

**POPULATION ASSESSMENT OF THE
COMMON SQUIRREL MONKEY (*SAIMIRI SCIUREUS*)
ON SUMAK ALLPA, ECUADOR**

by

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A thesis submitted to the Faculty of the University of Delaware in partial
fulfillment of the requirements for the degree of Bachelor of Arts in Environmental
Studies with Distinction

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EXECUTIVE SUMMARY

The following study will provide an analysis of the common squirrel monkey (*Saimiri sciureus*) population on Sumak Allpa, a primate sanctuary located in the Ecuadorean Amazon. Chapter 1 describes the population survey and analysis of troop home ranges conducted on this species. Chapter 2 evaluates reintroduction strategies of the species, furthering the material provided in Chapter 1.

Chapter 1

POPULATION SURVEY AND TROOP HOME RANGE ANALYSIS OF COMMON SQUIRREL MONKEYS ON SUMAK ALLPA, ECUADOR

Abstract

Sumak Allpa is a 113.5 hectare-island located within the Ecuadorean Amazon, serving as an active primate sanctuary for imperiled species. In order to measure the current status of the common squirrel monkey (*Saimiri sciureus*) on Sumak Allpa, I assessed their population and distribution using estimation techniques during 30 observation periods in the spring of 2014. My results indicated three larger troops, one small troop, and one solitary primate, with approximately 55 to 60 individuals currently inhabiting the island. Based on the infrequent displays of aggression observed among the common squirrel monkeys, it was assumed that the troops were not competing for resources. Compared to population counts from 2012, these results suggested a positive growth rate within the common squirrel monkey population of Sumak Allpa. Given this growth rate, it would be beneficial to consider primate reintroduction strategies using the island as a source population.

Introduction

Common Squirrel Monkey

The common squirrel monkey, a small and agile primate native to South America, is a New World (Platyrrhini) species of the genus *Saimiri* (Emmons & Feer, 1997). It is thought that the common squirrel monkey reached South America

approximately 26 million years ago, contributing to the high biological diversity of the region (Garber, 2009). It is now found in various regions of the Ecuadorean Amazon, ranging across the provinces of Orellana, Napo, Sucumbíos, Pastaza, and Morona-Santiago (Sumak Allpa, 2014). These diurnal and arboreal primates thrive in humid tropical areas at altitudes between 200 and 1200 meters (Tirira, 2007), preferring the sub-canopy and canopy levels of the forest containing dense vegetation, branches, and vines. In recent years, the unique social systems, reproductive biology, and mating strategies of New World primates have attracted the interest of primatology researchers and conservation programs (Garber, 2009).

The common squirrel monkey has a distinctive appearance, including a white mask of fur encircling the eyes, black muzzle, grey or olive fur coloration, and bright yellow color of the forelimbs, hands, and feet. Its long non-prehensile tail is used for balance, as opposed to grasping, while climbing and leaping through the forest for long distances. Common squirrel monkeys exhibit sexual dimorphism (Mitchell et al., 1991) and males tend to be 30-35% larger than females, exhibiting weight gain and increased hormone levels particularly during the breeding season (Garber, 2009).



Figure 1 Common squirrel monkey on Sumak Allpa, Ecuador – courtesy of Sumak Allpa Foundation.

The social structure of the common squirrel monkey is complex, largely due to the occurrence of sexual segregation (Leger et al., 1981). Males tend to be spatially separated and outnumbered by the females – who represent the “social unifiers and leaders” of the group (Coe & Rosenblum, 1974). In comparison to related Neotropical primate species, the common squirrel monkey lives in larger social groups, known as troops, for enhanced protection, cooperation, and resources (Garber, 2009).

Approximately 10 to 100 individuals may constitute a common squirrel monkey troop (Tirira, 2007), which travels together during the day and sleeps jointly at night.

Furthermore, the common squirrel monkeys exhibit a polygamous mating system, and only engage in seasonal reproduction once a year (Coe & Rosenblum, 1974). For that

reason, males intensely compete for reproductive females during the mating season (Mitchell et al., 1991), which occurs between September and November, while birthing occurs between February and April. Upon birth, the females nurse and care for their single infant until they reach independence, while the males defend the infant from predation. Hence, social dynamics play significant roles within the common squirrel monkey troops (Rhines, 2000).

Threats to the Common Squirrel Monkey

The common squirrel monkey is categorized as a species of “Least Concern” by the International Union for Conservation of Nature Red List of Threatened Species. Nonetheless, the common squirrel monkey continues to face endangerment in South America primarily from 1) human encroachment and deforestation, 2) illegal trading, and 3) laboratory research (Rhines, 2000). Global climate change has also increased the rate of various natural disasters, such as droughts, floods, and fires, degrading habitats that primates depend on for survival. Therefore, the biomass and survivorship of primate species have been adversely affected, resulting in extinctions throughout South America (Garber, 2009).

Human encroachment and deforestation are fueled by the rapid rate in which the human population is growing worldwide. In many tropical forests of South America, deforestation by means of human encroachment has occurred over several millennia (Garber, 2009). In particular, incessant colonization, timber harvesting, petroleum extraction, cattle ranching, and agricultural activities over the past 60 years have enhanced the rate of deforestation (Garber, 2009), with Ecuador suffering from one of the highest rates of deforestation in South America; Ecuador lost 28.6% of 1990 forest area in 2010 (McCracken et al., 2014). Consequently, primate species,

including the common squirrel monkey, are suffering from habitat degradation and diminishing resources in South America. Further, while disturbing biological diversity, extensive deforestation also threatens the overall resilience of ecosystems and their natural communities.

Adding to the threat of habitat loss, common squirrel monkeys are commonly found within the illegal trade market to be sold as household pets, both domestically and internationally (Boubli et al., 2008). In 1973, the Convention on International Trade in Endangered Species was enacted “to ensure that international trade in specimens of wild animals and plants does not threaten their survival” (CITES, n.d.). Despite this protection the international trade market of wildlife species represents a multi-billion dollar industry, in which regulation and enforcement mechanisms continue to be insufficient (Rosen & Smith, 2010). South America is particularly vulnerable to this illegal trade market due to the astounding biodiversity encompassing the continent.

Finally, common squirrel monkeys have been widely utilized as subjects in laboratories for biomedical research due to their phylogenetic similarities to humans; “Nonhuman primates constitute irreplaceable animal models for research areas in which their close evolutionary relationship to humans ensures high fidelity models with predictive and discriminative abilities that may not be available in other species” (Carlsson et al., 2004). Moreover, there are benefits of the common squirrel monkey being relatively small and docile (Rosenblum & Cooper, 1970). Accordingly, the use of wildlife species for laboratory research has given rise to various ethical issues, campaigning against the primates’ deprivation to natural social interactions and foraging activities (Abee, 1989).

