ba Langur	Critically Endangered
Trachypithecus leucocephalus	White-headed Langur	Critically Endangered
Trachypithecus delacouri	Delacour's Langur	Critically Endangered
Trachypithecus francoisi	François's Langur	Endangered
Trachypithecus ebenus	Black Langur	Endangered
Trachypithecus laotum	Laos Langur	Vulnerable
Trachypithecus hatinhensis	Hatinh Langur	Endangered

All leaf-eating monkeys have a hemochorial placenta that is usually composed of two lobes (occasionally just one) and is connected by large fetal vessels. Members of the genus *Trachypithecus* have placenta ranging from 65-105 grams, and umbilical cord lengths ranging from 8-26 centimeters in length (Benirscke, 2008).

Infanticide likely occurs in *Trachypithecus*. Observations of a group of silvered leaf monkeys (then *Presbytis cristata*, now likely *Trachypithecus cristatus*) on a 50 hectare wooded hill near Kuala Selangor in Peninsular Malaysia between 1972 and 1975 revealed an interesting pattern of male replacement. The observers noted the replacement of the single adult male in a group consisting of an adult male, several adult females, and some immature individuals. Three months after the replacement all the infants in the group vanished. This pattern of male replacement and infanticide has also been observed in Hanuman langurs and purple-faced langurs. The replacement of the adult male may be violent and is often followed by killing of dependent infants. Infanticide is widespread among langurs (Van Schaik and Janson, 2000). It is unlikely that infanticide is as major of a factor in population decline of langur species as threats such as poaching and habitat loss. However, in small isolated populations infanticide could compound these problems and lead to quicker population decline.

Trachypithecus and other genera within the Colobinae have been a focus of feeding ecology research, in part due to the leaf-eating habits of these species. Leaves are notoriously difficult to digest, as noted by Caton (1999); the polysaccharides found in leaves require microbial fermentation before they can be converted to energy. To accomplish this, leaf-eating monkeys in the genus *Trachypithecus* use gastro-colic fermentation to break down leaves. Langurs have multi-chambered stomachs filled with gut microbes that help in breaking down leaves. The regions of the stomach are not completely separate compartments like a ruminant, but are more like the Macropodidae.

Trachypithecus species, compared to species in the genus *Pygathrix* (another leaf-eating genus), are ingestive folivores, as opposed to digestive folivores (Wright et al., 2008a). Members of *Trachypithecus* chew leaves faster and have larger lower molars, along with a deeper mandibular corpus than members of *Pygathrix*. This shows that, compared with other leaf-eating monkeys, *Trachypithecus* species rely more on chewing and ingestive behaviors to process leaves than some other genera. However, this is not uniform within the genus. *T. delacouri* chews faster than *T. hatinhensis* (Wright et al., 2008b). Since *Trachypithecus* lacks a presaccus in the stomach, which *Pygathrix* has, these adaptations help it break down leaves in an alternate manner—by mastication (Wright et al., 2008b).

The feeding diversity within *Trachypithecus* is likely much greater than has been appreciated in the past. Though there is a paucity of data on the genus overall, with most of the twenty species having no data at all, the information available shows surprising diversity in feeding behavior and choice.

Despite their traditional characterization as leaf monkeys, species in the genus *Trachypithecus* have a much more varied diet than simply leaves. Some species (*T. cristatus*) do indeed eat a diet almost entirely made up of leaves (Harding, 2010). However, some species such as *T. auratus* eat up to 30.9% seeds (Kool, 1993). Still others, like *Trachypithecus pileatus*, have seasonal diets composed predominantly of fruit (Stanford, 1991).

Fruits, flowers, and seeds are consumed by most *Trachypithecus* species in significant amounts. Other species eat insects, herbs, figs, and even significant amounts of bamboo (Gang Hu, 2011; Lambert, 1990). This diversity is far greater than was previously thought. The differing diets of langurs in pristine as opposed to disturbed habitats reveal a remarkable ability to adapt to disturbed and degraded habitat. This adaptation can take the form of longer feeding bouts and, frequently, consumption of more species. *T. cristatus* eats nearly a hundred species of plants (Harding, 2010). They are not specialists, but rather practice highly selective feeding. Their wide dietary diversity shows an ability to consume different ratios of food sources and obtain nutrients from novel sources (e.g. mushrooms, bamboo, soil, water lilies) in different habitats (Ramachandran and Joseph, 2001; Gang Hu, 2011; Kumar and Solanki, 2004).

Though we now know that langurs do not merely eat leaves, we are far from understanding the full dietary range of this genus. The feeding ecology of many of the twenty species comprising the genus *Trachypithecus* has not been studied at all—others, just barely. In order to understand the range within the genus, more research should be conducted on unstudied species.

The feeding ecology research done so far reveals that langurs are capable of adapting to human presence by increasing their dietary breadth or changing such feeding behaviors as length of feeding time. By identifying the ability of each species to increase their dietary breadth or change their feeding habits and feeding time, we can determine which species are more sensitive to anthropogenic change (Gang Hu, 2011). This will help conservation efforts on a genus whose most abundant members are still listed as near threatened by the IUCN (Table 1).

Little else is known about the particulars of silvered langur behavior. Kirkpatrick (2010) discusses some specifics of Asian colobines that may act as guidelines for likely patterns of silvered langur behavior. Predation pressure on Asian colobines is low compared to African colobines. The Asian colobines are relatively unsocial. They have seasonal births with an average inter-birth interval of two years and tend to wean before age one. Alloparenting is virtually ubiquitous. Asian colobines mostly live in one-male groups that are not generally territorial. Males immigrate and may form all male units. Aggressive encounters between groups, when they occur, are generally due to males protecting their access to females, not their food sources. Males may tolerate grown sons, or drive them out with aggression. These two options occur with nearly equal frequency. Females may occasionally transfer groups, and their choices maintain internal group structure.

A study by Shelmidine et al. (2009) investigated the reproductive behavior of a group of *Trachypithecus cristatus* housed in the Bronx Zoo. This group consisted of one male at a time (seven males over the study period) and 30 total females over the study period. Twenty-two years of data were used. The birth sex ratio in this group was even and females showed no difference in maternal investment based on sex. This is in opposition to some other primate species where maternal investment is higher in males (Shelmidine et al., 2009). The mean receptive period of females was 4.3 days. The mean gestation length was 194.6 days with a mean inter-birth interval of 14.9 months and mean age at first birth of 2.9 years. The mean lactation period was 12.1 months. All births were singletons and were evenly distributed across the year. Due to lack of data on the reproductive behavior of this species in the wild, it is unknown how much of these data reflect the different nutritional condition of zoo animals. However, this study does give some idea of reproductive potential for this species.

Though all langurs live in forests, different species can live in varying forest types, including limestone hills, mangrove forests, and even degraded habitats (Zinner et al., 2013). There is evidence as far back as 1993 of silvered langurs (then *Presbytis cristata*) inhabiting true mangrove communities in Sarawak, Malaysia (Bennett and Reynolds, 1993). As noted by many previous authors, langurs inhabit a wide variety of habitats.

Trachypithecus germaini

Trachypithecus germaini or the Indochinese silvered langur (Figures 2 and 3) is restricted to southeastern Thailand, Cambodia, southern and central Lao PDR, and south and central Vietnam (Moody et al., 2011). The IUCN currently lists *T. germaini* as endangered (Nadler et al., 2008). This designation is based on a population decline exceeding 50% over the last thirty-six years (three generations). Prior to 2001, *T. germaini* was often considered to be synonymous with *T. cristatus* (Groves, 2001). Recent studies have suggested that *T. germaini* be divided into *T. germaini* [sensu stricto] and *T. margarita* using the Mekong River as the dividing line between the two species—*T. germaini* to the west and *T. margarita* to the east. However, this split is under debate and is not currently recognized by IUCN (Moody et al., 2011).

Figure 2: Silvered langurs at the Saigon Zoo, seated adults and a climbing infant. Photo by Robin Fiore.

Figure 3: A silvered langur infant that was able to slip through the bars and hang on the outside of the cage at the Saigon Zoo. Photo by Robin Fiore.

There is evidence for a split between *T. germaini* and *T. margarita*, despite its lack of official recognition. Analysis of a 573 base pair long fragment of the mitochondrial cytochrome b gene reported by Hoang Minh Duc et al. (2012) supports the argument that *T. germaini* and *T. margarita* are separate species. The Mekong River is likely the zoogeographical barrier between these species. Field observations and photos of wild individuals of both proposed species reveal high phenotypic variability within each species, making it difficult to diagnose each species morphologically. There are some obvious differences in morphology. These include the hairs on the head, which form a central occipital crest in *T. germaini* as opposed to a cap or hood—instead of a crest—on *T. margarita*, and a completely black face in *T. germaini* as contrasted with the paler eye rings in *T. margarita*.

The Indochinese Primate Conservation Genetics Program has also concluded that *T. germaini* and *T. margarita* should be considered separate species (Roos, 2008). This conclusion is based on their non-invasively collected genetic material compiled between 2003 and 2008.

Roos et al. (2008) further analyzed mitochondrial DNA of silvered langurs to posit that the split between *T. germaini* and *T. margarita* may have occurred 0.95+/-0.09 million years ago.

However, according to Denise et al. (2008) viable hybridization is known to occur between all five species of silvered langurs. This could be interpreted to indicate that *T. germaini* and *T. margarita* are not separate species. In fact, these authors suggest that all five species of silvered langurs may be one species. This argument is based partly on a lack of support for the five species concept from Y chromosome markers and partly on a disagreement over which species concept is the most viable.

This thesis accepts the splitting of *T. germaini* and *T. margarita* into separate species, though the accuracy of this designation has no direct bearing on the results of this study.

T. germaini, like *T. cristatus*, is diurnal and arboreal. These species are classed as active arboreal quadrupeds; displaying mainly arboreal quadrupedal locomotion with some pronograde walking, running, climbing, and leaping, and done with substantial agility and speed. Body mass data for *T. germaini* are not available, but measures of *T. cristatus* indicate mean body masses of 5.7 kilograms for females and 6.6 kilograms for males, making them less sexually dimorphic than some other colobines (though more so than *Presbytis*) (Harding, 2010). Personal observations of both *T. cristatus* and *T. germaini* in zoos by the author indicate that *T. germaini* may be slightly smaller than *T. cristatus*. *T. germaini* has a longer tail than *T. cristatus* and is grey, with darker hair on the body than on the limbs (Harding, 2010; Timmins et al., 2013). Like all *Trachypithecus* species, *T. germaini* gives birth to orange neonates with white skin on the hands, feet, and face. The skin color darkens to black within days of birth and the coat color reaches adult form within three to five months (Harding, 2010).

