RINGTAIL DISTRIBUTION, DERMATOGLYPHICS, AND DIET

IN ZION NATIONAL PARK, UTAH

by

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A thesis submitted in partial fulfillment
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in

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ABSTRACT

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by

Adrian Argie Roadman, Master of Science

Utah State University, 2014

Major Professor: Dr. S. Nicole Frey
Department: Wildland Resources

Current scientific knowledge of the ringtail (*Bassariscus astutus*) is limited, thus impeding appropriate management decisions. Ringtails in Zion National Park, Utah, are rarely seen, but are involved in increasing occurrences of negative interactions with park visitors and employees such as food theft and denning in buildings, interactions which are harmful to both parties. To manage this conflict, an update to the general knowledge about the status of the population is required as the only previous study on ringtails in this area was conducted in the 1960s. Using noninvasive techniques provides dependable large-scale population information. I used two noninvasive detection methods in combination to establish a robust occupancy estimate of the ringtail population in Zion National Park. Ringtails were detected in 2 of 3 focus areas in the park, but at low densities. This study included the development of a novel method to individually identify ringtails by their footprints. I used the Interactive Individual Identification System (I^3S) software to determine if individuals could be identified using the pattern formed by papillae and ridges of the footpad. Ringtails' footpad prints consistently resulted in a unique pattern recognizable by simple visual analysis and a computer-aided analysis of the prints in a database; however more research is needed for the applicability using field data. Ringtail densities were highest in the areas of greatest human activity. The proximity to humans may be impacting ringtail diet and consequently their health. I collected scat in areas of high and low human use to quantify the change in diet resulting from food acquired around human establishments. Ringtails living in areas of high human activity exhibited a change in diet, including the presence of human trash such as foil and plastic; this has implications for ringtail health and human safety. Ringtails acquiring food from human sources may increase their activities around buildings and areas with high human activity, resulting in an increased chance of direct and indirect human-ringtail interactions. Active management of human activities and regular building maintenance is required in the future to decrease negative consequences of ringtail use and presence in areas of high human activity.

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Ringtails (*Bassariscus astutus*), a member of the raccoon family, occur throughout southwestern North America. Their low densities and secretive nature contribute to the lack of scientific knowledge about ringtail ecology, which impedes species conservation and management. Ringtails in Zion National Park, Utah, although rarely seen, have been implicated in increased negative interactions with park visitors and employees. These conflicts include damage to buildings, food theft, and encounters which are harmful to both parties. The only previous study on ringtails in this national park was conducted in the 1960s. Using noninvasive detection techniques provided an avenue for gathering large-scale population information. I used two detection methods in combination to measure the distribution of the ringtail population in Zion National Park, Utah. Ringtails were detected in 2 of 3 focus areas in the park, but at low densities at each. This study also included the development of a new method to individually identify ringtails using their footprints. Ringtails' footpad prints consistently resulted in a unique pattern that was recognizable by simple visual analysis and a computer-aided analysis of the prints in a database; however more research is need on the applicability of this method with field data. Ringtail densities were highest in the areas of greatest human activity. The proximity to humans may be impacting ringtail diet and consequently their health. I collected scat in areas of high and low human density to measure the change in diet resulting from food acquired around human establishments. Ringtails living in areas of high human activity exhibited a change in diet, including the presence of human trash such as foil and plastic; this has implications for ringtail health and human safety. Ringtails acquiring food from human sources may increase their activities around buildings and areas with high human activity, resulting in an increased chance of direct and indirect human-ringtail interactions. Active management of human activities and regular building maintenance is required in the future to decrease negative consequences of ringtail use and presence in areas of high human activity.

"Everything will be okay in the end. If it's not okay, then it's not the end."

- Fernando Sabino


AAR 07/2014

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A. A. Roadman

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THESIS FORMAT

This thesis is written in a multi-paper format, allowing for various formatting styles according to the prospective journals to which the information will be submitted for publication. Chapter 1 is a general introduction and overview of the entire thesis and follows the format of the Journal of Wildlife Management. Chapter 2 is written and formatted as a manuscript that will be submitted for publication in the Journal of Wildlife Management. Chapter 3 is formatted according to the guidelines for submission to Methods in Ecology and Evolution. Chapter 4 is formatted for submission to The Southwestern Naturalist. Finally, Chapter 5 is a concluding commentary on the thesis as a whole and follows the guidelines of the Journal of Wildlife Management. The appendix is a final report prepared for Zion National Park discussing a portion of the research for this project that is not presented elsewhere within the thesis. This is written as a stand-alone document for the National Park's reference and is written in the format of the Journal of Wildlife Management.

CHAPTER 1

THESIS INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Despite its abundance throughout southwestern North America, due to their elusive and secretive nature, current scientific knowledge of the ringtail (*Bassariscus astutus*) is relatively limited (Ackerson and Harveson 2006). Aside from consistent entries in general works on mammals (e.g. Hall 1981), the current ecological information about ringtails is sparse when compared with that of other North American mammals. Although ringtails are present across a wide range, previous studies have only covered a small portion of their overall range. To date, a number of studies of ringtails investigated the diet of this small omnivore (Taylor 1954, Wood 1954, Trapp 1972, Chevalier 1984, Wyatt 1993, Alexander et al. 1994). A few studies focused on movement patterns, home ranges, and activity patterns (Trapp 1978, Toweill and Teer 1981, Lacy 1983, Ackerson and Harveson 2006, Montacer 2009, Myers 2010), while assorted other studies explored topics such as helminth load (Pence and Willis 1978), disease prevalence (Krebs et al. 2003), and behavioral trends (Winkler and Adams 1972, Richards 1976, Willey and Richards 1981, Gabriel et al. 2008, Harrison 2012). In more recent years, research investigated the genetic profile of the ringtails, analyzing phylogeny (Koepfli et al. 2007) and population variation of genetic structure (Schwiezer et al. 2009, Lonsinger 2010).

Physiology

This small, housecat-sized omnivore belongs to the family Procyonidae, the family also encompassing the cacomistle (*Bassariscus sumichrasti*), the kinkajou (*Potos flavus*), the raccoon (*Procyon lotor*), and the white-nosed coati (*Nasua narica*) (Baskin 2004, Koepfli et al. 2007). Ringtails are a small procyonid with an average weight of 0.7-1.8 kg (Poglyen-Neuwall and Toweill 1988, Ackerson and Harveson 2006). The total body lengths range between 616-811 mm, with males commonly larger than females, both by weight and morphometric measurements (Kaufman 1982, Gehrt 2003, Montacer 2009, Harrison 2012). The ringtail lifespan averages 12-14 years in captivity, with a maximum of 16.5 years (Poglayen-Neuwall 1987). Body pelage ranges from stony gray through light tan to chestnut with longer black-tipped guard hairs and thick, light colored belly fur (Hall 1981, Poglayen-Neuwall and Toweill 1988). The coloration differs across regions, matching surrounding habitat colorations, with more northerly regions favoring darker individuals and lighter individuals occurring in more southern and desert habitats (Poglayen-Neuwall and Toweill 1988, D. Wyatt, Sacramento City College, personal communication). The face is marked with a striking black and white mask around the eyes. An annulated tail with 7-8 alternating black and white stripes is nearly as long as the body and provides excellent balance, combined with the rotatable ankle joints for extremely quick and agile change in direction while climbing (Trapp 1972, Poglayen-Neuwall and Toweill 1988).