Importance of Population Estimate

Employing population survey techniques is valuable when monitoring the growth of a population, and is critical to wildlife conservation efforts (Krausman, 2002). Population growth can reflect the progress of an organization's conservation efforts, while demonstrating the strengths and weaknesses of existing practices. Furthermore, a population estimate serves as a reference for future studies and allows one to project population dynamics more accurately. Overall, population survey techniques serve to 1) evaluate the status/recovery program of species, 2) determine the status of introduction/reintroduction of a species to an area, 3) define the biological and ecological health of an area, and 4) understand the effects of management practices and activities on a species (Witmer, 2005). In this study I leveraged population surveys and logistic growth models to assess the population of common squirrel monkeys residing on Sumak Allpa.

Study Animals

The common squirrel monkey (*Saimiri sciureus*) represents the most prevalently found species in the illegal trade market. Between 2006 and 2008, approximately 11 common squirrel monkeys were confiscated from vendors throughout the surrounding areas of Coca, Ecuador, the capital of the Orellana Province, including Madeira River, Napo River, and Auca Road. Following, these primates were released to Sumak Allpa, an island located in the Ecuadorean Amazon. My study focused on the subsequent population of common squirrel monkeys currently inhabiting the island of Sumak Allpa.

In November of 2012, Claire Leichtner, identified one large troop consisting of approximately 17 adults and/or juveniles and 3 infants on Sumak Allpa. The presence

of an independent primate was also noted. Héctor Vargas (Sumak Allpa Founder) indicated that more than one large troop presumptively existed at the time of the study and that Leichter's fieldwork did not cover the entire island. For this reason I assumed that the common squirrel monkey population was at a minimum of 21 individuals in 2012, but likely higher. I used this data along with the initial population size of 11 individuals to augment my population analysis.

Study Areas

The Amazon

Sumak Allpa is a 113.5-hectare island situated in the Amazon region of Ecuador. The Amazon encompasses the world's most extensive tropical rainforest and river basin, extending across 6.7 million km² and nine different countries of South America: Ecuador, Peru, Colombia, Venezuela, Bolivia, Guyana, Suriname, French Guiana, and Brazil (Garber, 2009). Characterized by unparalleled biodiversity and endemism, the Amazon is home to 10% of known species on Earth (World Wildlife Fund, n.d.). To date, the array of flora and fauna in this region includes at least 40,000 plant species, 427 mammal species, 1,298 bird species, and 3,000 freshwater species (Silva et al., 2005). For these reasons, the Amazon represents one of 35 known "biodiversity hotspots" (Conservation International, n.d.). Accordingly, enhanced research efforts are being conducted on tropical rainforests, accounting for their unique ecological complexities and intense deforestation (Gentry, 1993).

The Ecuadorean Amazon is commonly referred to as the "Oriente" and ranges across 130,000 km² of the eastern lowlands of Ecuador (Encyclopedia Britannica, n.d.). Despite Ecuador's relatively small size, covering less than 0.2% of the planet

(Sumak Allpa, 2014), the nation represents one of the most biologically diverse locations. Unfortunately, Ecuador continues to face a 1.5-1.8% annual rate of deforestation (Garber, 2009), potentially the highest deforestation rate in all of South America. Hence, there is an urgency to reduce tropical deforestation and environmental degradation, in which Ecuador's vast biodiversity may be preserved.

Sumak Allpa

This study was conducted through the Sumak Allpa Foundation, a non-profit organization established as a primate sanctuary in 2005: "Sumak Allpa" translates to the "land of no pain" in the indigenous Kichwa language. The 113.5-hectare island is located on the eastern side of the Ecuadorian Amazon within the Orellana Province, bordering the Napo River (Figure 2). There are six trails encompassing the island: Jatun (West and East), Chichico, Titi, Sumak, Canela, and Huamak (Figure 2). Approximately 78-80% of the island consists of primary forest, reflecting the expanse of pristine tropical forests native to Ecuador (Héctor Vargas, Sumak Allpa Founder, Personal Communication).

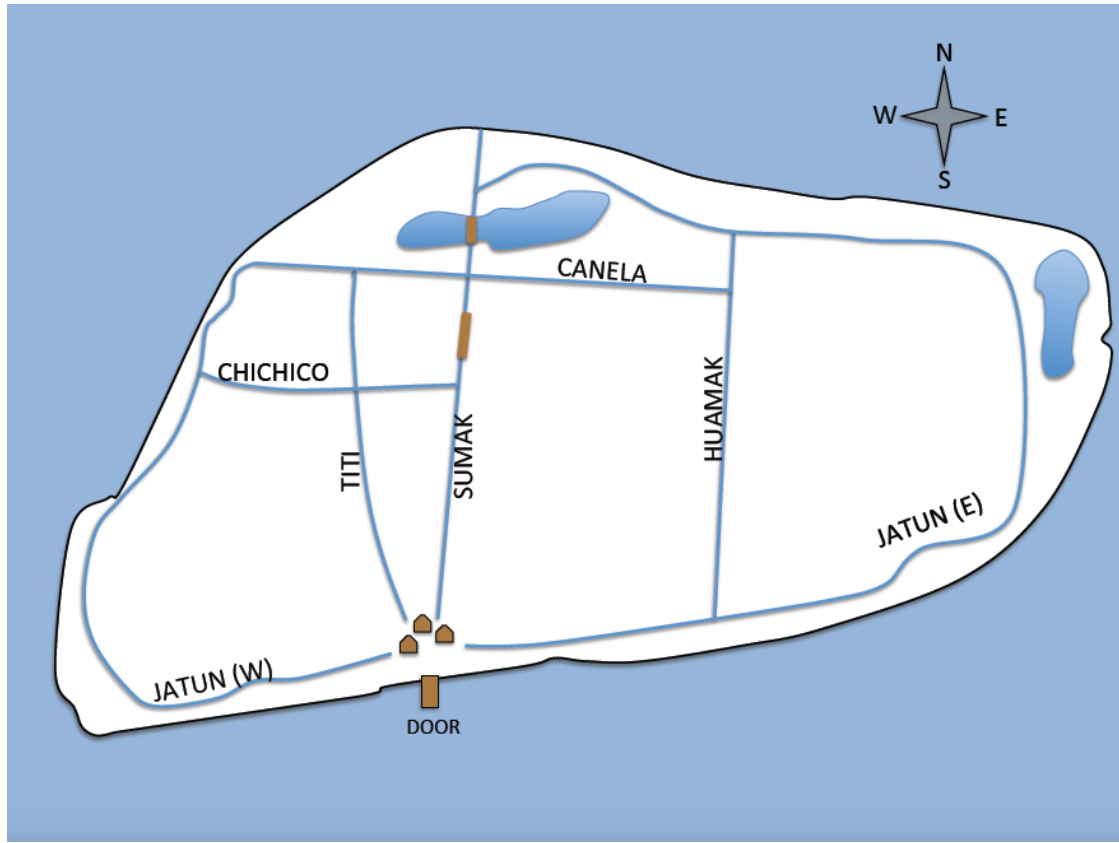


Figure 2 Map of Sumak Allpa, Ecuador.