In Cambodia Moody et al. (2011) note that *T. germaini* is most often found in lowland habitats of evergreen, semi-evergreen, mixed deciduous or riparian environments. They also occur in seasonally flooded forest, but not in true mangrove communities. In Cambodia, they are often in riverine and coastal forests and have not been recorded above 450 meters in altitude. In Lao PDR, *T. germaini* is known mostly in semi-evergreen forest with uneven canopy. Possible sightings have been recorded up to 550 meters in altitude and most sightings are within half a kilometer from water (Timmins et al., 2013). Much less is known about *T. germaini* in Vietnam, though populations occur on the limestone hills of the Kien Luong Karst Area (Covert and Hoang Minh Duc, 2013).

Transects

Number and Type

Eleven line transects ranging from slightly less than one kilometer to just over three kilometers were walked over fourteen field days. Nineteen total transects were scouted, but eight were discarded due to inadequate length. Each transect was walked two to three times. During each field day there were two or three groups conducting census work. Five transects were established on trails or roads, six went directly through dense jungle with minimal cutting of trails (Tables 2, 3, and 4 include specifics of each transect).

Transects surveyed many different types of habitat. Both dense and thin forests were surveyed, with high and low canopies. We also surveyed areas near human disturbance and noise pollution, as well as areas far from such disturbances.

Table 2: Number of times each transect was walked, transect habitat, whether there were sightings on the transect, and the dates each transect was walked by designation.

Transect Designation	Number of Times Transect was Walked	Habitat	Sightings on Transect	Dates Walked
T0	3	Dense jungle	Yes	July 15, July 16, July 17
T1	3	Dense jungle	No	July 15, July 16, July 17
T4	3	Road through dense jungle	No	July 15, July 16, July 17
T9	3	Established trail through thinner jungle	No	July 18, July 19, July 20
T8	2	Dense jungle	No	July 19, July 20
T10	3	Thinner jungle, lower canopy, dirt road	No	July 24, July 25, July 26
T11	2	Dense primary forest	Yes	July 24, July 25
T13	2	Medium thickness jungle, lots of understory, poorly cleared trail	No	July 27, July 28
T14	3	Dense primary forest	Yes	July 27, July 28, July 29
T17	3	Gravel road through dense primary forest	No	July 29, August 1, August 2
T18	2	Dense primary forest	No	August 1, August 2

Table 3: GPS starting and ending coordinates for each transect by designation.

Transect Designation	GPS Start Coordinates	GPS End Coordinates
T0	N10° 26.355' E103° 58.373'	N10° 27.098' E103° 59.767'
T1	N10° 25.931' E103° 58.709'	N10° 25.860' E103° 59.179'
T4	N10° 25.715' E103° 59.920'	N10° 25.816' E104° 00.172'
T9	N10° 23.576' E104° 00.935'	N10° 24.246' E104° 01.755'
T8	N10° 24.369' E103° 58.197'	N10° 22.763' E103° 58.203'
T10	N10° 21.848' E103° 59.482'	N10° 23.198' E103° 58.714'
T11	N10° 20.190' E103° 58.602'	N10° 21.348' E103° 59.587'
T13	N10° 21.734' E103° 51.923'	N10° 21.349' E103° 51.071'
T14	N10° 34.728' E104° 05.987	N10° 22.432' E104° 03.236'
T17	N10° 19.826' E103° 59.852'	N10° 19.746' E104° 01.494'
T18	N10° 22.058' E103° 59.736'	N10° 23.301' E104° 00.738'

Table 4: Straight length of transect (from starting to ending point) and walking length of transect (actual distance walked) by designation.

Transect Designation	Straight Length of Transect (in kilometers)	Walking Length of Transect (in kilometers)
T0	2.88	3.14
T1	0.90355	0.99182
T4	3.09	3.43
T9	1.93	2.01
T8	2.96	3.19
T10	2.94	3.08
T11	2.82	2.98
T13	1.71	2.09
T14	3.04	3.20
T17	3.01	3.43
T18	2.95	2.99

Location

An attempt was made to gain good coverage of all sections of the national park (Figure 4). However, this was somewhat hindered by practical restraints. Many areas were too treacherous to survey during the rainy season. In addition, foreigners were not allowed to visit some areas. Access to these areas was available to our Vietnamese colleagues, and we did gain permission to walk a road through one such location ourselves.

Transects locations were based on ranger suggestions. After communicating what we wanted—three kilometer long straight transects—the rangers suggested places where this might be possible. Transect locations were not chosen with regard to silvered langur sightings and habitat. We did not go solely to areas where silvered langurs were known to be, or areas with "good" langur habitat. All habitats were sampled, but we cannot assume they were sampled in the same proportion to their actual proportion within the national park.

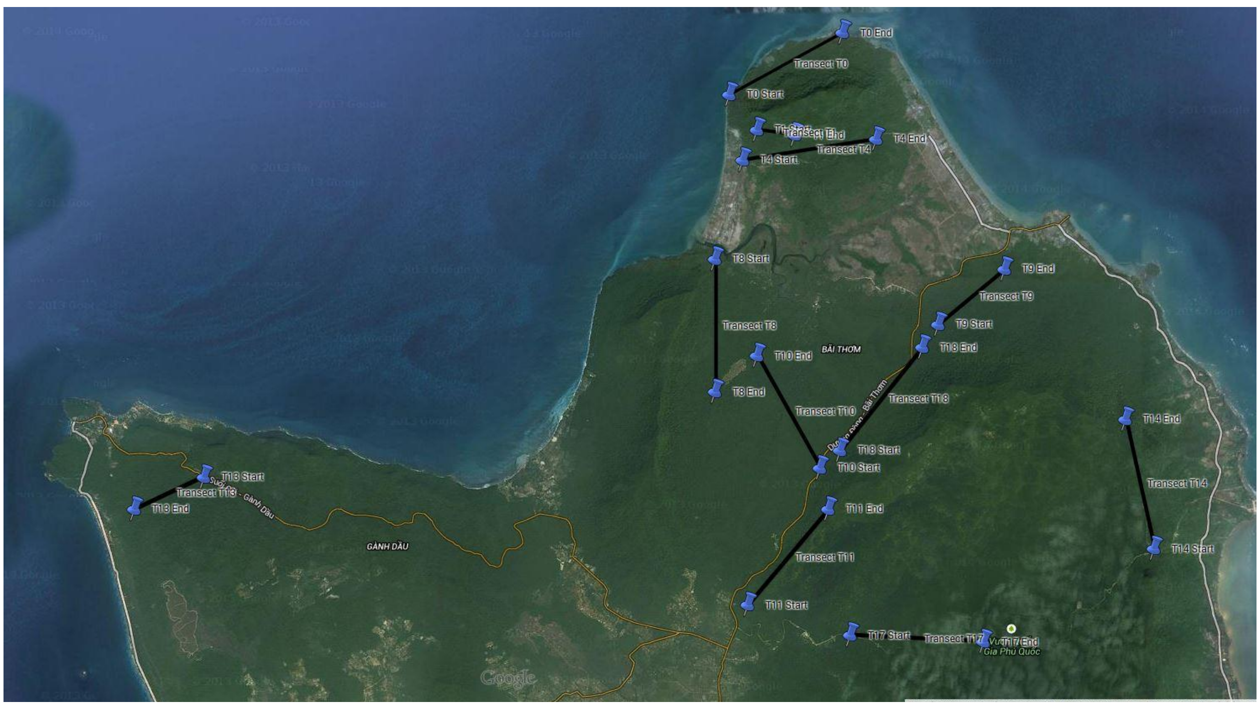

Figure 4: Map of transects, northern end of Phu Quoc Island. Note that transects on this and all figures are pictured as straight, while in reality they all deviated slightly from straight.

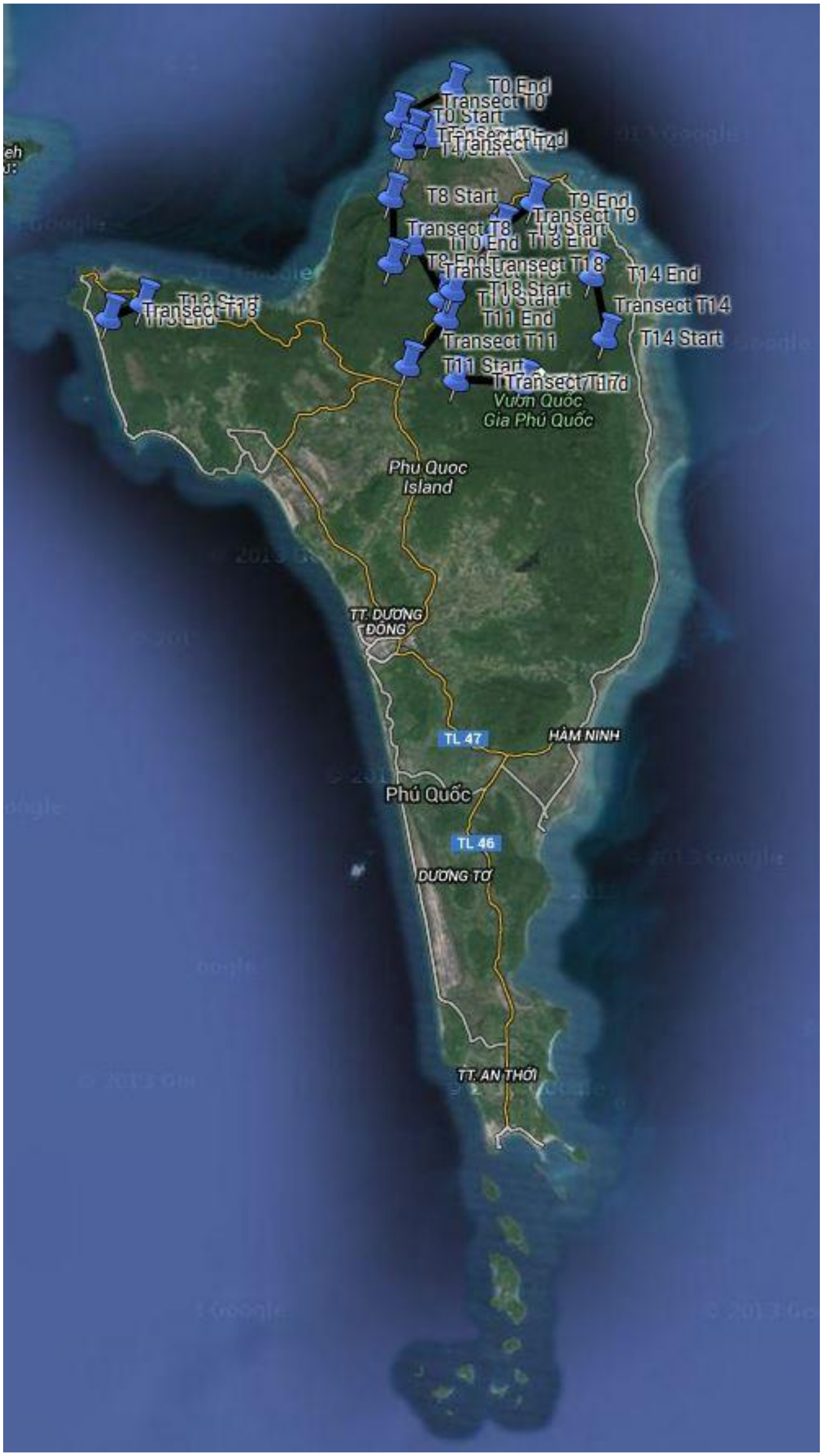

Figure 5: View of whole island with transects in northern section.