The feet are semi-plantigrade and pentadactyl with short, semi-retractable claws (Hall 1981, Poglayen-Neuwall and Toweill 1988). These claws and 180-degree-rotatable hind feet are used to skillfully climb trees, ascend nearly-vertical rock walls, and foray into extremely narrow rock crevices (Trapp 1978, Schmidly 2004).

Ringtails exhibit agile climbing techniques such as chimney-stemming, ricocheting, powerful leaps, reversing directions on narrow ledges, and claustrophilic behavior (Mandolf 1961, Trapp 1972). The ability to quickly maneuver their body into tiny, close fitting spaces is a mechanism used to escape predators. Both behavioral and anatomical adaptations allow ringtails to utilize almost any vertical habitat they encounter (Trapp 1972, Montacer 2009).

Diet and Foraging

Mesocarnivores are important members of an ecological community, playing a key role in seed dispersal, feeding on diverse species, and acting as prey to larger predator guilds. Ringtails fill this role in many of the places they live: they depredate and help control populations of rodents, insects, and reptiles while also eating fruits of various plants and dispersing their seeds. They do little stalking to obtain their live prey, but are instead a rush-and-pounce predator, often killing with a bite to the back of the head once the prey is pinned underfoot (Poglayen-Neuwall 1987). Supplementary to their efficient predation, ringtails are omnivorous and are opportunistic feeders (Taylor 1954, Lemoine 1977, Toweill and Teer 1977, Trapp 1978, Rodriguez-Estrella et al. 2000); their specific diet content shifts with food availability (Nelson 1918, Taylor 1954, Belluomini 1980, Alexander et al. 1994). They will consume fruit, nectar, and various plant materials when necessary (Kuban and Schwartz 1985; Poglayen-Neuwall and Toweill 1988). Diet selection is related to changes in seasonal environmental conditions (Taylor 1954, Wood

1954, Kuban and Schwartz 1985, Wyatt 1993). Berries and plant material are usually more present in summer and autumn diets (Taylor 1954, Bailey 1974, Alexander et al. 1994). In scats sampled, the occurrence of plant matter ranged from 67% in Zion National Park, Utah (Trapp 1978), to 93% in Oregon (Alexander et al. 1994). While rare in the winter, insects play a key role in the diet of many ringtail populations during summer and fall months, becoming a favored protein source when available (Taylor 1954; Davis 1960; Belluomini 1980; Poglayen-Neuwall 1987). In Utah, insect remains were present in 53% of the scats sampled (Trapp 1978) and in 32.4 % of the scats sampled in the Edwards Plateau, Texas (Toweill and Teer 1977). During the breeding season (spring), in particular, mammal content in the diet is highest, occurring in as many as 66% of scats sampled (Ackerson and Harveson 2006). Amphibians and reptiles have relatively low occurrences in scat, even being essentially absent from some diets (Alexander et al. 1994), but are recorded at low levels across many different diet studies (Taylor 1954, Wood 1954, Trapp 1978, Wyatt 1993). Birds are also present in many scats, but this is often seasonal, suggesting the remains are from nestlings and are the result of arboreal foraging (Alexander et al. 1994). For example, one incident documented a ringtail foraging on peregrine falcons nestlings along a cliff (White and Lloyd 1962). Finally, there have been observations of ringtails consuming carrion, mostly avian and during winter and early spring (Taylor 1954, Toweill and Teer 1977, Trapp 1978, Mead and van Devender 1981).

While ringtails will utilize open water if available, their kidney function is modified for water conservation (Poglayen-Neuwall and Toweill 1988). When water-stressed, as dietary or freestanding water becomes scarce or absent, both a high-protein diet and a diet supplemented with fruit, berries and insects, will allow a ringtail to forego drinking water completely, if necessary (Richards 1976; Chevalier 1984, 2005; Poglayen-Neuwall and Toweill 1988). Sometimes, even when freestanding water is present, ringtails will avoid it in favor of protection from predators (Tiedt 2011). Their ability to decrease dependency upon open water is particularly useful for lactating females, newly weaned young, and dispersing individuals.

Activity and Breeding Patterns

Ringtails are primarily nocturnal (Nelson 1918, Fry 1926, Grinnell et al. 1937, Leopold 1959, Kavanau 1970, Kavanau and Ramos 1972, Trapp 1978). Most of their daily activity occurs between 20 minutes after sunset and 60-120 minutes before sunrise, with peak activity just around midnight (Kavanau and Ramos 1972; Callas 1987). Rarely will an individual be active at dusk or dawn; even low levels of light solicited a strong negative reaction in captive ringtails (Kavanau 1970).

Ringtails remain solitary for the majority of the year and individuals den separately, except during the breeding season (Poglayen-Neuwall and Toweill 1988). The breeding season occurs from March to April with parturition occurring in May or June (Toweill 1976, Belluomini 1980, Poglayen-Neuwall and Poglayen-Neuwall 1980). Females are receptive to males for only one 24-36 hour period during estrus (Poglayen-Neuwall and Poglayen-Neuwall 1980), therefore scent marking within a territory may be used as a method of transferring information about the female's reproductive status in advance to attract males within the area (Callas 1987). Gestation is approximately 50 days and reported litter sizes usually range from 1-4 kits (Nelson 1918, Fry 1926, Grinnell et al. 1937, Taylor 1954, Poglayen-Neuwall and Toweill 1988, Schmidly 2004). When the kits are born, they have short white hair and are blind with closed ears. Eyes open 31-34 days after birth, ears a week earlier. Kits are weaned at approximately 73 days of age and the juvenile ringtails begin denning away from their mother at this time (Toweill 1976, Poglayen-Neuwall and Poglayen-Neuwall 1980). Initially, juvenile pelage is gray and downy, but by four months of age, the juveniles' pelage is indistinguishable from adults (Fry 1926, Richardson 1942, Toweill 1976, Toweill and Toweill 1978). The female parent mainly rears the litter, but some paternal care has been described, such as food provision to the litter while it is in the den (Fry 1926, Grinnell et al. 1937, Leopold 1959, Lemoine 1977, Kaufman 1982). Conclusive evidence about parental social structure is still largely unknown.

Both male and female ringtails will use urination and defecation to mark their territory (Tayler 1954, Barja and List 2006). Defecation marking is sometimes done with a single deposit, often near the center of the territory, but is also commonly done in latrines (Trapp 1978). Latrines are concentrations of feces and urine usually consist of 2 to 19 fecal deposits (Trapp 1978, Barja and List 2006), although some massive latrines have been observed in buildings consisting of many dozens of feces (A. Roadman, USU, personal observation). The placement of such latrines is either on conspicuous substrates or in conspicuous locations (Trapp 1978, Barja and List 2006). The latrine is commonly raised above ground level to increase the exposure of the marking (Barja and List 2006).