This island sanctuary is currently home to seven threatened primate species native to Ecuador: common squirrel monkey (*Saimiri sciureus*), silvery woolly monkey (*Lagothrix poeppigii*), black-mantled tamarin (*Saguinus nigricollis*), golden-mantled tamarin (*Saguinus tripartitus*), monk saki (*Pithecia monachus*), pigmy marmoset (*Cebuella pygmaea*), and Spix's night/owl monkey (*Aotus vociferans*). Sumak Allpa upholds a unique philosophy that differs from many other primate centers, aiming to rescue, rehabilitate, and repopulate species not held in captivity. Therefore, primate species native to Ecuador live freely on the island without human intervention, enabling them to foster natural skills from a near-wild existence.

Through such management practices, Sumak Allpa strives to reintroduce the animals into the wild, and thereby strengthen the unique ecosystems of Ecuador.

Methods

I conducted fieldwork between April 14 and May 4 of 2014 on Sumak Allpa, during which I gathered data during 30 observation periods occurring twice daily, unless logistically impossible. The morning periods ranged between 6:00 am and 9:00 am, while the afternoon periods ranged between 3:00 pm and 6:00 pm. Both trails and off-trail transects of the island were surveyed in order to track the common squirrel monkey troops.

During the first 18 observation periods (April 14 to April 25 of 2014) I used Huamak Trail as a division between the east and west sides of the island. To survey the entirety of the island each day, I observed a different side of the island in the morning than in the afternoon. As part of each survey, I recorded the date, time, and weather/temperature, at the beginning of each observation period.

For my final 12 observation periods (April 27th-May 4th 2014) I trekked directly to the estimated home ranges and/or territories where primate troops were frequently sighted to improve efficiency. Additionally, for two observation periods I was able to use a field team to search for troops simultaneously on the other side of the island from my location. This collaboration was instrumental in determining the exact number of common squirrel monkey troops inhabiting Sumak Allpa.

Given the agility and small size of the common squirrel monkey, troops were best identified by 1) listening to the rustling of trees as the primates climbed through the forest, 2) following and imitating the “chuck” call of the primates, 3) observing

fallen fruit on the forest ground, and 4) following the black-mantled tamarins with whom one common squirrel monkey troop often associated with.

Results

Population Estimate

By employing population survey techniques, I found an estimated 58 individuals in the common squirrel monkey population of Sumak Allpa. Three large troops and one small troop were monitored throughout the study, with a solitary primate frequently joining and separating from the smaller troop (Table 1). My observations supported Kappeler's (2002) findings that solitary individuals forage alone, while also maintaining social relationships. This was an increase of 37 individuals compared to the population assessment from 2012, and of 47 individuals since the initial foundation of the population. I also recorded the sex of individual monkeys whenever possible (Table 1), however, due to the agility and small size of the common squirrel monkeys, it is important to note that this data remains incomplete.

Table 1 Estimated population counts of troops on Sumak Allpa, Ecuador and the number of females and males identified in each (2014).

	Troop 1	Troop 2	Troop 3	Troop 4
Individuals/Troop	22	12	20	3-4
Identified number of females	2	N/A	2	N/A
Identified number of males	5	N/A	6	3

Troop Home Ranges

While surveying the population of common squirrel monkeys residing on Sumak Allpa, I also mapped their spatial location (Figure 3) to estimate the troop home ranges (Figure 4).

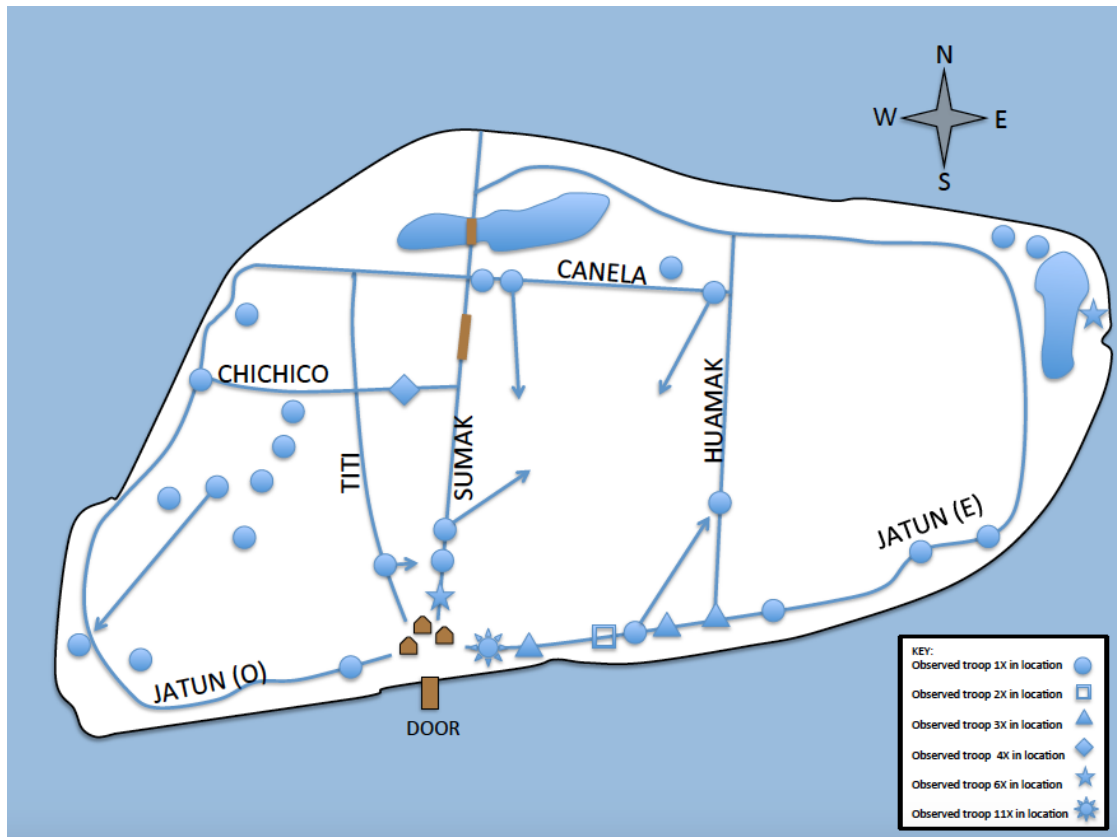


Figure 3 Map of troop sightings on Sumak Allpa, Ecuador.