Specifics of Walked Transects

Transects were walked in groups of three to five people, which always included at least one forest ranger. Each team was supplied with a laser rangefinder, GPS, and compass for measuring the distance of the monkey and its angle to the transect. In this way, perpendicular transect to animal distances could be calculated and used in data analysis.

Transects were walked in the morning (one or two walks occurred in the early afternoon). Every effort was made to keep a steady walking pace of 1-2 km per hour. This was not always possible and speeds often reached 3 km per hour. Continuous scanning for animals was done by all team members; excepting where care was needed to pass the terrain and we had to focus on our footing. Visual scanning for movement and actual animals was done, as was listening for breaking branches or animal calls. Team members were also told to be aware of animal smells and possible sightings of feces or partially eaten leaves or other food items.

Noise while walking transects was restricted to normal walking noises and quiet speaking voices. Animals were not pursued when seen, though minor attempts to flush animals were made when it could not be determined what animal we were hearing. Disturbance to wildlife was minimal and animals were never pursued if they fled after being seen.

Each time an animal was sighted its distance from the observer and angle to the transect were recorded. The number of animals in the group was also recorded along with the approximate life stages of each animal (adult, juvenile, infant) where possible. Photographs were also attempted whenever animals were seen, though this was difficult due to the density of the jungle.

Statistical Analysis of Data

GPS start and end coordinates of transects, GPS coordinates of sightings of animals, straight length of transects, and walking lengths of transects were all obtained in Garmin Basecamp. Visualization of transects and sightings were done in Google Maps. Tables were created using Microsoft Excel.

All calculations of density of animals, number of animals, areas surveyed, and encounter rates were done by hand.

An estimate for number of animals in Phu Quoc National Park was made. At the outset of the project, we hoped to use the program DISTANCE to estimate this number, as is the common practice when conducting a line transect survey. However, DISTANCE requires a minimum of twenty independent sightings to give an estimate; forty to sixty gives a robust estimate. We did not obtain that many sightings; the project would need to run much longer in order to use DISTANCE (or be conducted in the dry season when it is reported that the animals are easier to see and the terrain is easier to cross).

Since DISTANCE could not be used, data analysis was conducted in a manner that attempted to stay true to the theory behind line transects. That is; line transects survey a subset of the total habitat and the number of animals in that subset may be used to proportionally estimate the number of animals in the entire habitat. Therefore, a rough estimate of area surveyed and population size was done by hand. Each transect was turned into a rectangle with length of the transect and width of how far out animals could be spotted, mimicking as closely as possible the detection function used by DISTANCE to calculate the area surveyed by line transects. The areas of these rectangles were then added to obtain an estimate of area surveyed. Number of animals seen was used to calculate density of animals in the area studied. A proportion was used to estimate total number of animals in the national park. This methodology aligned most closely with what DISTANCE does and how line transect data is generally analyzed.

Sightings on Transects

Five sightings occurred on transects during the survey period. Table 5 shows the specifics of each sighting.

Table 5: Date of sighting, GPS coordinate of sighting, transect the sighting occurred on, observer to animal distance of sighting, angle to transect of sighting, perpendicular distance of sighting, and number of animals seen for each sighting by number.

Sighting Number	Date of Sighting	GPS Coordinate of Sighting	Transect Sighting Occurred On	Observer to Animal Distance (in meters)	Angle to Transect (in degrees)	Perpendicular Distance (in meters)	Number of Animals Seen
1	15-Jul-14	N10° 27.040' E103° 59.632'	T0	25.6	6°	2.7	1
2	16-Jul-14	N10° 27.046' E103° 59.655'	T0	23.4	24°	9.5	1
3	25-Jul-14	N10° 21.107' E103° 59.419'	T11	20	100°	19.7	3-5
4	27-Jul-14	N10° 22.078' E104° 03.368'	T14	12.6	37°	7.6	8-9
5	27-Jul-14	N10° 21.971' E104° 03.385'	T14	10.6	42°	7.1	2

As each sighting occurred, the distance from the observer to the animal (first animal seen) was measured using a laser rangefinder. The angle from the transect to the animal was also measured. Counts were made by all observers of the number of animals in the group. Where counts differed, the difference has been preserved as a possible range of animals seen. Observer to animal distance and angle to transect were then used to calculate perpendicular distance from the transect to the animal using right triangles and trigonomic functions, as shown in Figure 6.

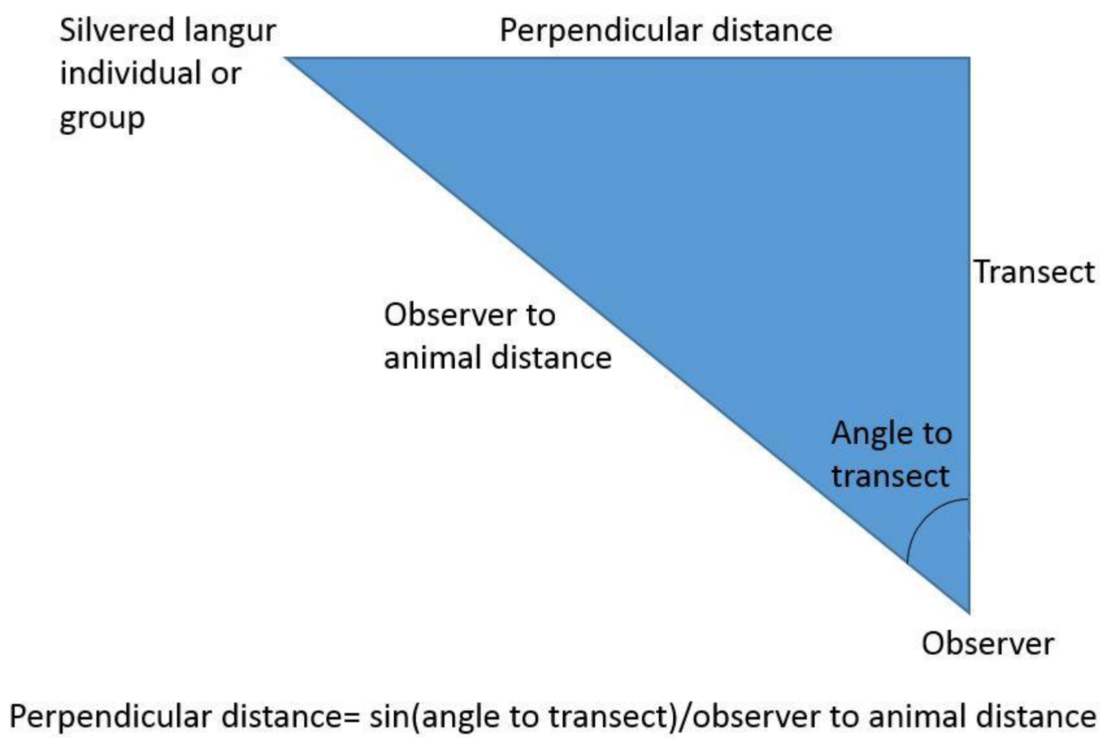

Figure 6: Method for calculating the perpendicular distance of the animal to the transect.

Since the sine function of an angle is equal to the opposite side divided by the hypotenuse, this procedure allowed calculation of the perpendicular distance of each sighting fairly easily.

The GPS locations of sightings and transect of occurrence are noted in Table 4. Figures 7, 8, 9, and 10 show the sightings on maps.