Denning

Ringtails use a wide variety of formations and items as dens including: tree stumps, brush piles, downed logs, tree snags, rock piles, caves, cliff walls, underground cavities, hollow trees, and even duck nesting boxes (Naylor and Wilson 1956, Toweill 1976, Trapp 1978, Lacy 1983, Callas 1987, Yarchin 1990, Alexander et al. 1994). Ackerson and Harveson (2006) found that ringtails exclusively denned in rock piles in Brewster County, Texas, despite the presence of many brush piles and downed logs available. Trees accounted for 68% of den sites selected in northwestern California, and Douglas fir (*Pseudotsuga menziesii*) was strongly selected for, although black oak (*Quercus velutina*), ponderosa pine (*Pinus ponderosa*), and canyon live oak (*Quercus chrysolepis*) were also used (Callas 1987). In winter, rock piles are not used as heavily as more insulating den sites such as downed logs, or tree hollows. The inverse was true in high temperature areas where the rock piles or rock crevices are selected for during the summer, potentially for the thermo-regulative properties of the rock (Toweill 1976, Trapp 1978, Callas 1987, Yarchin 1990). Callas (1987) reported 89% of the rock piles selected by ringtails as den sites were on south facing slopes, suggesting thermoregulation was a factor in den selection. Bedding was not used in establishing the den, even when young were present (Toweill and Teer 1981, Schmidly 2004). Den sharing occasionally happens, and can be intrasexual or intersexual (Callas 1987, pilot study 2011); however, Toweill and Teer (1981) recorded 268 ringtail den uses and never observed two adults using the same den at the same time.

Outside of the breeding season, adult ringtails will rarely use the same den for consecutive days (Toweill 1976, Callas 1987, Yarchin 1990). The average time a ringtail stayed at one den ranges from 2.17 days across both sexes (Ackerson and Harveson 2006) to 1.58 days stayed by males and 2.25 days stayed by females in central Texas (Toweill 1976). Higher den fidelity was documented near Calistoga, California where each ringtail used 3-10 dens, but continued to rotate regularly between den sites (Koch and Brody 1981).

Predation

The primary predation threats to ringtails are nocturnal aerial predators, such as the great-horned owl (*Bubo virginianus*). However, coyotes (*Canis latrans*), raccoons (*Procyon lotor*), bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*) also will take ringtails, if able (Mollhagen et al. 1972, Poglayen-Neuwall and Toweill 1988, Ackerson and Haverson 2006). Mortality can occur as a result of snakes, domestic dogs and cats (*Canis lupus familiaris* and *Felis catus*), human trappers, and increasingly automobiles, particularly in Texas (Kaufman 1982; Orloff 1988). Disease does not appear to be a significant issue, with only minor occurrences of rabies and feline or canine distemper (Poglayen-Neuwall 1987). Various parasites do infest ringtails, notably fleas and ticks (Pence and Willis 1978, D. Wyatt, personal communication), and these potentially play a key role in population control (Poglayen-Neuwall 1987).

Distribution and Density

Currently in North America, ringtail distribution extends from Mexico along the western coast of the United States into southwestern Oregon and through the southwest to Colorado, Nebraska, Arkansas, Oklahoma, Texas, and Louisiana (Fig. 1-1; Bradley and Hansen 1965, Hall 1981, Anderson and Holzem 1992, Wozencraft 2005). Ringtails occur from sea level (Grinnell et al. 1937) to nearly 3000 m (Schempf and White 1977), spanning a vast range of habitats. Across many elevations, they show a preference for rough, rocky terrain independent of the vegetation community or presence of trees (Grinnel et al. 1937, Davis 1960, Hall and Dalquest 1963). They often make use of chaparral, piñon-juniper woodland (*Juniperus osteosperma*, *Pinus edulis,* and *P. monophylla*), blackbrush (*Coleogyne ramosissima*), and various scrub vegetation communities (Grinnell et al. 1937, Trapp 1978), or at higher elevations, select for Douglas fir forests (Alexander et al. 1994). The importance of a riparian zone has been shown in many studies (Naylor and Wilson 1956, Trapp 1972, Koch and Brody 1981, Toweill and Teer 1981, Belluomini 1983, Lacy 1983, Belluomini and Trapp 1984), although this is potentially a factor of the resource abundance in the riparian areas (Poglayen-Neuwall and Toweill 1988).

Competition between ringtails and sympatric mesocarnivores throughout their range may also act to concentrate ringtail activity into riparian areas (Yarchin 1990). However, in both Texas and California, ringtails exploit nearly every available type of habitat within their range (Taylor 1954, Orloff 1988). The use of these habitats is not always proportional, though, suggesting a gradient of habitat preference and an importance of habitat structure to the distribution of these ringtails (Lacy 1983, Yarchin 1990, Ackerson 2001). This variation in habitat structure and use may explain the variation of ringtail densities observed across many studies, because resource abundance plays a key factor in the carrying capacity of a habitat (Ackerson and Harveson 2006). In Utah, the population density was considered low compared to other regions (1.5 ringtails/km^2; Trapp 1978, Poglayen-Neuwall and Toweill 1988). In riparian areas of central California, densities of 10.5-20.5 ringtails/km^2 and 7-20 ringtails/ km^2 were observed (Belluomini 1983, Lacy 1983), the highest reported density. The lowest density reported is 0.8 ringtails/ km^2 in northwestern California (Callas 1987).

Home Range

Home range estimates of ringtails are site-specific and vary greatly based on the local habitat and research techniques used to gather the information. Some of the largest recorded home ranges were observed in Calistoga, California with an average home range of 221 ha for 4 observed ringtails (Koch and Brody 1981). In Zion National Park in the late 1960s, the home ranges of 2 adult females monitored over periods of 5 to 10 days averaged 129 ± 11.8 (SD) ha and 7 adult males monitored over the same period averaged 139 ± 53 (SD) ha (Trapp 1978). During this study, males tended to use a larger home range in the winter than females, and the females held the largest home ranges in April. Most studies have shown significantly smaller ringtail home ranges: 43.4 ± 11.8 (SD) ha and 20.3 ± 6.5 (SD) ha in Kerr County, Texas, for two males and three females, respectively (Toweill and Teer 1981), 5.0-13.8 ha in Central Valley of California (Lacy 1983), 28 ±16.3 (SD) ha and 63 ha ± 21.9 (SD) ha for summer and winter months in the Trans Pecos region of Texas (Ackerson and Harveson 2006), and 35.9 – 81.2 ha for 3 males and 2.76 ha for 1 female in Palo Duro Canyon State Park, Texas (Montacer 2009). Instead of a home range in northwestern California, a mean denning range was calculated to be 175 ± 111 (SD) ha (278 ha for males, 124 ha for females; Callas 1987).

Usually, female home ranges will not overlap those of other adult females, while male home ranges may include pieces of many distinct female home ranges (but will not overlap those of other males; Trapp 1978, Toweill and Teer 1981, Lacy 1983, Callas 1987, Montacer 2009). However, a study in Brewster County, Texas, documented the overlap of both intersexual and intrasexual ranges on many occasions (Ackerson and Harveson 2006). The differences in home range size and usage are likely tied to the climate, habitat, and resources available in the sampled area, but some discrepancy may be an artifact of the varying methods used to monitor telemetered ringtails as well as methods used to analyze the identified locations (Montacer 2009).