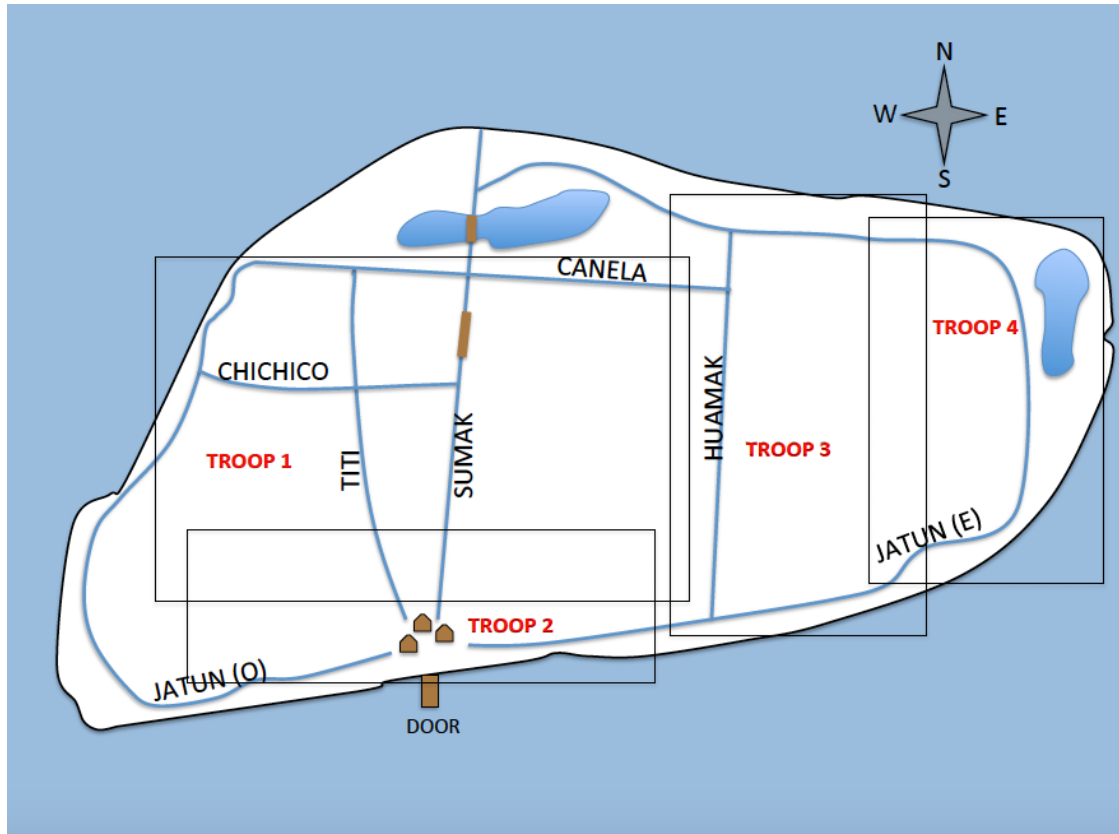


Figure 4 Map of estimated troop home ranges on Sumak Allpa, Ecuador.

Minimum Convex Polygon

This study employed home range analysis techniques, namely minimum convex polygons, to better understand the distribution, resource-use, and social interactions of the common squirrel monkey population on Sumak Allpa. A home range may be defined as “that area traversed by the individual in its normal activities of food gathering, mating, and caring for young”, often being influenced by the population density, species’ size, and resource availability (Burt, 1943). Significantly, the method of minimum convex polygon encloses data points by constructing convex

polygons, as opposed to concave polygons (Calenge, 2015). Here, the data points represented the locations of primate troop sightings.

By adopting the rudimentary maps depicting the recorded troop sightings (Figure 3) and estimated troop home ranges (Figure 4), I created a minimum convex polygon map. In addition, reviewing my observations from the fieldwork on Sumak Allpa was particularly helpful during this process. Ultimately, 33 data points were used to create four distinct polygons, providing a detailed visual of the troop home ranges dispersed across the island.

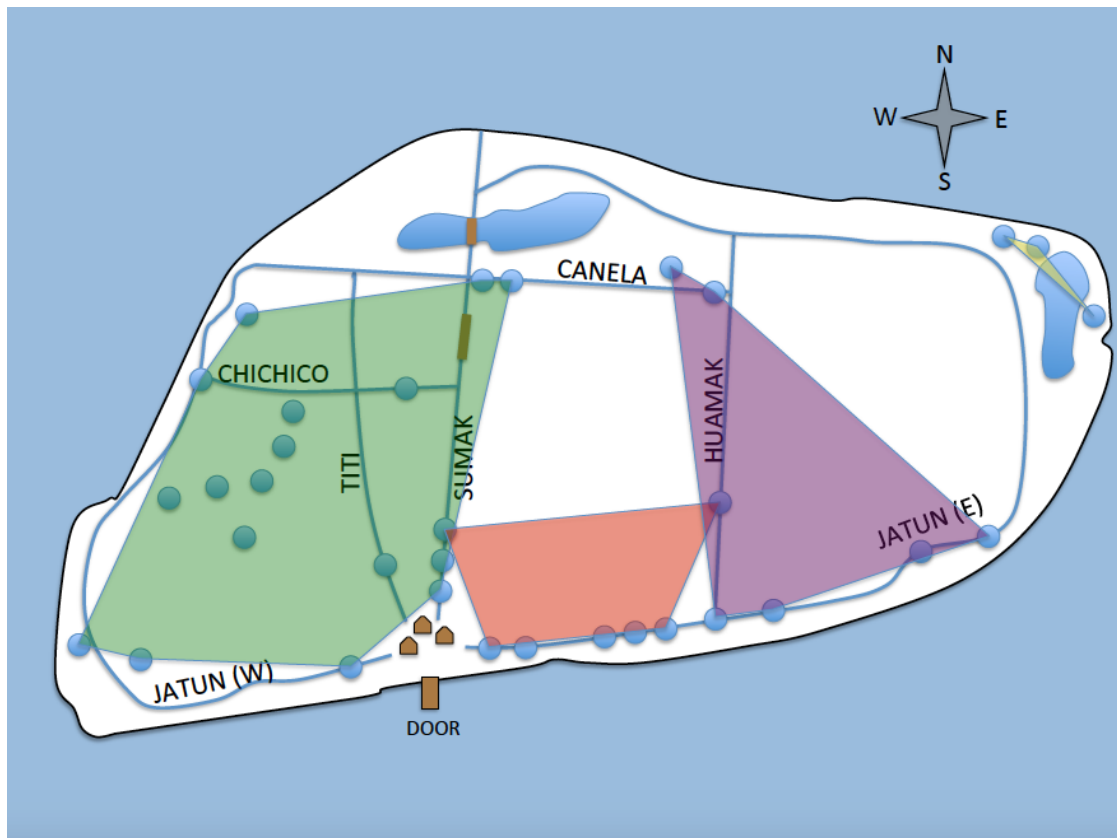


Figure 5 Minimum convex polygon map of troop home ranges on Sumak Allpa, Ecuador.

Social Interactions

I also monitored the complex social dynamics of the common squirrel monkey during the study, particularly in respect to displays of aggression. In fact, aggressive behavior was observed for 13.33% of the observation periods. Such behavior occurred among members of the same species, namely intraspecific competition, being indicated by high-pitched screeches contrasting with the regular “chuck” calls of the common squirrel monkeys. A lack of intraspecific aggression between troops during my research suggested that adequate resources were available, at least during this time period, for the current population size.

Discussion

Analysis of Troop Home Ranges

Considering the dense foliage of Sumak Allpa and our lack of a Global Positioning System (GPS), the trails encompassing the island are neither detectable through imagery nor available in our raw data. The only available spatial data was markings I made during each observation period on a simple paper trail map depicting the island. Accordingly, the most applicable method for home range delineation in my study was the use of minimum convex polygons. The technique of minimum convex polygon is widely applied for home range analysis, which is appealing due to its simplicity (Moorcroft & Lewis, 2006).