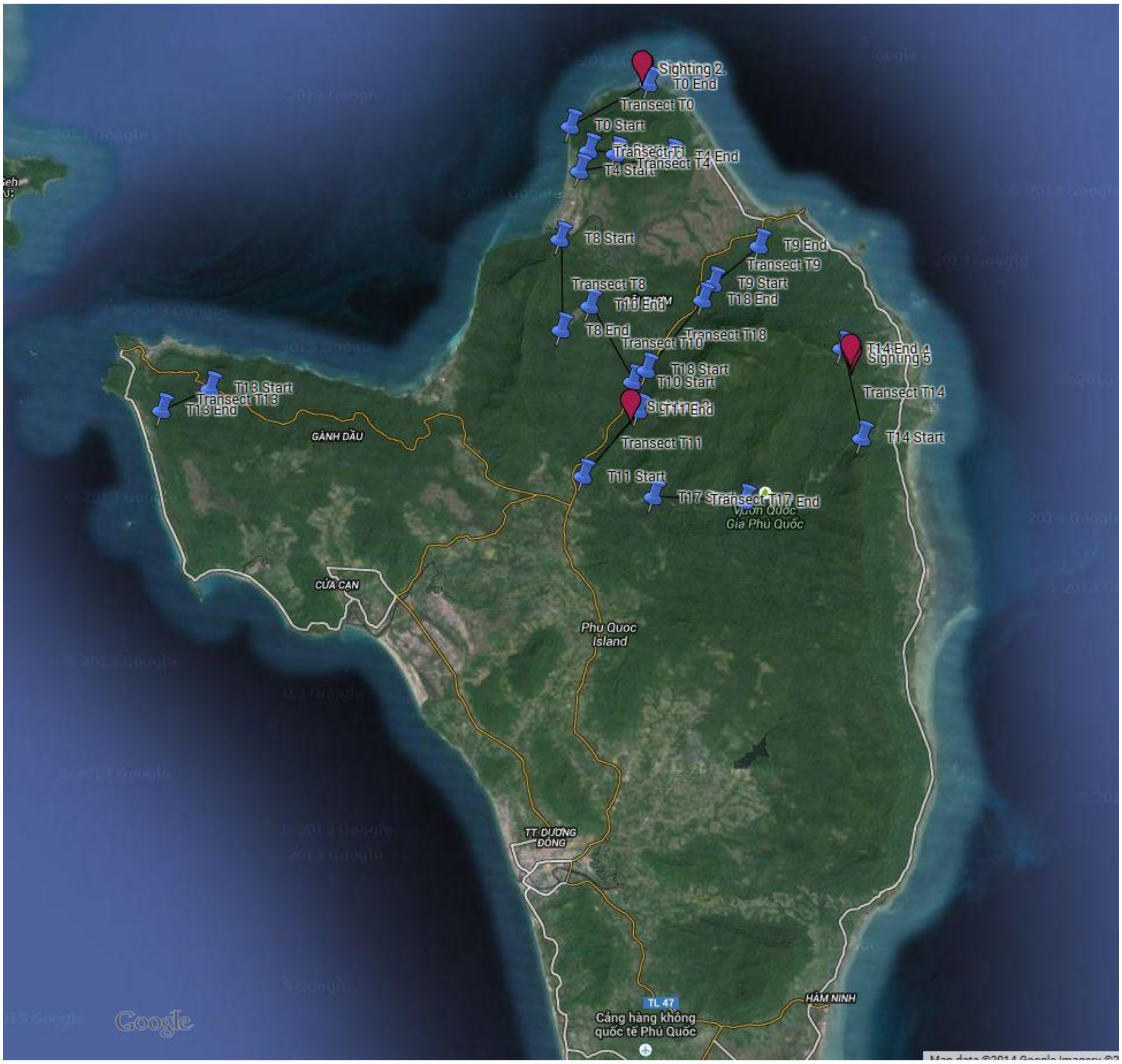

Figure 7: Locations of sightings pictured as red markers.

Figure 8: Transect T0 with two sightings shown as red markers.

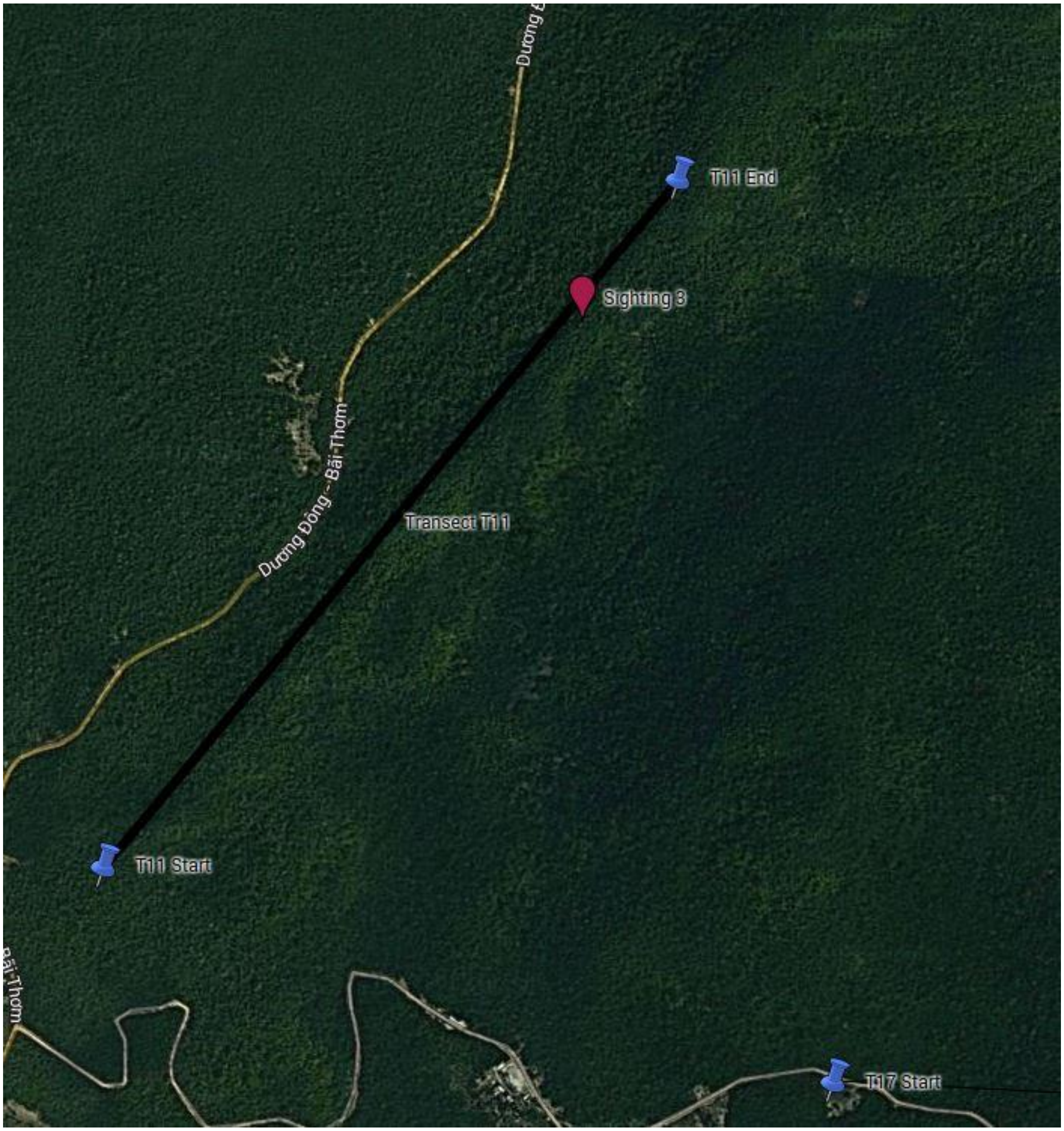

Figure 9: Transect T11 with one sighting shown as a red marker.

Figure 10: Transect T14 with two sightings shown as red markers.

The two sightings on transect T0 are close together and likely represent the same group of animals. On both days that this group was sighted, only one animal could be seen. Though movement suggested more animals, a good estimate of number could not be made.

The two sightings on transect T14 occurred on the same day. Though close together, the researchers present at the time do not believe they were the same group of animals. Sighting 4 represents a much larger group that did not flee along the transect.

Sightings Off Transects

Two additional sightings occurred off transects. These occurred as researchers were headed to transect T8. See Table 6 for the specifics of these sightings.

Table 6: Date sighting occurred, nearest transect, number of animals, and additional information for sightings off transects.

Sighting	Date Sighting Occurred On	Transect Nearest to Sighting	Number of Animals Seen	Additional Information
6	19-Jul-14	T8	7-8	Possibly the same group as sighting 7
7	20-Jul-14	T8	7-8	Seen from a boat

Since these sightings were not technically in the researched area, they were not included in the following data analysis. However, it is interesting to note that there may be a group of 7-8 individuals (including one infant that was directly observed) in the vicinity of transect T8.

RESULTS

Encounter Rate

Encounter rate of animals (silvered langurs) encountered per kilometers walked was calculated for each transect and overall using both the straight length of the transect and the walking length of the transect. These numbers do not differ greatly, but they do lead to small differences in the calculated encounter rate. To calculate encounter rate by transect, distance (straight and walking) of the transect was multiplied by the number of times the transect was walked to get total distance walked along the transect. Total number of animals seen on the transect was then divided by the distance walked along the transect. An average encounter rate for all eleven transects was calculated. Overall encounter rate was calculated using the total number of animals seen on transects divided by the total distance walked along all transects. Tables 7 and 8 show encounter rate information using walking length of the transect, while Tables 9 and 10 show the same information using the straight length of the transect.

Table 7: Encounter rate information using walking length of transect.

Transect	Walking Distance (in kilometers)	Number of Times Walked	Total Distance Walked on Transect (in kilometers)	Total Number of Animals Seen on Transect	Average Number of Animals Per Transect Walk	Encounter Rate in Animals Encountered Per Kilometers Walked
T0	3.14	3	9.42	2	0.67	0.21
T1	0.99182	3	2.98	0	0	0
T4	3.43	3	10.29	0	0	0
T9	2.01	3	6.03	0	0	0
T8	3.19	2	6.38	0	0	0
T10	3.08	3	9.24	0	0	0
T11	2.98	2	5.96	3-5	1.5-2.5	0.50-0.84
T13	2.09	2	4.18	0	0	0
T14	3.20	3	9.6	10-11	3.33-3.67	1.04-1.15
T17	3.43	3	10.29	0	0	0
T18	2.99	2	5.98	0	0	0

Table 8: Average encounter rate across transects and overall encounter rate using walking length of transect.

Average Encounter Rate Across Transects	0.58-0.73
Total Distance Walked Along Transects	80.25 km
Total Animals Seen	15-18
Overall Encounter Rate in Animals Encountered Per Kilometers Walked	0.187-0.224

Table 9: Encounter rate information using straight length of transect.

Transect	Straight Length of Transect (in kilometers)	Number of Times Walked	Total Distance Walked on Transect (in kilometers)	Total Number of Animals Seen on Transect	Average Number of Animals Per Transect Walk	Encounter Rate in Animals Encountered Per Kilometers Walked
T0	2.88	3	8.64	2	0.67	0.23
T1	0.90355	3	2.71	0	0	0
T4	3.09	3	9.27	0	0	0
T9	1.93	3	5.79	0	0	0
T8	2.96	2	5.92	0	0	0
T10	2.94	3	8.82	0	0	0
T11	2.82	2	5.64	3-5	1.5-2.5	0.53-0.89
T13	1.71	2	3.42	0	0	0
T14	3.04	3	9.12	10-11	3.33-3.67	1.10-1.21
T17	3.01	3	9.03	0	0	0
T18	2.95	2	5.90	0	0	0

Table 10: Average encounter rate across transects and overall encounter rate using straight length of transect.

Average Encounter Rate Across Transects	0.62-0.78
Total Distance Walked Along Transects	74.26
Total Animals Seen	15-18
Overall Encounter Rate in Animals Encountered Per Kilometers Walked	0.202-0.242

Using straight length of the transect leads to a slightly higher encounter rate than using walking length. Straight length is the more accurate measure if animals could still be seen from the straight line drawn. In cases where we had to deviate around obstacles, it is possible we went so far off the transect we might have brought animals into view that would not have been in view had the transect been straight. Therefore, both measures are provided here. The actual encounter rate likely lies somewhere in the middle of these two calculations.