Zion National Park Distribution

The most likely habitat used by ringtails –boulder-strewn riparian areas (Trapp 1972)–overlaps with the areas of highest human activity within the park boundaries. This overlap leads to an increased frequency of ringtail conflict and damage. Most ringtail sightings occurred around human structures in the main canyon, implying at least a presence of ringtails in this area, if not a distinct concentration (C. Crow, NPS, personal communication). Three main areas of highest concern for ringtail conflict were: the National Park Service Maintenance Complex, the National Park Service Headquarters Complex, and the Zion Lodge Complex (Fig. 1-2).

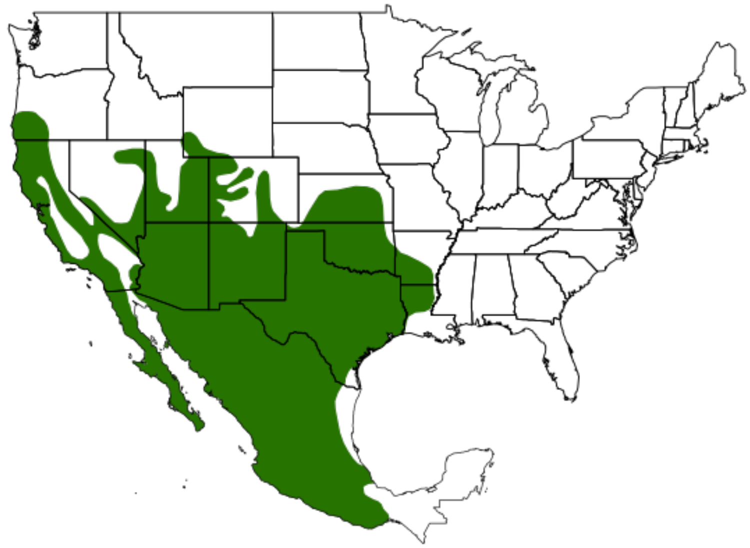

Figure 1-1. Distribution of ringtails (*Bassariscus astutus*) throughout southwestern North America, as of 2008.

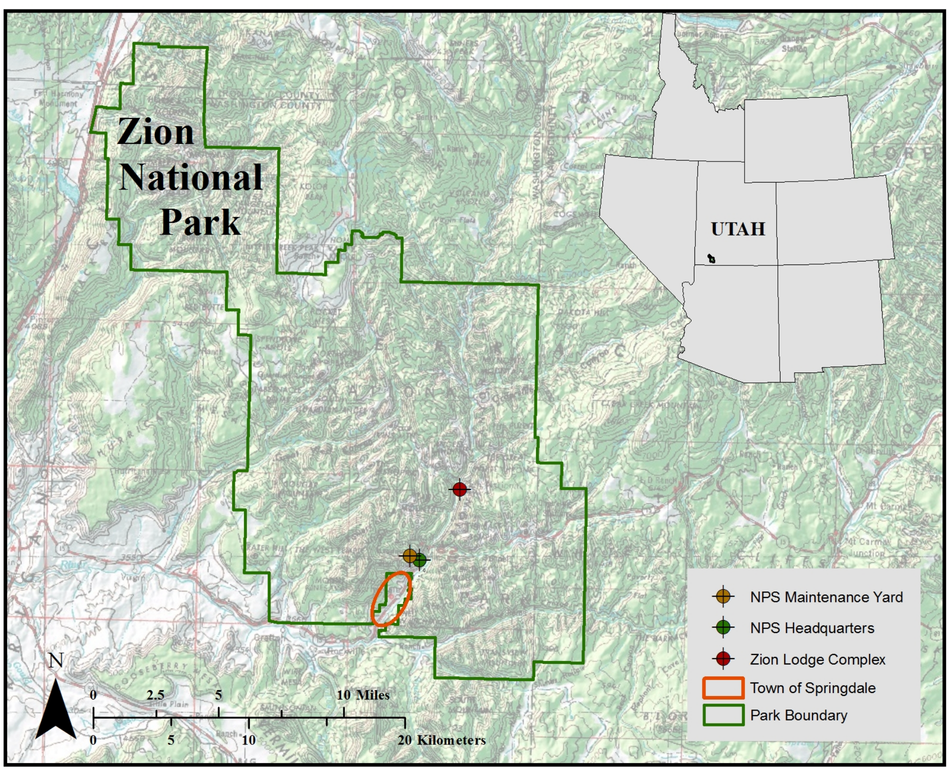

Figure 1-2. Map showing National Park Service (NPS) and Zion Lodge properties with high concern for human-ringtail (*Bassariscus astutus*) conflict in and around Zion National Park, Utah, from August 2011 to September 2013.

Interactions with Humans

Across their range, reported ringtail conflicts with humans involved damage to structures, theft of food stores, and the occasional raiding of a chicken coop (Belluomini 1980). They rarely den in buildings occupied by humans (Schmidly 2004). However, one of many common names for this animal, the "miner's cat," resulted from the historic domestication of ringtails in mining camps due to their excellent rodent-hunting skills (Poglayen-Neuwall and Toweill 1988). Although ringtails are sometimes kept as exotic pets, the extent of this practice is not widely documented.

In southern Utah's Zion National Park, ringtails are found year-round in cabins, maintenance buildings, historic sites, and restaurants and cause varying levels of financial, historical, and aesthetic damage (C. Crow, personal communication). The ringtails may enter these buildings to follow food sources (infesting rodents, exposed human food, etc.) and to seek warmth and shelter. Ringtails can enter any hole large enough to fit their skull, allowing them easy access into many buildings (Fig. 1-3). All of these characteristics combine to create a population of mesocarnivores capable of regularly entering human structures via neglected access points, and damaging merchandise and historic structures, or causing personal unease. The financial implications of human-ringtail interactions are increasing; the influence of these interactions on ringtail biology is largely unknown.

To properly manage for ringtail damage, better ecological information is needed to help identify and mitigate the cause for conflicts with humans. Much of the basic ecological information such as ringtail population size, extent, distribution, and habitat use in Utah is currently unknown, vague, anecdotal, or antiquated. To date, the only scientific analysis of ringtails in Zion National Park occurred in 1966-1967 and focused on movement patterns and activity budgets (Trapp 1978). Because of the potentially outdated nature of this information in relation to population dynamics and human settlement expansion in the canyon, current management decisions require updated information.

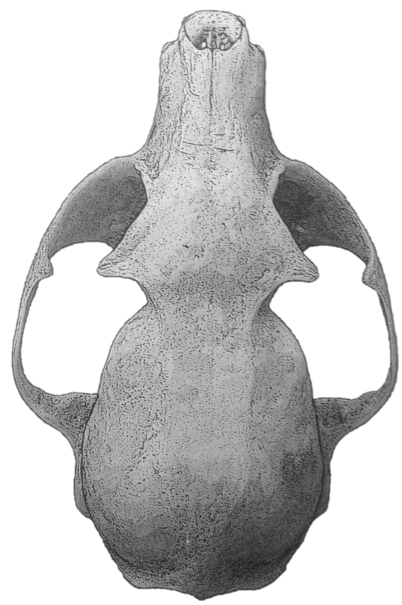

Figure 1-3. Life-sized representation of a ringtail (*Bassariscus astutus*) skull displaying the maximum width of the skull between the zygomatic arches of an average adult male ringtail.