Of interest, the minimum convex polygon map (Figure 9) showed the overlap of adjacent home ranges on Sumak Allpa, highlighting the challenges faced in discriminating between the primate troops. One study noted overlapping home ranges, with primates displaying mutual avoidance when close in proximity (Boinski, 1988). Moreover, the troop home ranges of the common squirrel monkey population were

estimated be a maximum of 30-40 hectares. While home ranges of this species tend to encompass 100-500 hectares, those of Sumak Allpa were likely confined by the boundaries of the 113.5-hectare island (Emmons & Feer, 1997).

Finally, troop home ranges may shift between seasons, largely depending on the abundance of food (Boinski, 1987). My fieldwork occurred during the rainy season in the Amazon, a time when guava trees flourish across the island. As the common squirrel monkeys of Sumak Allpa fed on cultivated fruit, including guava, banana, and cacao, it was assumed that the distribution of troop home ranges depended on the availability of resources.

Associations between Primate Species

As an anecdotal aside, I observed a close association between the common squirrel monkey (*Saimiri sciureus*) and the black-mantled tamarin (*Saguinus graellsii*) during my research. Recurrently sited within the same vicinity of the island, namely the western side, the largest common squirrel monkey troop (Troop 1) and the black-mantled tamarins appeared to have a symbiotic relationship; this interaction may have improved foraging efficiency and/or predator avoidance (Levi et al., 2013). By recognizing the *Saimiri-Saguinus* association during the study, I was better equipped to track the common squirrel monkey troops on Sumak Allpa. Related studies indicate that “primate diversity can be maintained when species partition habitat types, food resources, and vertical canopy structure in accordance with the classic paradigm of the fundamental niche” (Levi et al., 2013), exemplifying positive mixed-species interactions.

In particular, primatologists have observed an intriguing semi-permanent association existing between the common squirrel monkey (*Saimiri sciureus*) and the

brown capuchin monkey (*Cebus apella*). While brown capuchins were not present on Sumak Allpa during the study, the two species have been observed to feed and travel together for 90% of the time (Levi et al., 2013). This association may simply result from similar preferences in fruiting and resting trees (Baldwin & Baldwin, 1971), in which further evaluation of the *Saimiri-Cebus* relationship is necessary.

Limitations of Study

A number of limiting factors were encountered during this study, likely affecting the data and results. First, natural fluctuations of the Napo River and movement generated by travelling motorboats allowed river water to permeate the island. As a result, observation periods occurring on the afternoons of April 19 and April 20 of 2014 were altered. Avoiding the deeply flooded areas of Sumak Allpa, I surveyed the west side of the island as opposed to the east side during these observation periods. Secondly, intense rainfall impacted fieldwork on April 24, April 29, April 30, and May 2 of 2014, impeding my ability to track the primates and collect data. As a tributary of the Amazon River, the Napo River extends from the eastern slopes of Ecuador to the Peruvian border, experiencing an average monthly rainfall of 260 millimeters (Napo Wildlife Center, n.d.). The subsequent intense seasonal rainfall of the Amazon biome induced various limitations throughout my study.

I also faced challenges in locating the common squirrel monkey troops due to their agility and small size. This, coupled with the dense vegetation of Sumak Allpa often led to primates being concealed within the depths of the Amazon rainforest. This suggests that individuals within the common squirrel monkey population may have been double counted during my observation periods. Therefore, the study revealed 58 common squirrel monkeys on Sumak Allpa, but it is likely that the true population

size was at least a few individuals larger or smaller. Without a better study design it is impossible to evaluate our accuracy or precision, however, given the island's small size and my repeated efforts to count troops sizes, I am confident that my findings are close to the true value.

In addition, it was particularly challenging to determine the sex composition of the troops due to their agility and small size; primates quickly fled in reaction to observers in the field as well. My observation periods reflected Kinzey's (1997) difficulties in evaluating troop composition and distinguishing males from females, largely due to the rapidity and wide dispersion of the troops. Determining the number of females and males comprising the common squirrel monkey troops on Sumak Allpa would be beneficial in understanding their multifaceted social dynamics, thereby warranting future research.

Ultimately, I conducted a total of 30 observation periods on Sumak Allpa between April 14 and May 4 of 2014, reflecting the short nature of the internship for this study. I recognize that increasing the duration of fieldwork, along with an improved study design, would have improved my ability to make inferences.

Conclusion

The Sumak Allpa Foundation would like to begin reintroduction efforts for the common squirrel monkey into the mainland rainforest within the foreseeable future, using the island population as a source (Héctor Vargas, Sumak Allpa Founder, Personal Communication). The common squirrel monkeys will be released to protected sites of the Ecuadorean Amazon, including Yasuni National Park and other surrounding reserves. My findings will be crucial to developing an appropriate reintroduction strategy in order to maintain a viable source population on the island.

After reintroducing the primates into the wild, continual monitoring will determine the and survival rates of the species. Fortunately, the unique management practices of Sumak Allpa provide near-wild existences to the primates, and they are likely to thrive and enrich their ecosystems.

Chapter 2

ANALYSIS OF REINTRODUCTION OF COMMON SQUIRREL MONKEYS ON SUMAK ALLPA, ECUADOR

Abstract

Sumak Allpa is a 113.5 hectare-island located within the Ecuadorean Amazon, serving as an active primate sanctuary for imperiled species. In order to examine reintroduction strategies of the common squirrel monkey (*Saimiri sciureus*) on Sumak Allpa, I employed the population survey from 2014 (Chapter 1) to leverage logistic growth models. Based on the findings and analysis, reintroduction may commence after monitoring the primates for a few more years, thereby employing a conservative approach to removing primates. Through the long-term monitoring of primates released to the mainland of Ecuador, Sumak Allpa will enhance the overall survival of threatened species, namely the common squirrel monkey.

Introduction

The common squirrel monkey (*Saimiri sciureus*) is a small and agile primate species native to South America, characterized by a white mask of fur encircling the eyes, black muzzle, grey or olive fur coloration, and bright yellow color of the forelimbs, hands, and feet (Emmons & Feer, 1997). These primates inhabit humid tropical areas with dense vegetation, branches, and vines, including the Amazon region of Ecuador (Tirira, 2007).

While being categorized as a species of “Least Concern” by the International Union for Conservation of Nature Red List of Threatened Species, the common squirrel monkey has attracted the interest of primatology researchers and conservation programs (Garber, 2009). These primates face endangerment from continual 1) human encroachment and deforestation, 2) illegal trading, and 3) laboratory research (Rhines, 2000). Hence, primate sanctuaries play active roles in rescuing, rehabilitating, and repopulating imperiled species, namely Sumak Allpa of the Ecuadorean Amazon, followed by long-term monitoring of reintroduced primates.