Estimating Number of Animals in the National Park

In order to make an estimate of total animals in the national park without the program DISTANCE, each transect was turned into a rectangle. Each rectangle formed from a transect was given the length of the straight length of the transect. Walking length was not used as it would stretch out the transects into larger rectangles than were actually surveyed. To calculate width the observer to animal distances were used. I believe this was more accurate than using perpendicular distance for the purpose of this analysis. The width of the rectangle needed to be the width within which animals could be seen. An animal seen 25.6 meters away at an angle to the transect could still be seen 25.6 meters away if it was perpendicular to the transect. Making the width of the transect the area in which animals could be seen was done to mimic as closely as possible the detection function used by DISTANCE to calculate the width surveyed by each transect.

Average observer to animal distance was doubled to find the width of each transect with sightings on it. Transect T0 had a width of 49 meters, T11 had a width of 40 meters, and T14 had a width of 23.2 meters. The average of these three widths (37.4 meters) was assigned as the width for all transects with no sightings. The area of the rectangle (the areas surveyed by each transect) was found by multiplying the straight length by the effective width found above (Table 11).

Table 11: Calculation of area surveyed by each transect.

Transect	Straight Length of Transect (in kilometers)	Average Observer to Animal Distance of Sightings (in meters)	Effective Width of Transect (in meters)	Area Surveyed by Transect (in km²)
T0	2.88	24.5	49	0.141
T11	2.82	20	40	0.113
T14	3.04	11.6	23.2	0.071
T1	0.90355	0	37.4	0.034
T4	3.09	0	37.4	0.116
T8	2.96	0	37.4	0.111
T9	1.93	0	37.4	0.072
T10	2.94	0	37.4	0.110
T13	1.71	0	37.4	0.064
T17	3.01	0	37.4	0.113
T18	2.95	0	37.4	0.110

The areas surveyed by each transect were added to determine the total area surveyed. Total number of animals seen (a range) was divided by the total area surveyed to find density of animals in the area surveyed. To find an estimate of total number of animals in the national park two proportions were done. The first used the total area of the national park (314.42 km^2) as follows.

$$\frac{Total\ Animals\ Seen}{Total\ Area\ Surveyed} = \frac{Number\ of\ Animals\ in\ National\ Park}{Total\ Area\ of\ National\ Park}$$

The same proportion was done again using the total area of strictly protected zone instead of total area of national park (Table 12).

Table 12: Density of animals in area surveyed and projections for total number of animals in national park based on total area of park and total area of strictly protected zone.

Total Area Surveyed	1.055 km²
Total Area of National Park	314.42 km²
Total Animals Seen	15-18
Density for Area Surveyed in Animals per Square Kilometer	14.22-17.06
Projected Number of Total Animals in National Park	4,471.05-5,364.01
Total Area of Strictly Protected Zone	87.86 km²
Projected Number of Total Animals in Strictly Protected Zone	1,249.37-1,498.89

The estimate for total animals in the strictly protected zone—1,249.37 to 1,498.89—is likely the much more realistic projection. Silvered langurs are shy animals that are almost never spotted near roads or settlements. All sightings during this study were in dense jungle with minimal human disturbance and no permanent occupation. The strictly protected zone of the national park is likely the only area that is inhabited by silvered langurs.

Other Estimates of Total Population Size

Using Above Method with Different Transect Widths

The procedure described above can be performed in two other ways to give different estimates of total population size. The width of all transects can be assigned as twice the maximum observer to animals distance (25.6 meters, making the width of all transects 51.2 meters); the calculations for this estimate are shown in tables13 and 14. Similarly, the width of all transects can be assigned as twice the minimum observer to animal distance (10.6 meters, making the width of all transects 21.2 meters), which is shown in tables 15 and 16.

Table 13: Area surveyed by each transect using twice the maximum observer to animal distance as the width of all transects.

Transect	Straight Length of Transect	Effective Width of Transect	Area Surveyed by Transect
T0	2.88 km	51.2 m	0.147 km²
T11	2.82 km	51.2 m	0.144 km²
T14	3.04 km	51.2 m	0.156 km²
T1	903.55 m	51.2 m	0.046 km²
T4	3.09 km	51.2 m	0.158 km²
T8	2.96 km	51.2 m	0.152 km²
T9	1.93 km	51.2 m	0.099 km²
T10	2.94 km	51.2 m	0.151 km²
T13	1.71 km	51.2 m	0.088 km²
T17	3.01 km	51.2 m	0.154 km²
T18	2.95 km	51.2 m	0.151 km²

Table 14: Calculation of total number of animals in the national park and in the strictly protected zone using twice the maximum observer to animal distance as the width of all transects.

Total Area Surveyed	1.446 km²
Total Area of National Park	314.42 km²
Total Animals Seen	15-18
Density for Area Surveyed in Animals per Square Kilometer	10.37-12.45
Projected Number of Total Animals in National Park	3,261.62-3,913.94
Total Area of Strictly Protected Zone	87.86 km²
Projected Number of Total Animals in Strictly Protected Zone	911.41-1,093.69

Table 15: Area surveyed by each transect using twice the minimum observer to animal distance as the width of all transects.

Transect	Straight Length of Transect	Effective Width of Transect	Area Surveyed by Transect
T0	2.88 km	21.2 m	0.061 km²
T11	2.82 km	21.2 m	0.060 km²
T14	3.04 km	21.2 m	0.064 km²
T1	903.55 m	21.2 m	0.019 km²
T4	3.09 km	21.2 m	0.066 km²
T8	2.96 km	21.2 m	0.063 km²
T9	1.93 km	21.2 m	0.041 km²
T10	2.94 km	21.2 m	0.062 km²
T13	1.71 km	21.2 m	0.036 km²
T17	3.01 km	21.2 m	0.064 km²
T18	2.95 km	21.2 m	0.063 km²

Table 16: Calculation of total number of animals in the national park and in the strictly protected zone using twice the minimum observer to animal distance as the width of all transects.

Total Area Surveyed	0.599 km²
Total Area of National Park	314.42 km²
Total Animals Seen	15-18
Density for Area Surveyed in Animals per Square Kilometer	25.04-30.05
Projected Number of Total Animals in National Park	7,873.62-9,448.35
Total Area of Strictly Protected Zone	87.86 km²
Projected Number of Total Animals in Strictly Protected Zone	2,200.17-2,640.20

Using twice the maximum observer to animal distance as the width of all transects gives a lower estimate for number of animals in the strictly protected zone (911.41 to 1,093.69). This is a more conservative estimate of animal numbers in the national park because it assumes that on most transects there were no animals further out than the ones that were spotted. This more conservative estimate is a good place to start when planning conservation strategies. Assuming numbers are lower than the first estimate will help ensure good conservation practices.

Using twice the minimum observer to animal distance for all transects gives a much higher estimate of animals in the strictly protected zone (2,200.17 to 2,640.20). This is probably a vast overestimate, as it assumes that all animals were in a very small area. In reality, we surveyed a larger area than this estimate suggests. This estimate should not be used when planning conservation practices as it assumes there were more animals in a smaller area than there actually were and could lead to conservation strategies that are too moderate or slow.

Using the Method from Richardson (2007) as an Alternative

An estimate of total animals in the national park can also be made using the procedure described by Richardson (2007) for analyzing line transect data by hand. This procedure is useful as it follows common line transect analysis methods but can be done when there is a limited amount of data.

This method is based around the following equation:

$$density\ estimate = \frac{n + u}{2wL}$$

In this equation n is the number of animals seen, u is the number of unseen animals (the number that should have been seen), w is the maximum distance away animals were seen, and L is the length that was walked along transects.

The major benefit of using this equation to analyze line transect data is that it approximates the detection function. A similar equation to the one above is often used for line transect data and is described by Krebs (2014). However, this method uses a constant—*a*—that is the area under the detection function. The constant *a* is found using either the HAYNE estimator (using the computer program HAYNE) or the Fourier Series Estimator (using the computer program TRANSECT). HAYNE and TRANSECT are forerunners of DISTANCE and require a similar number of sightings to function, precluding their use in this analysis. However, by calculating number of animals that may have been missed the Richardson equation approximates the detection function using simple histograms, which can be done even when there are very few data points to work with, as is the case here.

The Richardson (2007) method uses the perpendicular distance of animals from the transect. These perpendicular distances can be plotted in a histogram of number of animals by distance from the transect. This histogram must be plotted in such a way so the first bin on the histogram has the most animals in it (if the first bin does not have the most animals, it violates the assumption that detection drops off as animals are further from the transect). Here, this was accomplished by widening bins to 10 meter divisions from the transect. A second histogram can then be made showing the theoretical distribution of animals. It is assumed that there are not actually fewer animals further from the transect, but that detection drops off due to observer bias. This second theoretical histogram reveals *u*, the number of unseen animals that are implied to be present.

For the purposes of this analysis, two sets of histograms were created; one using the low estimate of animals seen (15) and one using the high estimate of animals seen (18). An actual and theoretical histogram for each was created so the Richardson equation could be done twice. Bins 10 meters wide were used, so all animals seen on transects between 0 and 10 meters away (perpendicular distance from transect) were grouped into one bin, and all animals seen between 10 and 20 meters away (perpendicular distance from the transect) were grouped into another bin. Table 17 shows the results of this grouping for minimum estimates of animals.

Table 17: Frequency of animals by distance from transect for minimum animals seen.

Distance (m)	Frequency/Number of Animals Seen
10	12
20	3

Figures 11 and 12 show the actual and theoretical histograms for the minimum animals seen.

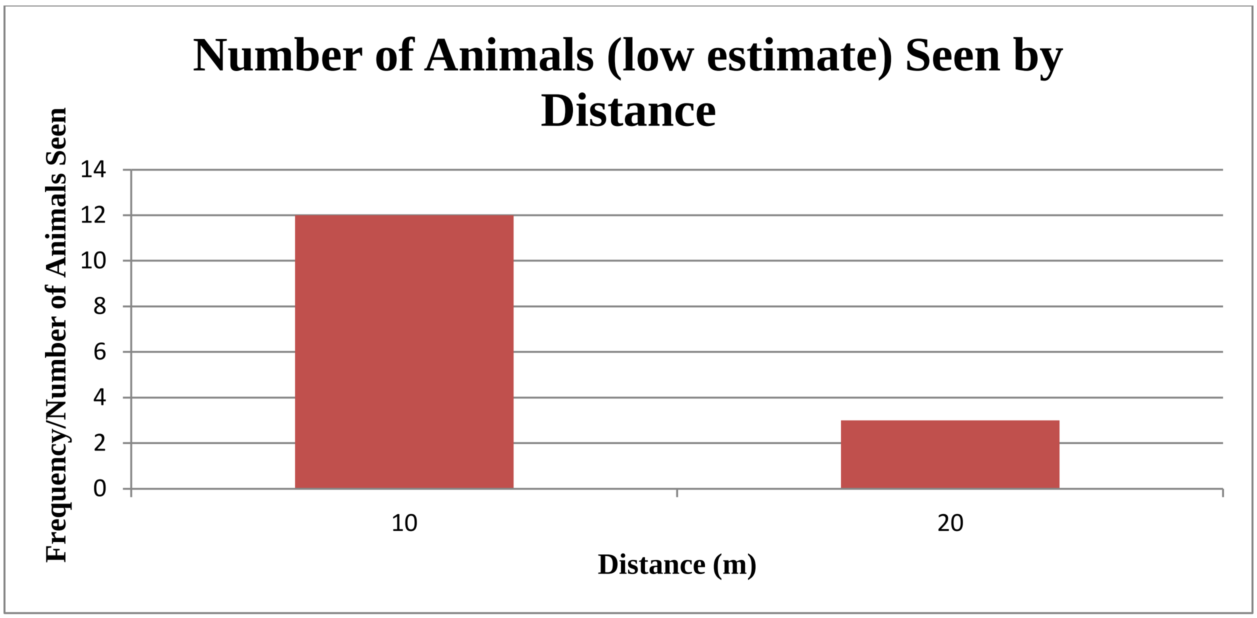

Figure 11: Histogram of number of animals seen by perpendicular distance from transect for the low estimate of animals seen.