STUDY PURPOSE AND RESEARCH OBJECTIVES

The ringtail population of Zion National Park is a valuable and distinctive resource that is an important component of the local ecosystem which also provides great enjoyment to the visitors of the national park. Unfortunately, the level of damage caused by individuals throughout the year has reached an intolerable level for the governing body of the park, prompting them to request a study on current ringtail distribution and diet.

In past years, “conflict” ringtails have been live-trapped from buildings and relocated, but multiple repeat visits within a short time indicate that the relocations were not successful, and preventative methods may be the best tool to manage this human-wildlife interaction (C. Crow, personal communication, N. Frey, USU Extension, personal observation).

This study examined basic ecology of the ringtail and reviewed various attempts to exclude ringtails from buildings while developing management suggestions to prevent future ringtail damage. The objectives of this research were to: 1) confirm ringtail use of known habitat types, 2) review detection methods of ringtails and assess population size, and 3) determine impact of human conflict on ringtail biology. All three of these objectives will contribute to the development of a ringtail management recommendation for Zion National Park based on updated ecological information.

Research Questions

Question 1: What is the distribution of ringtails in Zion National Park?

H_0: Ringtails will not be associated with perennial water and will be detected equivalently throughout the study area.

H_1: Ringtails will be associated with perennial water

H_2: Ringtails will be detected more often in Zion Canyon than in other portions of Zion National Park

Question 2: Can ringtails be individually identified through dermatoglyphics of the feet?

H_0: The patterning on the ringtail's footpads is not distinct to individual.

H_1: The patterning on the ringtail's footpads is detailed and distinct enough between individuals to be an identifying characteristic.

H_2: The above method is accurate enough to use in the field.

Question 3: What is the diet structure of ringtails in Zion National Park?

H_0: Ringtail diet will not differ based on proximity to human activity.

H_1: Ringtails living in close proximity to humans and human activity will have a different diet than those living away from most human activity.

H_2: Generally, ringtails in Zion National Park will have a similar diet to those published in previous literature.

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CHAPTER 2

DETECTION RATES OF RINGTAILS (*BASSARISCUS ASTUTUS*) IN ZION NATIONAL PARK USING COMBINED NONINVASIVE SURVEY METHODS

ABSTRACT

Noninvasive methods for detecting wildlife presence provide the means to gather large-scale population information about elusive or wary individuals in desert ecosystems. One such animal present throughout the southwest is the nocturnal ringtail (*Bassariscus astutus*). For ringtails, a reliable noninvasive detection method is not well documented. I evaluated 2 methods in combination: camera-traps and track-plates, to establish a robust occupancy estimate of the ringtail population in Zion National Park, Utah. Both methods successfully detected ringtails in various habitats in all four seasons sampled. Combining camera-traps with track-plates increased the likelihood that a site will register a positive detection when a ringtail is present. These methods were used to build an occupancy estimate of ringtails (ψ=0.270, SE=0.092, 95% CI=0.130, 0.480) as well as an estimated probability of detection (p=0.120, SE=0.092, 95% CI=0.130, 0.480). The addition of the track-plate to the camera trap does not statistically improve the occupancy model; however, it increased the number of sites at which an animal was detected.

The ringtail (*Bassariscus astutus*) is a small mammal in the family Procyonidae, commonly found throughout the southwestern regions of North America. However, the extent of scientific research conducted on this species' ecology is disproportionately narrow when compared to their widespread occurrence. In southwestern Utah, the ringtail is most well known for its presence in Zion National Park (hereafter "Zion"), the location of a major ringtail research project in the late 1960s (Trapp 1973). Since then, there has been no formal ecological research conducted to assess or monitor the demography, distribution, or resource needs of ringtails in Utah. The lack of this information potentially impedes current management efforts; without baseline data about population trends and history, it is difficult to make accurate decisions to enact change on the population or to maintain the status quo.

Dependable monitoring techniques and protocols are vital to the success of determining the occupancy of ringtails in Zion. A well-defined survey protocol and schedule would allow investigators to gather better information such as presence-absence data, activity and habitat use patterns, and response to human presence and utilize this information for improved species management (Hackett et al. 2007). Documenting ringtail occupancy throughout Zion will provide park managers with better information about distribution, habitat use, demography, or other population variables.

Most carnivore species are challenging to survey due to their elusive, often solitary nature and relatively low population densities. While abundance information can be gathered by live-trapping, this can be invasive, labor intensive, expensive, and stressful to the animals, as well as problematic or even impossible in areas of regular public visitation, such as Zion.

To identify the presence of carnivores and determine occupancy across large areas or in specific habitat types, researchers are increasingly turning to noninvasive survey methods. Not only do noninvasive methods have the potential to increase the temporal and spatial scale available for sampling, they can decrease the labor, expense, and animal stress necessary to obtain accurate abundance estimates (Kelly and Holub 2008, Harrison et al. 2002, Gompper et al. 2006).

Certain species may avoid equipment or station designs, potentially leading to a false negative for a particular location (Gompper et al. 2006, Vanak and Gompper 2007), so a range of noninvasive techniques are available and have been found to be effective in measuring presence-absence, and sometimes relative abundance, of mesocarnivores (Zielinski and Kucera 1995, Zielinkski and Stauffer 1996, Gese 2001, Wilson and Delahay 2001, Campbell 2004, Vanak and Gompper 2007). Some common noninvasive methods in use are: motion-triggered cameras, track-plates, track plots, scent stations, snow-tracking, scat surveys, and hair snare surveys (Gompper et al. 2006). While snow-tracking is weather, habitat, and species dependent, hair snaring and scat surveys are suitable methods for numerous species (Gompper et al. 2006). However, the financial requirements of the subsequent genetic analysis required for hair snare and scat surveys can ultimately limit the scope of these methods. The two most common methods used to noninvasively sample small to mid-sized carnivores are motion-triggered camera-traps and track-plates, both of which employ an attractant, either scent or bait, to lure a target species to a station, logging the animal’s presence with a photograph or a track print (Zielinski and Kucera 1995; Foresman and Pearson 1998; Gese 2001, 2004; Wilson and

Delahay 2001). While both methods are useful, the efficacy of these methods depends on the species of interest.

Common Detection Methods

Camera-trapping uses motion-triggered, infrared, semi-covert, night-vision cameras, or a combination of these, placed strategically throughout a habitat to capture and document animal occurrence. Although camera-trapping has been used to survey animals with individual coat or pelage patterns to build an accurate abundance estimate with mark-recapture analyses (Karanth and Nichols 1998, Maffei et al. 2004, Núñez-Pérez 2011), it can be adapted to obtain presence-absence information of species without individual coat designs. The significant technological advances in recent years, such as digital photograph storage instead of film, longer battery life, and a more compact size, have allowed for greater development of this technique with finer image detail and more data storage capabilities. Along with increased affordability and reliability of camera-trapping, the effort needed to execute this method has decreased in comparison to the data provided, when compared to alternative methods (Gompper et al. 2006).

Track-plates or plots record animal tracks using either charcoal track-plates or sand-based track plots. Track-plates and track plots have been used for many years to provide a trend of population size of many mammals (Wemmer et al. 1996, Lyra-Jorge et al. 2008).