Sumak Allpa represents a 113.5-hectare island situated within the Orellana Province of Ecuador, currently home to seven threatened primate species: common squirrel monkey (*Saimiri sciureus*), silvery woolly monkey (*Lagothrix poeppigii*), black-mantled tamarin (*Saguinus nigricollis*), golden-mantled tamarin (*Saguinus tripartitus*), monk saki (*Pithecia monachus*), pigmy marmoset (*Cebuella pygmaea*), and Spix’s night/owl monkey (*Aotus vociferans*). Ultimately, Sumak Allpa upholds a unique philosophy differing from other primate sanctuaries, enabling species to foster natural skills from near-wild existences.

Between 2006 and 2008, 11 common squirrel monkeys confiscated from illegal vendors of Ecuador were released to Sumak Allpa as the source population. Referencing Chapter 1, at least 21 individuals were estimated in 2012 while 58 individuals were estimated in 2014. Despite the lack of intraspecific aggression displayed between common squirrel monkey troops, in addition to the availability of resources during the study, it proved beneficial to consider primate reintroduction by leveraging logistic growth models.



Figure 6 Common squirrel monkeys on Sumak Allpa, Ecuador – courtesy of Sumak Allpa Foundation.

Methods

K-Carrying Capacity

The concept of carrying capacity is imperative to conserving and managing wildlife populations, including the common squirrel monkeys of Sumak Allpa. Represented by the variable “K”, carrying capacity evaluates the maximum number of animals supported by the availability of resources in a specific area (Krausman, 2002). While the concept of carrying capacity has been applied to an array of definitions, it should certainly be ecologically based. As such, carrying capacity serves as the basis for various population growth models, with one being the basic logistic growth model

depicting population growth in correspondence with carrying capacity (Krausman, 2002).

In order to estimate the carrying capacity of the common squirrel monkey population on Sumak Allpa I first compared my estimated population density to those available in published literature. In Corcovado National Park, Costa Rica, Boinski (1987) found the squirrel monkey population to be at 0.36 individuals/hectare, while in Manu, Peru, Mitchell et al. (1991) found the squirrel monkey population to be at a density of 0.60 individuals/hectare. Given my estimated population size of 58 individuals (Chapter 1) and an estimated 113.5 hectares of available habitat, I calculated a 0.51 individuals/hectare density of the common squirrel monkeys on Sumak Allpa. This density appears reasonable as it falls between those in the published literature, being very similar to that of the Peruvian study. Considering that the population is near the maximum density seen in other studies, I opted to use 60 individuals as the overall carrying capacity for the purpose of this study.

Logistic Growth

Developed by Belgian mathematician, Pierre-François Verhulst, the logistic growth equation (Equation 1) and model illustrate population growth of a species over time (Krausman, 2002). The availability of resources, namely food, water, and space, determine the growth of a population as the environment varies between favorable and unfavorable conditions. By considering growth-depressing factors, a logistic growth or S-shaped curve will result. The concept of carrying capacity is of particular importance for this model, because it represents the equilibrium level at which limited resources curtail population growth (Krausman, 2002). Notably, logistic growth contrasts with the constant and unrestricted nature of exponential growth. I applied the

logistic growth equation to the population of common squirrel monkeys on Sumak Allpa in order to develop growth and yield curves for use in designing a primate reintroduction strategy.

Equation 1. Logistic population growth.

$$N_t = \frac{K}{1 + \left[\frac{K - N_0}{N_0} \right] e^{-rt}}$$

N_0 = starting population size
 N_t = population size at later date
 K = carrying capacity
 r = intrinsic rate of increase
 t = time

Results

Based on the available population data from 2008, 2012, and 2014, growth curves of the common squirrel monkey population on Sumak Allpa were produced, depicting the removal of two, four, and six primates yearly (Figures 7-9). Considering that K-carrying capacity may exceed 60, different scenarios of growth curves are presented in correspondence with varying carrying capacities. The graphs illustrate changes in population size (N) over changes in time (2008-2032), following the S-shaped curve of a logistic growth model as the population reaches an equilibrium level.

Employing the same data in different configurations, the yield curves of the common squirrel population on Sumak Allpa were subsequently generated (Figure 10). Likewise, different scenarios of yield curves are presented based on varying carrying capacities, addressing the possibility that K-carrying capacity may surpass the

estimated value of 60. These graphs illustrate the relationship between population growth (yield) and population size (N), indicating the number of individuals added to the population in various time steps. Notably, the dotted black line denotes the estimated 58 individuals within the common squirrel monkey population in 2014.

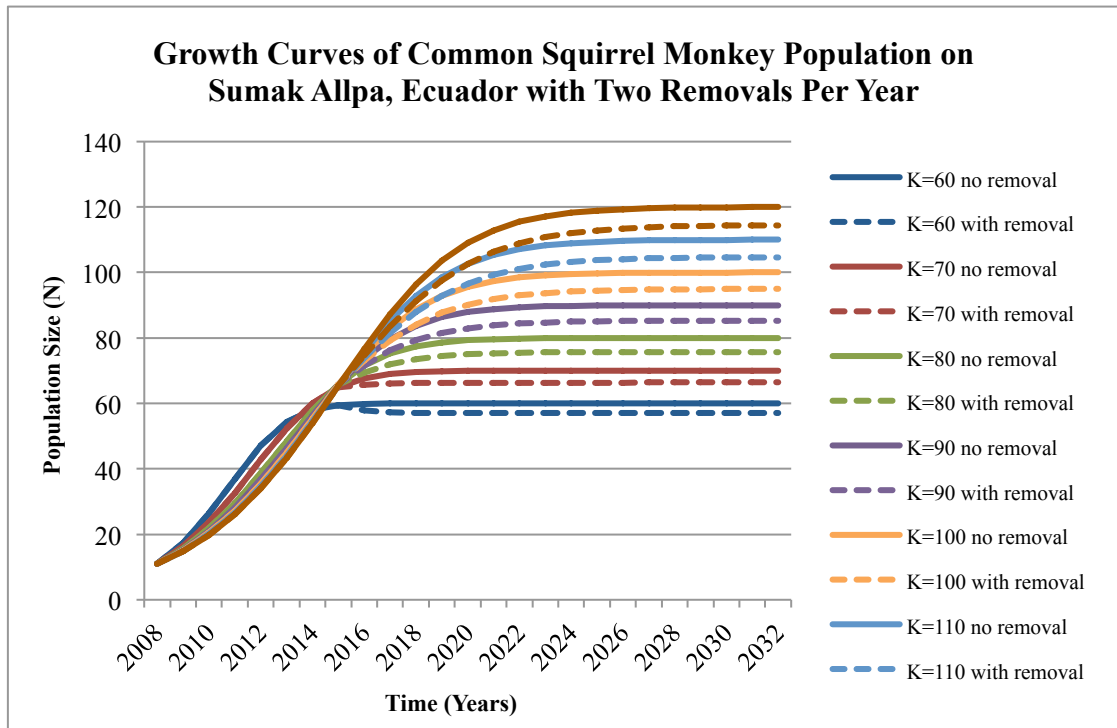


Figure 7 Growth curves following the logistic growth equation, depicting two common squirrel monkey removals yearly.