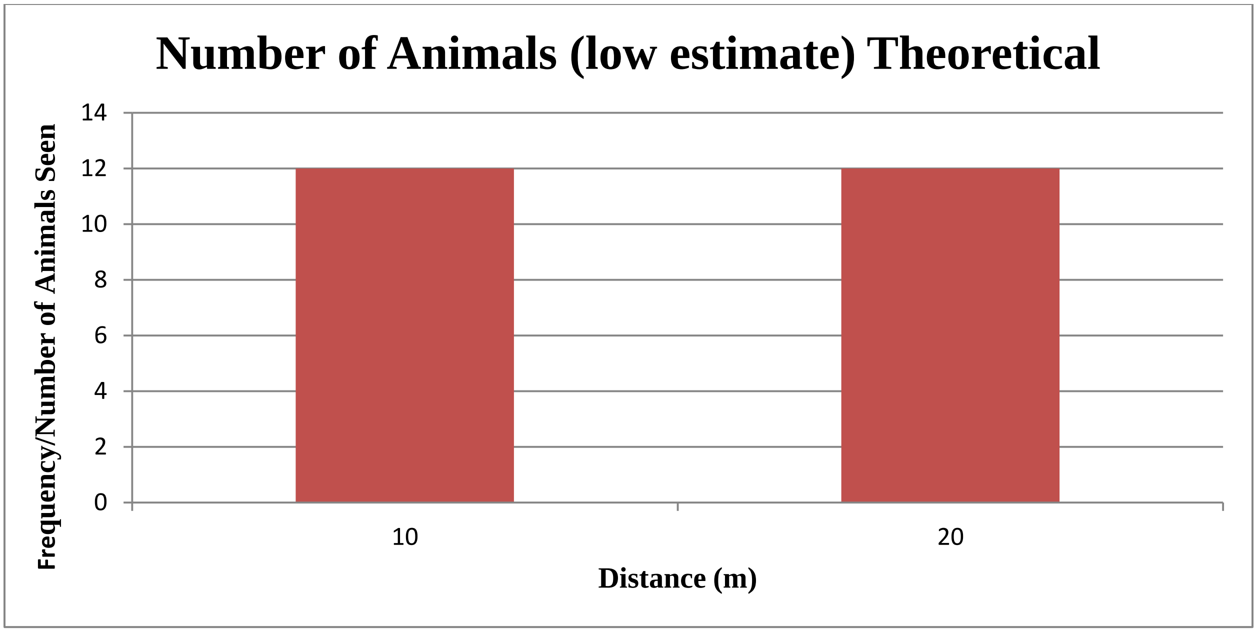

Figure12: Theoretical histogram of number of animals that should have been seen by perpendicular distance from the transect.

For minimum animals seen the theoretical histogram gives a *u* value of 9 (by counting all animals that should have been seen and subtracting number of animal that were seen from it). The value of *n* is animals actually seen (15), *w* is the maximum value of the last bin (20 meters or 0.02 kilometers, slightly above our actual furthest sighting), and *L* is the combined walking length of all 11 transects (74.26 kilometers). The results of the equation give a density estimate of 8.08 animals per square kilometer. By multiplying the density estimate by total area of the national park and the strictly protected zone, we reach an estimate of 2,450.51 animals in the national park and 709.91 animals in the strictly protected zone (Table 18).

Table 18: Density estimate and population estimate for national park and strictly protected zone using the minimum number of animals seen.

Density Estimate	8.08 animals/km²
Estimate of Total Animals in National Park	2,540.51
Estimate of Total Animals in Strictly Protected Zone	709.91

The same procedure can be done using the maximum possible animals seen (18). The grouping for this analysis is in Table 19 below.

Table 19: Frequency of animals by distance from transect for maximum animals seen.

Distance (m)	Frequency/Number of Animals Seen
10	13
20	5

Figures 13 and 14 show the actual and theoretical histograms for the maximum animals seen.

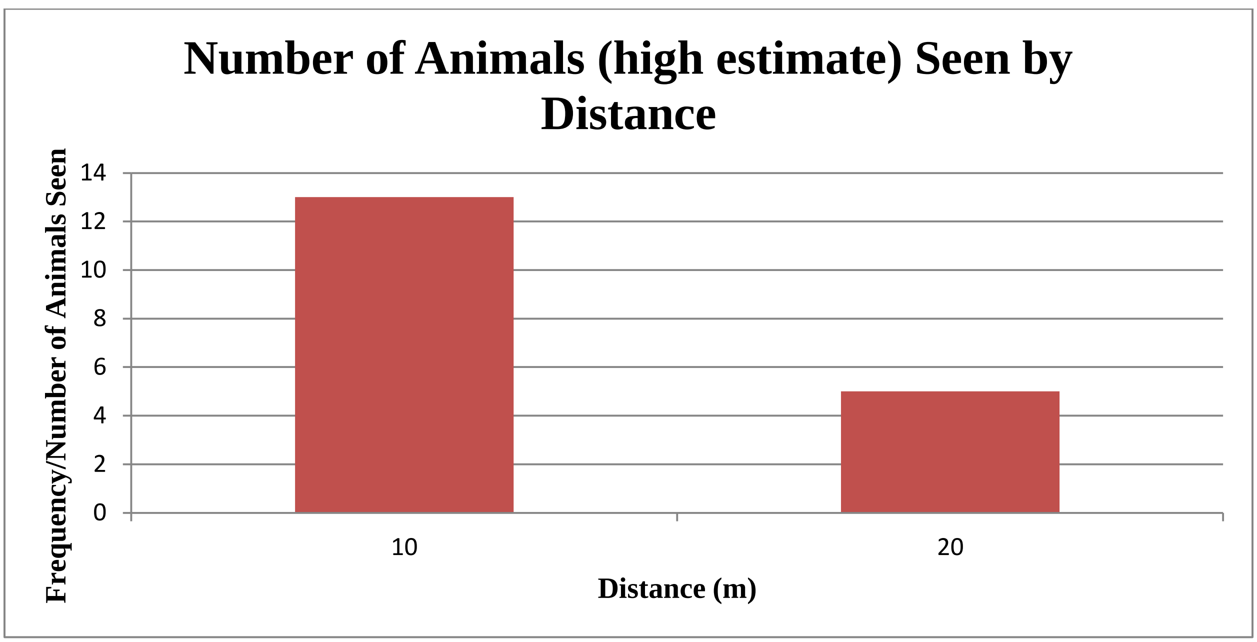

Figure 13: Histogram of number of animals seen by perpendicular distance from transect for the high estimate of animals seen.

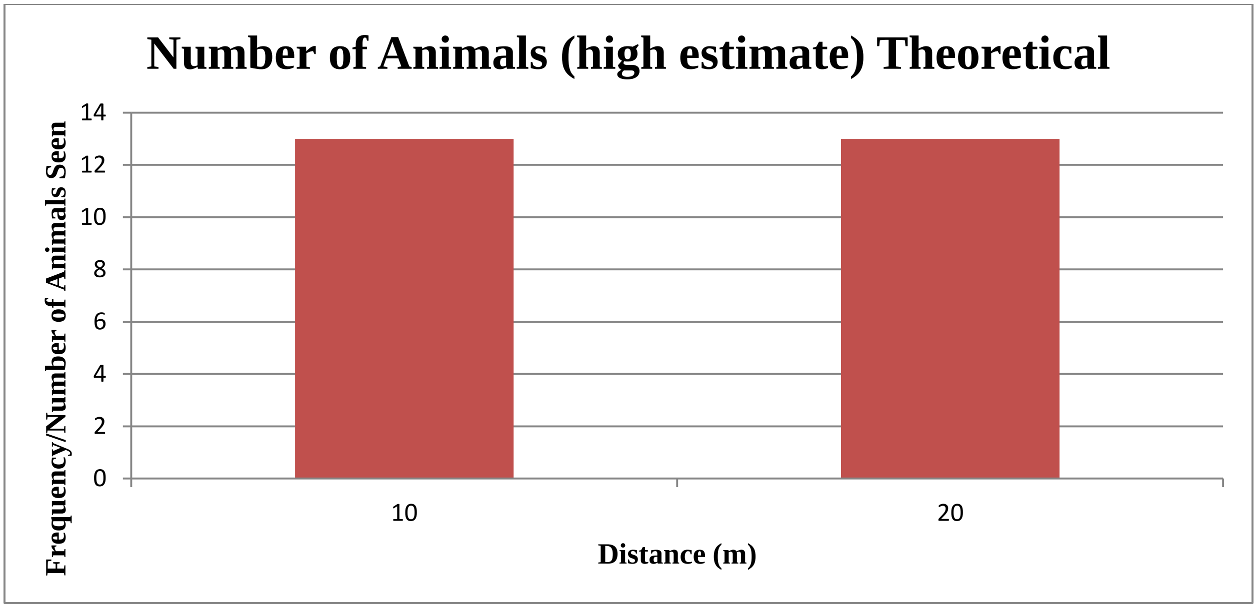

Figure 14: Theoretical histogram of number of animals that should have been seen by perpendicular distance from the transect.

For maximum animals seen the theoretical histogram gives a *u* value of 8. The value of *n* is animals actually seen (18), *w* is still the maximum value of the last bin (20 meters or 0.02 kilometers), and L is still the combined walking length of all 11 transects (74.26 kilometers). The results of the equation give a density estimate of 8.75 animals per square kilometer. By multiplying the density estimate by total area of the national park and the strictly protected zone, we reach an estimate of 2,751.18 animals in the national park and 768.78 animals in the strictly protected zone (Table 20).