Track-plates, sooted aluminum plates which record a footprint negative or positive based on design, have been used extensively throughout habitat types (Gompper et al. 2006). Track-plates are most commonly used to document small and mid-sized animals due to the practicality of setup and the logistics of building an enclosure, which are often inefficient when studying a large-bodied animal (Zielinski and Kucera 1995, Gese 2001, Wilson and Delahay 2001, Glennon et al. 2002, Gompper et al. 2006). Track-plots, which are open pits of sand or dirt created to record footprint negative or footprint mold, have been more commonly employed in forested or heavily covered areas with elusive carnivores or small mammals (Wemmer et al. 1996).

Detection Method Selection

The ringtail is a small (1 kg), elusive, nocturnal omnivore that is capable of utilizing a wide range of habitat types (Trapp 1972, Trapp 1973). They are opportunistic feeders, and habitat generalists, making use of caves, crevices, cliffs, boulder piles, fallen logs, living trees, and buildings, if there is an access point (Trapp 1973). In Zion, ringtails are most commonly located in the riparian habitats. Their tie to the riparian habitat is due to their reliance on the higher abundance of food sources available in riparian areas of the desert ecosystem (Trapp 1978, Poglayen-Neuwall and Toweill 1988).

Objectives

The objectives of my study were to measure ringtail presence within known ringtail habitat (Trapp 1973) and estimate the distribution of ringtails throughout Zion National Park. I hypothesized that ringtails would be associated with perennial water and would be more often detected in Zion Canyon than other regions of the park, due to the high concentration of habitat in this area that is known to be used by ringtails.

STUDY AREA

I conducted my research in 3 main sections of Zion National Park, Washington County, Utah U.S.A (hereafter 'Zion'): Zion Canyon, Kolob Terrace, and the Kolob Canyons (Fig. 2-1). Zion Canyon, which is composed of the lushest wildlife habitat and the majority of the riparian habitat in Zion, experiences the highest human visitation of any portion of the park. The highest visitation on record, 2.97 million visitors, occurred in 2012. The Kolob Canyons portion receives only a fraction of that human volume. In the same year, 2012, only 175,000 visitors spent time in Kolob Canyons. It is tricky to measure visitation in the third area of interest, Kolob Terrace, because it is not controlled by an entrance gate, but is instead bisected by a public road, the Kolob Terrace Road. The majority of the land is designated wilderness and only accessible through technical hiking or canyoneering. This region of the park has only one primitive campground and no other amenities. Until 2011, a traffic count through this region was collected, but data is not reported for 2012 or 2013. In 2011, 40 thousand vehicles used the road throughout the year (NPS 2014).

The Virgin R. flows continuously through Zion Canyon, although in the hot, dry summer months, the tributary drainages throughout the study area tend to dry or become intermittent, exposing long stretches of dry streambed. Vegetation throughout the park varies with the elevation. At the lower elevations of Zion Canyon, desert vegetation associated with the Sonoran Desert is present. Piñon-juniper communities (*Juniperus osteosperma*, *Pinus edulis,* and *P. monophylla*) are most common at intermediate elevations; ponderosa pine (*Pinus ponderosa*) forests with Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) present in cooler, moister areas at the highest elevations (Nelson 1976). On the floor of the canyon, near the Virgin R., a deciduous forest prevails with Fremont's cottonwood (*Populus fremontii*), velvet ash (*Fraxinus velutina*), bigtooth maple (*Acer grandidentatum*), and Gambel Oak (*Quercus gambelii*). The Kolob Terrace region has small tributaries to the Virgin R. but these are all ephemeral. The elevation here is some of the highest in the park, and firs and ponderosa pine are most common, with a few piñon-juniper communities included. Year-round water is isolated to a few narrow slot canyons. The Kolob Canyons portion of Zion has one major body of water, Taylor Creek, which feeds into LaVerkin creek just outside of the park boundary.

METHODS

Survey Locations

The survey was conducted throughout all 3 major regions of the park: Zion Canyon, Kolob Terrace, and Kolob Canyons (Fig. 2-1). I used ArcGIS (version 10.0, Environmental Systems Research Institute, Redlands, CA) to determine random trap locations throughout each of the 3 regions. I overlaid a map of the entire park with road and water layers. Next, I created a 1-km buffer around both the road and water layers, and extracted the area that was both 1-km from a road and 1-km from water. The road buffer ensured that I would be able to reach any selected detection locations efficiently, safely, and consistently. Finally, I created a grid of locations 50 m apart, and fit it to the area I had delineated. With this final layer of points within 1-km of a road and water, 50 locations were randomly selected for sampling. If the random point produced was in an inaccessible area (e.g. inaccessible cliff top), the point was thrown out and another selected. Due to the high concentration of human presence and known potential ringtail habitat in the Zion Canyon regions, 50% of the sampling locations were selected to fall within this area.