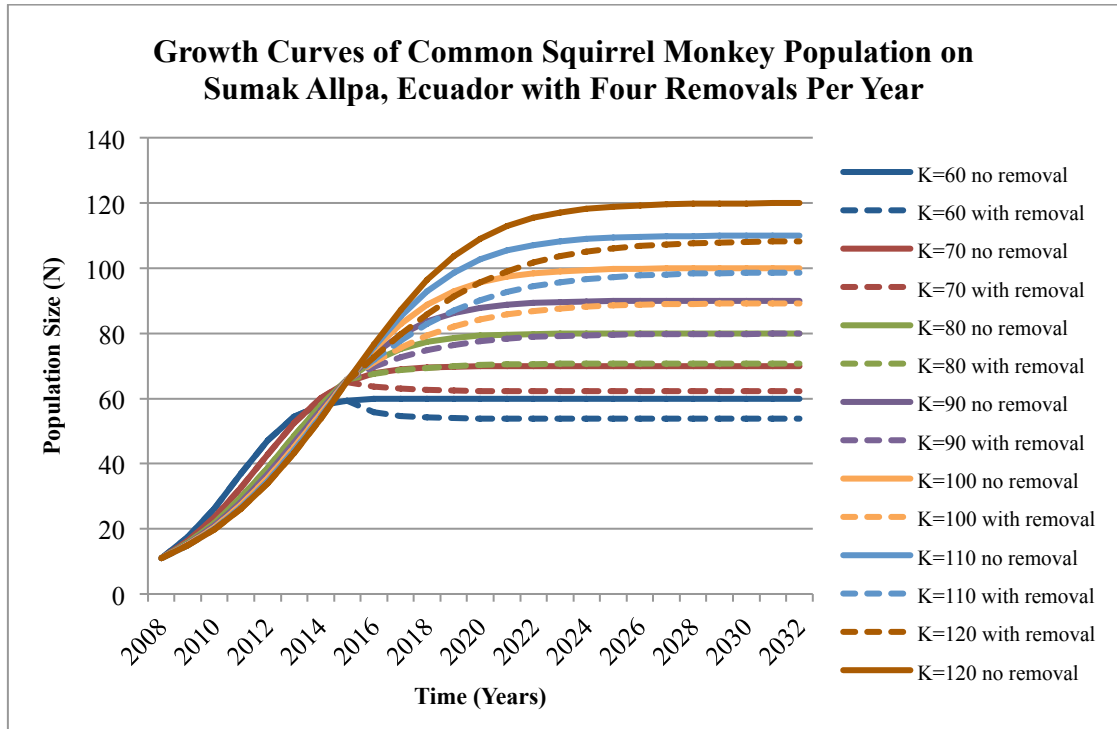


Figure 8 Growth curves following the logistic growth equation, depicting four common squirrel monkey removals yearly.

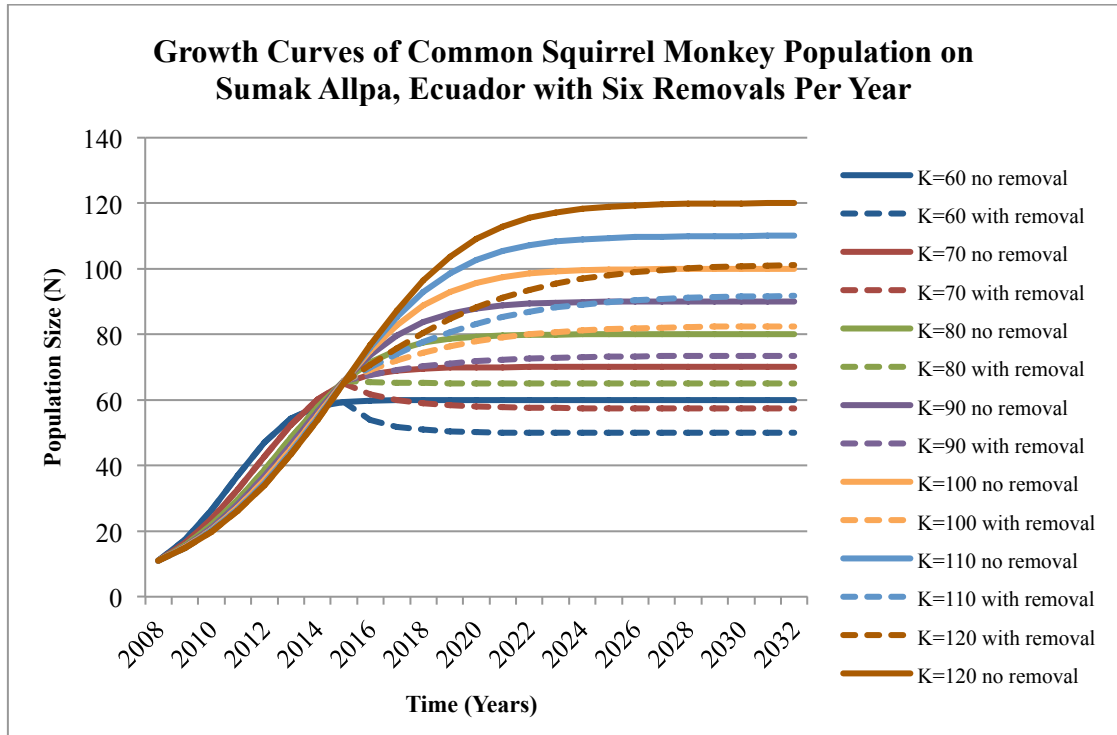


Figure 9 Growth curves following the logistic growth equation, depicting six common squirrel monkey removals yearly.

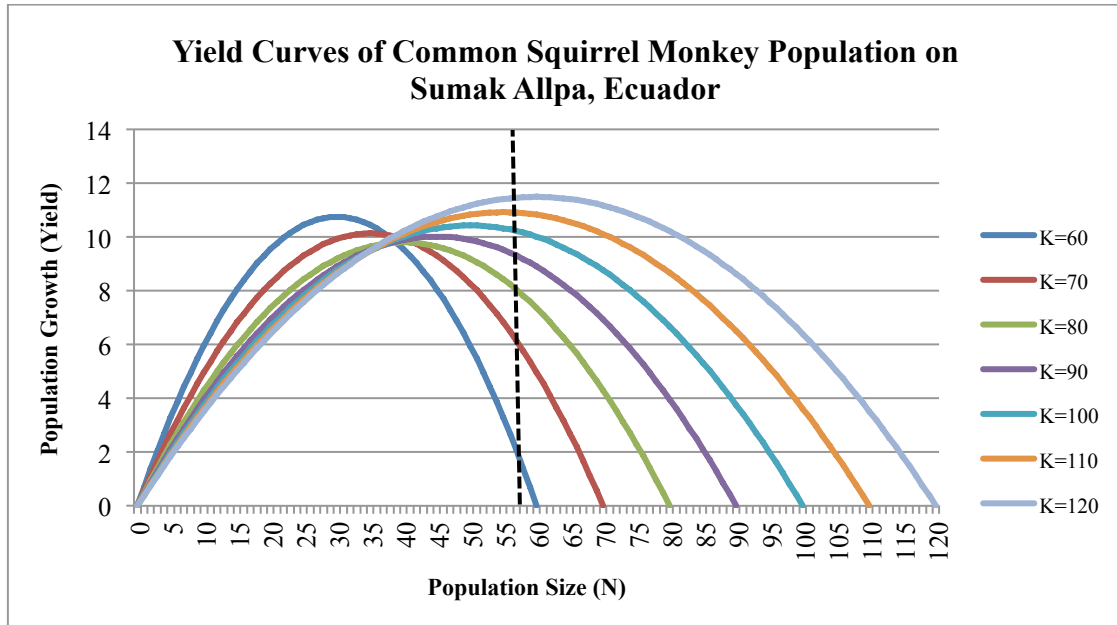


Figure 10 Yield curves following the logistic growth equation, displaying dN/dt at any given population size.