Table 20: Density estimate and population estimate for national park and strictly protected zone using the maximum number of animals seen.

Density Estimate	8.75 animals/km^2
Estimate of Total Animals in National Park	2,751.18
Estimate of Total Animals in Strictly Protected Zone	768.78

The Richardson method gives an estimate of 709.91 to 768.78 animals in the strictly protected zone. This is lower than the previous estimate. This method gives a higher estimate for total area surveyed (2.97 km^2 rather than the 1.055 km^2 of the previous method) and therefore a lower density of animals. This is due to the assumption that all transects have a width equal to the maximum perpendicular distance of a sighting. This may be an overestimation of transect width, since some transects went through denser jungle than others and therefore likely did not have the same potential for sightings at 20 meters.

This is the lowest estimate of total number of animals in the strictly protected zone obtained from any method used. However, it is still a promisingly high estimate. The range of 709.91 to 768.78 animals in the strictly protected zone would be the largest population of silvered langurs in Vietnam and would be a population with the potential to be resilient to inbreeding effects; barring severe fragmentation.

DISCUSSION

The final estimate (using the original method) of 1249.37 to 1498.89 silvered langurs in Phu Quoc National Park is a rough estimate based on fourteen field days. Only the area of the strictly protected zone was used to obtain this estimate. Park ranger testimony and personal observations indicate that silvered langurs do not stray into areas with heavy human presence; thus, our choice to use only the area of the strictly protected zone is likely justified. Using the area of the entire national park would likely lead to a huge overestimation of animal numbers. Limitations of this estimate are discussed below.

Comparison of Estimate to Dry Season Data

Le Khac Quyet and Nguyen Vu Khoi (2010) directly counted twenty-two animals and estimated thirty-one to forty-four animals total during the dry season. This study recorded fewer total animals (fifteen to eighteen) but estimated a much higher total population. The dry season survey estimate was only for the area surveyed, not for the entire national park. A comparable number of field days were conducted—fourteen for this survey and fifteen for the dry season data—in both studies and a similar number of animals were seen. The higher number of animals seen in the dry season is likely due to two factors: 1) the visibility of animals during the dry season is higher, and 2) the dry season survey was conducted only in core areas of dense forest where silvered langurs are more common. This survey attempted to gain coverage of areas with some human disturbance where silvered langur numbers may be lower.

Due to these factors, the data across the dry and wet seasons are comparable and represent similar rough estimates for total population within the national park. More field days are needed to strengthen this population estimate.

The population estimate would also be greatly strengthened by a better understanding of silvered langur habitat preference. This study assumed that dense primary forest is the preferred habitat of silvered langurs. This is based on some formal data and a lot of informal observation by rangers and researchers. Studies in this and other areas on silvered langur habitat preference would help refine the population estimate. By combining habitat preference data with good GIS (geographic information system) data we could assess how much of the national park is actually preferred habitat, rather than assuming that the strictly protected area is preferred and the rest of the park is not. This assumption may not take into account all silvered langur habitat preferences.

For instance, presence of certain species of trees or plants may be more of a deciding factor in habitat preference than human disturbance.

Viability of Population

If any of the estimates given are accurate, this population should be resilient to inbreeding effects and disasters. However, the viability of this population cannot be safely asserted without more information. A great deal of fragmentation was observed, even in the core areas of the national park; roads, trails, homes, and rivers are all observed barriers to silvered langur habitat. A quantitative statement on level of habitat fragmentation is needed in order to discern how much habitat, food, and potential mates each group of silvered langurs has access to. With high levels of fragmentation, even a large population can experience inbreeding depression.

Effects of human disturbance on birth and death rates of silvered langurs are currently unknown. Poaching is known to exist at low levels in the national park. Tourism within Phu Quoc National Park is increasing rapidly and no study has been conducted on the effects of this increased disturbance on the fauna of the area. It is possible that disturbance, stress, and lower food availability will decrease breeding success and birth rates. A population viability analysis is recommended for this population when more demographic data are available. Birth and death rates are a major factor in the viability of any biological population (Boyce, 1992).

Translocation of Mainland Animals into Phu Quoc National Park

The translocation being considered—movement of silvered langurs from Kien Luong karst area to Phu Quoc, an already populated area—is classified as population restoration, and reinforcement specifically (IUCN/SSC, 2013). Reinforcement involves introducing new animals into an already populated area and intends to enhance the viability of the population. This can be achieved through enhanced genetic viability or simply increased population size (IUCN/SSC, 2013). This type of translocation should therefore only be done if there will be benefits to the current population, the introduced animals, and the ecological system of Phu Quoc.

All translocations come with risks that must be balanced against the potential benefits. Translocation is an involved and often expensive conservation action. It is a commitment to long-term conservation work in the area (frequent progress reviews and monitoring are needed) and should not be undertaken without extensive planning and analysis (IUCN/SSC, 2013). It is essential that a translocation has clearly defined goals for all invested parties. In this case, the benefits to the existing population of silvered langurs are unclear. If the population estimate provided in this report is accurate, additional animals may not be needed or even wanted. If the habitat is highly fragmented then additional animals could put a strain on animals in resource poor fragments. If fragments are resource rich, however, additional animals could help genetic variability and access to mates. Research on extent of habitat fragmentation and available resources within the fragments is needed.

Whenever a translocation is proposed, the needs of the translocated animal—biotic and abiotic—must be known and met in the new habitat (IUCN/SSC, 2013). Though the proposed translocation is into an area already occupied by the same species, this is not a guarantee of success. The langurs in Kien Luong may have different habits and dietary practices that will not easily transfer to Phu Quoc. The plant species composition on Phu Quoc might be quite different from Kien Luong, leading to stress if the animals are unable to find the food resources they usually rely on. Inter-species interactions are also a major unknown factor. There is a different composition of species on Phu Quoc that may cause unforeseen interaction issues. Research into silvered langur interactions with other species (such as macaques and squirrels) should be undertaken.

Part of the risk assessment for translocation involves studying the costs to the ecological community (IUCN/SSC, 2013). The risk here is not just to the translocated langurs or the langurs of Phu Quoc, it is to the entire floral and faunal community of Phu Quoc. Excess strain to the environment of the island, or to other native animal and plant species, is unacceptable.

Disease and parasite transfer is an issue that must be considered (IUCN/SSC, 2013). Animals from Kien Luong could have parasites unfamiliar to the Phu Quoc population or vice versa. Unfamiliar parasites could harm both populations and result in failure of the translocation or unacceptable harm to the existing population or environment. Additionally, new parasites could be harmful to other species living on Phu Quoc, such as the long tailed macaques. Pedersen et al. (2005) found that 68% of primate parasites could infect multiple species, even those from different families or orders. A clear picture of the parasite and pathogen load of both Kien Luong silvered langurs and Phu Quoc langurs is needed.

Another critical factor that must be taken into account is the effect of the proposed translocation on the human community of Phu Quoc, both socially and economically (IUCN/SSC, 2013). It is easy to imagine that the local community could benefit through increased tourism to view monkeys, as well as the presence of more scientists in the area spending money on lodging, food, and equipment. However, many people on Phu Quoc still use forest resources heavily. Potential competition for resources must be assessed. Silvered langurs do not generally participate in crop raiding or interfere with humans, but local human population concerns over this should be addressed. *Trachypithecus francoisi* has been known to eat crop plants (corn) in China, so concerns over crop raiding are not entirely misplaced (Gang Hu, 2011).

Communication is essential when trying to recruit the support and help of the local community. Conservation efforts can be improved by involving locals.

If risk assessment and modeling show that a translocation has a good chance of success, there will still be many more factors to be assessed before it is actually carried out. Planning is critical, and specific release sites, mode of capture and release, and permits to move animals will all be considerations in the future (IUCN/SSC, 2013).

Personal observation of habitat in Phu Quoc National Park indicates a large amount of unoccupied habitat. This very brief and ephemeral examination suggests a promising possibility of successful translocation. However, there are too many unknowns at this point to endorse, enthusiastically, a translocation project. It would be irresponsible to suggest such an extreme conservation measure without reservation; these are only the beginning of the unknown factors. A great deal more research on silvered langurs and the environment of Phu Quoc must be conducted before a translocation can enter the planning phase. Possibly the most pressing factors concern the amount of fragmentation in the habitat and the resource availability within each fragment—key components before moving forward with conservation on Phu Quoc.

Limitations of Estimate

This population estimate is limited by several factors—uncontrollable in the research design.

The habitat of the national park is not homogenous. Care was taken to sample different types of habitat (dense forest, human disturbed forest, forest along roads, coastal forest), but we cannot assume that all habitats were sampled in proportion to their actual percentage of the national park. Settlements and roads are common, even in the strictly protected area. At this time we do not know the relative proportions of different forest types within the national park. We also do not have much data on which forest types might be preferred by silvered langurs. Without behavioral and feeding ecology data, it is hard to predict which areas may be preferred.

It is very possible that the reported amounts of land in the strictly protected zone and other zones are not accurate. There are no surveys detailing the number of roads and settlements in the national park. Therefore, amount of actual forest cannot be stated with certainty.

There is also a land use issue. While surveying in the national park (on transect T13) we came across a vast area of cleared land. We were told that several hundred hectares of the national park had recently been leased to a development company. This development company was in the process of clearing the land to build a golf course and resort in the area. They also paved a new road to reach the area more easily. Figure 15 shows the area cleared for the golf course and Figure 16 shows the traffic on the new paved road. This land was technically still within the boundaries of the national park and is still reported as part of the park, despite its clear unsuitability as silvered langur habitat. The people living on the leased land were in the process of being relocated to other areas within the national park. Figures 17 and 18 show the area being cleared for the relocations. Without a thorough survey of the park, other cases of significant land clearing remain unknown. There may be many such areas that are reported as part of the national park (or even the strictly protected zone) that cannot be inhabited by silvered langurs. The land for towns and settlements is not suitable habitat, but is still included as part of the national park. These areas may be made much larger if people are gathering forest products on large scales or engaging in clearing or other noisy pursuits that may cause silvered langurs to avoid large areas.

Figure 15: Land cleared for a golf course. Photo by Robin Fiore.


Figure 16: Traffic along a newly paved road. Photo by Robin Fiore.


Figure 17: Land cleared to provide housing for people relocated from golf course. Photo by Robin Fiore.


Figure 18: Land cleared to provide housing for people relocated from the golf course. Photo by Robin Fiore.