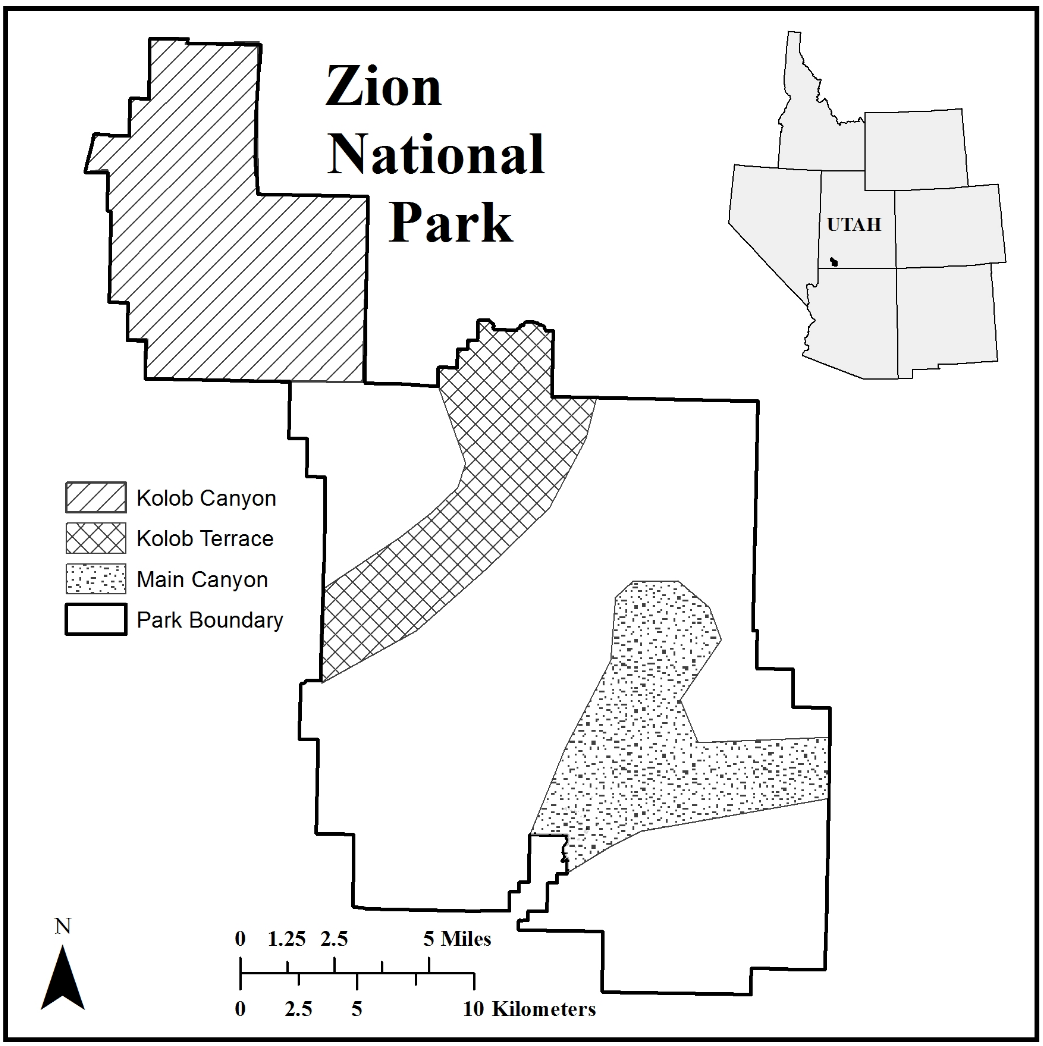

Figure 2-1. Map showing 3 sampling regions within Zion National Park, Utah, where ringtails (*Bassariscus astutus*) noninvasively sampled, May 2012 - August 2013.

Survey Methods

I used a combination of detection methods for a survey of ringtail distribution and habitat use in Zion. To gain the most temporally accurate information, I surveyed throughout suitable habitat in Zion using camera-traps. However, to add an additional measure of detection, as well as increasing the likelihood of individual identification, I included a track-plate at every camera location. The recent innovations in computer-aided pattern recognition software may allow for the identification of individuals based on the patterning of the footpad and the subsequent detail left in the footprints registered on the track-plate (Herzog et al. 2007). By combining the camera-trap with a track-plate at every site, I aimed to increase the potential detection and reduce error in my detection rate.

Each sampling station consisted of two digital trail cameras (Bushnell® Trophy Cam™ 8 megapixel, Bushnell Corp., Overland Park, KS) focused on a corrugated plastic tunnel (Coroplast ®, Dallas, TX) enclosing a 0.32 cm thick aluminum plate (Clinton Aluminum, Clinton, OH) coated in charcoal (Gompper et al. 2006) and an olfactory raccoon attractant (F&T Fur Harvester's Trading Post).

To begin the survey setup I placed the track-plate tunnel at the chosen location. The track-plate tunnel was a collapsible corrugated plastic tunnel measuring 30.5 cm x 30.5 cm x 91.4 cm with overhanging lips to protect from rain and sun (Gompper et al. 2006). Four guylines, one tied through a hole at each corner, staked the tunnel to ground to combat wind gusts (Fig. 2-2). A 30.5 cm x 91.4 cm plate of either aluminum or corrugated plastic lay on the bottom of each track-plate tunnel. At one end of the track plate, I placed plain white adhesive drawer lining paper (Con-Tact Brand®, Pomona, CA) to cover 30 cm of the plate in front of the camera. This was attached with tape so that it was adhesive side up on the plate with the protective paper removed.

A plastic cable tie secured a small plastic vial to the sidewall of the tunnel directly over the adhesive paper. Each vial contained a cotton swab dipped in olfactory lure. Three types of commercially available olfactory raccoon lure were included and randomly selected for application at each site: June’s Ridgerunner Coon Lure, Miranda’s Creekbank Coon Lure, and Wildlife Research Center’s Hard-Core Raccoon Lure #1. In place of the traditional sooted aluminum plate method using an acetylene torch (Herzog et al. 2007), I designed and implemented a new method for this study. Using a 1:6 concentration of black powdered artist’s charcoal (General’s, Jersey City, NJ) and 70% isopropyl alcohol to create a charcoal slurry, I painted the remaining length of plate beyond the adhesive paper and just below and behind the camera. The alcohol quickly evaporated, leaving a thin, even layer of charcoal lightly adhered to the plate. As an animal walked into the tunnel to investigate the lure, the animal’s footpads picked up this fine charcoal and deposited it as a positive footprint onto the adhesive paper present in the tunnel underneath the lure.

I situated two trail cameras to detect animals visiting the site. The first of the two cameras dedicated to each site was attached to the end of the tunnel using polypropylene webbing and metal snaps secured to the plastic walls (Fig. 2-2). This camera detected animals that ventured inside the track plate tunnel. The second motion-triggered camera was placed in an overlooking position exterior to the track-plate tunnel to detect any individuals that visited the trap site, but did not enter the tunnel. This camera was strapped to available trees, rocks, or stumps using webbing, buckles, bungee cords, and

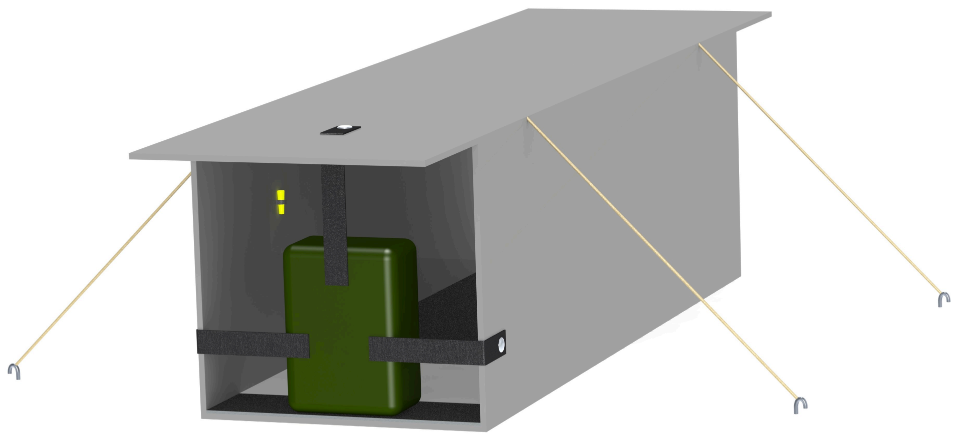

Figure 2-2. Schematic of the combination camera-trap and track-plate tunnel used to noninvasively sample ringtails (*Bassariscus astutus*), May 2012 - August 2013 in Zion National Park, Utah.

cable locks 2-4 m from the tunnel to provide proper angle of detection in the surrounding area. Exterior cameras were programmed to record 3 photos at every motion trigger on a normal sensitivity and then remain inactive for a 30 second interval before becoming sensitive again. The camera within the tunnel was only inactive for 15 s between potential triggers. The cameras were set to record the date and time of a triggering event.

Survey Sampling Design

I divided the calendar year into 3 sampling seasons based on ringtail natural history: spring 2013 (January-April), summer 2012, 2013 (May-August), and fall/winter 2012 (September-December). The spring period represented the time just before breeding (late March/early April) and summer encompassed the main kit-rearing season. Because activity declined and denning increased when temperatures dropped, and the timing of this was unpredictable, I combined fall and winter months. Each sampling season consisted of sampling 5 locations for 7 consecutive nights, then sampling the next 5 random locations for 7 nights, until all 50 locations had been sampled for 7 nights each.