Discussion

Analysis of Logistic Growth Models

While an array of models has been developed in addressing population dynamics, logistic growth is a simple model considering the carrying capacity of an ecological system. During this study, I encountered challenges when calculating the r -value of the logistic growth equation, which represents the intrinsic rate of increase. In fact, gauging a population's rate of increase is considered to be the single most important statistic (Krausman, 2002). Due to the limited availability of data on the common squirrel monkey population, I iteratively adjusted the r -value until the equation reached 1) 11 for the initial population in 2008, 2) 58 for the population in 2014, and 3) 60, 70, 80, 90, 100, 110, or 120 for the estimated carrying capacities.

Thus, the logistic growth equation enabled me to generate population growth and yield curves, depicting the same data in different configurations.

The growth curves (Figures 7-9) depict the common squirrel monkey population approaching an equilibrium level, whether two, four, or six primates are removed yearly from Sumak Allpa and reintroduced to the mainland of Ecuador. Given the conservativeness of removing two, four, or six primates, the source population of Sumak Allpa is not likely to be jeopardized. While removing eight individuals from the common squirrel monkey population is mathematically viable, uncertainties remain as to how the source population may be effected. Thus, cautiously removing primates from Sumak Allpa is an intelligent option, in which adaptive management is critical for long-term success of a reintroduction program.

Furthermore, the yield curves (Figure 10) correspond to a concept known as sustained yield, describing the number of animals that may be removed from a population at any given proportion of K without causing a population decline. To avoid the pitfalls of managing too closely to a “maximum sustained yield”, it would be more conservative to maintain the common squirrel monkey population at an “optimum sustained yield”, remaining above $K/2$. We must also consider that competition for resources and reproductive partners will intensify as the population reaches the carrying capacity of Sumak Allpa. Ultimately, removing conservative yields from Sumak Allpa yearly, namely two, four, or six primates, will maintain a viable source population. The common squirrel monkeys of Sumak Allpa should be systematically monitored on a yearly basis to ensure that primate removals are not overexploiting the assumed yield, or causing undue stress to individual troops.

Considerations for Primate Reintroduction

As primate species worldwide, including the common squirrel monkey, face increased endangerment from natural and anthropogenic pressures, reintroduction approaches have become progressively more important. Accordingly, the IUCN developed guidelines for primate reintroduction programs in 2002 (Table 4). Ultimately, the overarching objective of primate reintroduction is to

Table 2 Basic principles of primate reintroduction programs reproduced from the IUCN Guidelines for Nonhuman Primate Re-Introductions (Baker, 2002).

Basic Principles of Re-Introductions
1) Identify the need for re-introduction and conduct a rapid overall assessment (determine if the key requirements-habitat, socioeconomic, financial, legal, management, release-stock suitability, veterinary, post-release monitoring-are likely to be met).
2) Define aims, objectives, and time frame.
3) Establish a multidisciplinary team.
4) Assess the proposed release-site habitat and determine its suitability.
5) Review the socioecological and behavioral data on the taxon of interest.
6) Determine if the socioeconomic, financial, and legal requirements can be met in the short and long terms.
7) Assess the suitability of the release stock.
8) Evaluate the genetic status of the release stock.
9) Ensure release stock has been cleared for release by a qualified veterinary team.
10) Develop strategy and time frame for transport and final release of animals.
11) Establish and enact post-release monitoring and other follow-up activities.
12) Document project outcomes on an ongoing basis.

According to IUCN Guidelines for Nonhuman Primate Re-Introductions, post-release monitoring of primates is a fundamental component of reintroduction efforts (Baker, 2002). Unfortunately, reintroduction practices have historically encountered challenges with locating primates, lacking technical and financial resources, and

geographic barriers (Trayford & Farmer, 2012). Developments in modern technology, however, have made it increasingly possible to examine the results of primate reintroduction. In particular, the use of telemetry (tracking) devices has enhanced the quality and ability in which primates are monitored. In fact, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) have revolutionized the field of telemetry, allowing researchers to assess primate locations, home range patterns, movements, habitat-use, and behavior (Trayford & Farmer, 2012). Telemetry devices may include neck or wrist collars, backpacks, and subcutaneous implants, to name a few (Trayford & Farmer, 2012).

By surveying various primate centers/sanctuaries by means of questionnaires, one study assessed the use of telemetry in primate reintroduction programs. Results demonstrated that 60% of the respondents use, or have used, telemetry devices in monitoring primates released into the wild, with collars being most commonly used (Trayford & Farmer, 2012). Notably, primate sanctuaries from the Americas encountered greater challenges in tracking individuals after release than sanctuaries from Asia or Asia; this discrepancy may perhaps be “explained by larger numbers of small, often arboreal, primates released at one time that makes identification harder in comparison to primates released singly or in smaller social groups...” (Trayford & Farmer, 2012). Given that modern technology and long-term monitoring collectively enhance reintroduction efforts and survivorship of vulnerable primate species, it is advisable to consider their use during the planned reintroductions from Sumak Allpa.

Management Recommendations

Due to the relative lack of data on the common squirrel monkey population of Sumak Allpa, the primates must be removed in a conservative manner. As many of the

figures provided throughout this study are estimates, namely K-carrying capacity, it would be beneficial to monitor the primates for a few more years before initiating reintroduction processes. Once primate reintroduction begins, remove fewer numbers initially and subsequently evaluate behavioral responses of the source population. Over time, the release potential of the primates may be maximized without jeopardizing the common squirrel monkeys of Sumak Allpa. Thus, upholding the precautionary principle should guide all reintroduction strategies, ensuring the utmost protection of wildlife populations (Beck et al., 2007).

Conclusion

According to this study, the common squirrel monkey population inhabiting Sumak Allpa, a 113.5-hectare island of the Ecuadorean Amazon, is thriving due to favorable resource availability and reproductive capacity. My findings and analyses suggest that primate reintroduction may commence within the foreseeable future, following a few more years of monitoring. After conservatively releasing primates to the mainland of Ecuador, long-term monitoring will be imperative in determining the species' reproductive and survival rates. Hence, Sumak Allpa represents a successful primate sanctuary for rescuing, rehabilitating, and repopulating imperiled species without human intervention, ensuring the overall resilience of the common squirrel monkeys in Ecuador.

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