At this time, it is not possible to quantify the amount of actual human disturbance in the national park. It is likely that there are unreported people living within the boundaries. These people are probably clearing land for farming and using forest products on an unknown scale. Despite having rules that prohibit development within protected areas, it is not uncommon in many areas of Vietnam for development and use of forest products to go forward in such areas. While walking transect T10, we came across several men who were cutting leaves off trees—to be used for wrapping rice. The ranger accompanying us made the men return to our starting point and wait while other rangers were called. While cutting these leaves is not usually allowed, these men had obtained prior permission from the park rangers and so were allowed to continue. We were unsure whether this permission was official or obtained through bribery.

Surveying is limited by the presence of a military area within Phu Quoc National Park. This military area is closed to all foreigners. Our Vietnamese colleagues were able to survey in this area, but only two transects were established (T11 and T14). It is unknown how much of the military area is dense undisturbed forest and how much is cleared for military activities and structures. Scientists do not have access to the exact size of this area. It is also unknown what goes on in this military area. It is part of the strictly protected zone, but large areas could be cleared for military structures and it could be permanently inhabited by a significant number of people, who are likely using forest products and disturbing the habitat. If there is weapons testing or target practice taking place within this area, there could be significant noise pollution, causing animals to avoid certain areas within the strictly protected zone.

Though our estimate is based only on the strictly protected area, it is possible that animals within the national park are outside this area. Without good GIS data and a survey of amount of fragmentation, land clearance, and disturbance in the national park, we can only assume that areas within the strictly protected zone are suitable habitat and areas outside of it are not. This is probably not the case; there are certainly areas within the strictly protected zone (like the military area) that are not suited for silvered langurs. Similarly, there is almost certainly dense undisturbed forest outside the strictly protected area that is inhabited by silvered langurs. It is also likely that there are silvered langurs outside of the national park. The southern end of the island around the new airport houses dense forest. Much of this forest is undisturbed and potentially home to silvered langurs. Surveys in this area are recommended. If silvered langurs do exist there, they should be protected from encroachment and development, or relocated to the already protected areas.

Lack of behavioral and feeding ecology data also limits our ability to estimate how much of the national is good langur habitat. Information on food preferences and sleeping tree preferences would help us understand if certain areas were habitable for silvered langurs. Without this data, we can only make a cursory and superficial assessment of whether we believe a habitat is suitable for silvered langurs.

The estimate is also limited by the methodology used to find it. The small number of sightings obtained means an accurate detection function is not possible to find. Without it, we are limited to rough estimates. The primary method used here estimates the number of animals in the total area by estimating the total area surveyed in this census. There are multiple ways to estimate total area surveyed, each yielding different results. However, even the lowest estimate of animals in the national park is a fairly high population. The Richardson method estimates the detection function by calculating number of animals that should have been seen. This method also gives a lower estimate than the primary method, though, just as before, it is a fairly high population size compared to other populations in Vietnam.

Continued Threats

Habitat fragmentation is a continuing and serious threat to the survival and viability of the population. The park is already fragmented by numerous roads, trails, settlements, and areas of land clearance. Development of existing towns and new resorts, such as the one mentioned above, threaten the quality of the habitat.

Tourism is encroaching more and more into the forest as tourist activities diversify into hiking and animal sightseeing pursuits. The Discover Phu Quoc website lists the national park as a main sightseeing destination and gives the names of numerous tour companies operating there, as well as available motorbike rentals. Large groups making considerable noise will further fragment and reduce habitat. Along with this sort of tourism will come parking lots, cleared trails, souvenir shops, and restaurants. The tourists themselves present a danger through noise pollution and littering.

The dangers of fragmentation and tourism can be mitigated with further research and survey. It is possible to develop tourism sustainably. Tourism to the mountain gorillas in Rwanda has brought money into the area and helped increase the mountain gorilla population (International Gorilla Conservation Programme, 2014). Development must be done cautiously. With careful surveys, areas not heavily used by silvered langurs can be developed, rather than destroying critical habitat. Vegetation surveys will ensure supplies of critical foods are not reduced. Fragmentation can be reduced by building only in certain areas and by using canopy bridges. Canopy bridges have been shown to help reduce fragmentation and stress and increase access to food and habitat for hoolock gibbons in Borajan Reserve, India (Das et al., 2009). Canopy bridges can also be placed strategically to allow tourist viewing of animals with minimal disturbance. The density of the forest would require tourists to approach quite near the animals to see them, which will cause disturbance and stress. Distance viewing on canopy bridges would be a better alternative.

Poaching has been a minor threat in Phu Quoc National Park. It is important that it remains minor. Sustainable development of surrounding settlements should help remove the pressure on forest products and food. Poaching has been punished quite severely in the past. Two poachers caught in 2013 were sentenced to up to two and a half years in prison (Education for Nature-Vietnam, 2014). Incarceration is one way of guaranteeing it does not continue at high levels.

As stated, genetic viability is a concern for this population. A population viability analysis would be extremely useful in identifying and reducing the risks this population is facing.

Natural disasters are a common concern for island populations everywhere. The estimated size of this population should make it resistant to disastrous events. It is doubtful that a single event will obliterate the whole population. This danger can be reduced by verifying silvered langurs are able to live in all of their historic habitats. Driving the whole population into one area or habitat would increase the risk that a natural disaster could decimate the population.

CONCLUSION

This research has focused on expanding our knowledge of the number and distribution of silvered langurs in Phu Quoc National Park. The final estimate (using the original method) of 1249.37 to 1498.89 animals in the strictly protected area was obtained over fourteen field days and eleven line transects. Though the total area surveyed is small compared to the area of the entire national park, this is the first survey done during the wet season and adds considerably to our knowledge of the situation on Phu Quoc.

Possible problems with this estimate have been presented. Despite these potential weaknesses, an estimate was obtained that is similar to the dry season data, adding to the likelihood that the estimate is close to the actual number of animals.

Continuing Research

This project is just beginning and more transects are currently being planned by the Southern Institute of Ecology in Vietnam. The intention of this research was to gain preliminary wet season data and assist in planning a larger scale survey; it has been successful. Good relations were established with the park rangers and administrative staff of Phu Quoc National Park. Partnerships between the University of Colorado Boulder, the Southern Institute of Ecology, and Phu Quoc National Park have been formed and will be maintained as further research is conducted in the area.

Additional research needed with this population has been discussed. It is of critical importance that a survey, larger in scope than either the dry season survey conducted by Le Khac Quyet and Nguyen Vu Khoi (2010) or the wet season survey discussed here be undertaken. The number and distribution of langurs throughout the national park should be estimated more precisely before any successful conservation plans can be initiated. Though our estimate for total animals seems high, we do not yet understand habitat fragmentation or the distribution of sub-populations.

Feeding ecology data is also essential for this population. Different langur species and even different populations can have vastly dissimilar diets. Data on dietary composition of this species is needed both for their conservation and for planning the proposed translocation. Some research has been done on the faunal composition of the area, but this should be expanded and compared to silvered langur dietary data in order to gain a better understanding of resource availability and distribution as it relates to silvered langur population numbers.

Resource availability and distribution should be compared to the level of competition for the same food resources taking place within the national park. Several species are likely competing with silvered langurs for the same food resources, including abundant long tailed macaques, several species of squirrels, and numerous bird species. Population sizes of these other animals should be estimated in order to better understand resource distribution.

Additional data needed for a possible translocation was discussed, including parasite and pathogen data and information on how the translocation will affect the human population.

Much research is still needed. This is true of almost every animal on the planet in need of conservation action. New projects are already being planned for this species and area. Their placement in an area that is already protected means that the chance of conserving the current population is excellent.

Global Plight of Species

Trachypithecus germaini is currently listed as endangered by the IUCN due to a population decline of over 50% in the last thirty-six years throughout its range of south-eastern Thailand, Cambodia, southern and central Lao PDR, and south and central Vietnam (Nadler et al., 2008). Though Cambodia is generally considered the global stronghold of the species, this study indicates a large population could be living in Vietnam as well (Moody et al., 2011).

Threats to *T. germaini* throughout its range include habitat loss due to agricultural expansion and mining, hunting for food and medicine, and the pet trade (Nadler et al., 2008). In certain areas, low genetic variability and low access to mates from habitat fragmentation are also major problems. This is especially salient on the limestone hills of the Kien Luong Karst Area where small groups have been isolated from each other.

The Phu Quoc population is less susceptible than most to some of these major threats. Hunting and the pet trade are rare and are punished severely. The Vietnam Penal Code allows for anyone who illegally hunts, kills, breeds, or cages endangered wild animals to be given a fine up to 500 million VND (US $23,654) and up to seven years in prison (Nguyen Quang Thong, 2013). Habitat loss is still a problem due to possible human incursions into the national park for homes and resorts. Fragmentation is a concern of unknown severity for this population.

Importance of this Population and Area

If the population estimate obtained from this research is accurate, this is a hugely important population to the species overall. Phu Quoc National Park has the potential to be a new stronghold for the species in Vietnam and globally. If fragmentation is not severe, this area could be a reservoir of critical genetic diversity. The potential to translocate individuals threatened by human activity into the national park could further increase the population by saving animals that could not have survived otherwise.

The importance of such a potentially large population already being in a protected area cannot be overstated. Simply declaring the area a national park has likely already contributed to conserving silvered langurs. Punishing poachers with time in prison is also a critical step toward ensuring the area remains a safe haven for the species.

However, it is critical to determine—quickly—how accurate this estimate is. If the population is actually this large, it could be used as motivation to expand the strictly protected area and ban other activities within the national park, such as development for resorts. Further protection will be needed to maintain the current population and safeguard any additional animals added to it. It is well known that animals on islands are more susceptible to disaster and disease, so extra caution will be required.

Research in Phu Quoc National Park can be challenging. This is a largely unstudied area of dense jungle, difficult terrain, and taxing weather. During the course of this research, we saw abundant long tailed macaques, giant black squirrels, smaller squirrels, hornbills, and numerous beautiful birds of all sizes. All of these species are waiting to be observed and studied. Phu Quoc National Park has the potential to be an excellent site of research and new discoveries for professional and amateur scientists. Well-informed development of tourism could raise awareness for the importance of this area to the unique flora and fauna inhabiting it, especially the beautiful and endangered silvered langur that may have found a safe and stable stronghold on Phu Quoc.

Figure 19: Three members of the research team on a path in Phu Quoc National Park. From left, Dr. Jonathan O'Brien of the University of Colorado Boulder, a technical specialist, and a park ranger from Phu Quoc. Photo by Robin Fiore.


Figure 20: The author, Robin Fiore, along a trail in Phu Quoc National Park. Photo by Dr. Jonathan O'Brien.

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