Data Analysis

I analyzed the detection rate of ringtails using the two noninvasive methods across seasons with a general linearized mixed model (GLMM; Royle et al. 2009) with binomial error distribution and logit link, using the statistical software SAS (version 9.4, SAS Institute Inc., Cary, NC). To validate the comparison and combination of these two methods, I additionally compared the detection rates of two species of similar body size to ringtails: chipmunks (*Neotamias* spp.), and rock squirrels (*Otospermophilus variegatus*). These two species both fit into the range of body sizes targeted with this method to capture ringtails.

For estimating probability of detection and occupancy, photographs recorded by the camera traps were categorized into a positive or negative detection per species per trap night. When compiling detections within on trap night, multiple occurrences of a species were counted as a singular positive detection for that date. Track-plates were set up at the same time as the cameras, and checked when the equipment was removed 7 days later. Thus, every site was recorded with a present or absent for each species over the capture interval based on the presence or absence of a footprint track on the adhesive paper.

I used an open robust design in program MARK (version 6.1, White and Burnham 1999) to calculate the probability of detection and occupancy (MacKenzie et al. 2002) of ringtails and the two supporting species, chipmunks and rock squirrels. The probability of detection, *p*, is the likelihood that a species was detected with a given technique when present at a survey site. The other measure of interest is occupancy, ψ, which is the probability that the animal of interest occupies a sampled site at the time of sampling. The modeling here differs from that of MacKenzie et al. (2002) because I did not model seasonal colonizations or extinctions, but instead used the program to model presence-absence at each site. Of the two methods used, camera traps and track-plates, the more effective technique would result in a higher probability of detection and more precise occupancy estimation. Similarly, the combination of the methods would produce a higher probability of detection and more precise occupancy estimation if the combination was more effective than using one method alone.

The camera-trap data were analyzed in MARK, and then a combined dataset was analyzed in which the track-plate data was added as an additional measure. To use these multiple data sources for the combined data analysis, the camera-trap and track-plate data were treated as successive sessions in which every sampling site received capture information per trap night from the cameras and an additional trap night represented the track-plate. The 7 total trap nights at each location were pooled into 4 nights and 3 nights to provide two distinct time steps per site per season. For example, when building the encounter history for each location sampled, encounter 1 represented trap nights 1-4, encounter 2 represented trap nights 5-7, and encounter 3 represented the track-plate data (Boulanger et al. 2008). In this low detection dataset, pooling the number of detection days into two subsets allows for a more interpretable detection rate. The track-plates could not be analyzed independently from the cameras because the sites were not visited and checked multiple times during the 7-night setup, providing no recapture data at each site during each season. Therefore these data were used to enhance the camera-trap data, but had limited informative value alone.

Model designs considered in the MARK program for camera-trap data alone included: a null model with no covariates {p(•)}, a time model incorporating the two time steps—4 nights and 3 nights—{p(Sample Interval)}, and a standard time model in which encounters were separated into seasons {p(Season)}. For the combined data, all these models were used again with the combined encounter histories, but a fourth model was added distinguishing the track-plate as a separate covariate {p(Track-plate)}.

This modeling method used a maximum likelihood approach to estimate the probability that a species will be detected at least once when it is present at a site and assumes that the likelihood of detection does not change over the course of the survey effort (White and Burnham 1999).

Using an information theoretic approach, I ranked the resultant competing models based on a sample-size adjusted Akaike's Information Criterion (AIC_c) to determine the model best supported by the data. The lowest AIC_c score represented the top-ranking model that best balanced bias and precision (Burnham and Anderson 2002). Using the difference in AIC_c (ΔAIC_c) and Akaike weights (ω_i), I assessed the strength of the suggested model (Burnham and Anderson 2002).

RESULTS

Between May 2012 and August 2013, I sampled 47 locations during 4 seasonal sampling intervals. The data from Summer 2012 and Summer 2013 were analyzed separately, rather than combined as 1 interval, despite being the same season, to control for sampling protocol improvement. The first 4 weeks sampled of Summer 2012 had problems with study setup and location and therefore may not have recorded effectively.

These weeks were excluded from the analysis, but the two summer sessions were not analyzed together as a result. In total, the cameras were set for 1260 camera-trap nights. Over this time, 1013 total captures were recorded, representing 26 different species. Some animals could not be accurately identified to species level, and were therefore recorded at the genus level (e.g. chipmunk; Table 2-1). The track-plates were active for 1220 trap nights, resulting in 116 captures of 8 species (Table 2-1). Camera-traps had higher detection rates than track-plates when all species were included ($F_{1,275} = 15.40$, $p = 0.0001$).

Of these total captures, the 3 main species of interest were captured 326 times with cameras, and 27 times with track-plates (Fig. 2-3). The most detections were recorded in Summer 2013 ($F_{3,275} = 14.96$, $P < 0.0001$), and cameras recorded more detections than track-plates ($t_{275} = -3.69$, $P = 0.0003$).

Table 2-1. Photograph and footprint detection rates for all animals detected between May 2012 and August 2013 in Zion National Park, Utah, quantified as number of captures per 100 trap nights (TN). Total number of capture events per species is given in parentheses.

Species		Camera-traps					Track-plates	
		Summer 2012	Fall/Winter 2012	Spring 2013	Summer 2013	Total/100 TN	Capture Rate /100 TN	Capture Rate/trap event (6-14 day interval)
Bobcat	*Lynx rufus*	--	0.1 (1)	--	0.2 (3)	0.3 (4)	--	--
Bighorn Sheep	*Ovis canadensis nelsoni*	0.2 (3)	--	0.2 (3)	--	0.3 (4)	--	--
Bird	--	0.5 (6)	0.7 (9)	1.2 (16)	1.2 (17)	3.8 (48)	0.1 (1)	0.0 (1)
California Condor	*Gymnogyps californianus*	--	--	0.2 (3)	--	0.1 (1)	--	--
Chipmunk	*Neotamias* spp.	0.5 (6)	1.7 (22)	3.7 (47)	5.2 (66)	11.2 (141)	2.9 (35)	0.3 (35)
Cow	*Bos primigenius*	--	0.2 (2)	--	--	0.1 (1)	--	--
Coyote	*Canis latrans*	--	0.1 (1)	--	--	0.1 (1)	--	--
Domestic Dog	*Canis lupus familiaris*	--	0.1 (1)	--	0.1 (1)	0.2 (2)	--	--
Gray Fox	*Urocyon cinereoargenteus*	2.9 (37)	3.3 (41)	0.9 (11)	1.1 (14)	7.0 (88)	0.1 (1)	0.0 (1)
Human	*Homo sapiens*	1.9 (24)	1.6 (20)	3.4 (43)	3.4 (43)	7.9 (100)	--	--
Horse	*Equus ferus caballus*	0.2 (2)	--	--	--	0.2 (2)	--	--
Merriam's Kangaroo Rat	*Dipodomys merriami*	--	0.7 (10)	0.4 (5)	--	1.2 (15)	0.2 (2)	0.0 (2)
Invertebrate	--	0.9 (11)	1.6 (20)	3.3 (42)	1.0 (12)	5.8 (73)	0.4 (5)	0.0 (5)
Lizard	--	1.0 (13)	0.4 (5)	1.0 (12)	3.0 (38)	4.3 (54)	--	--
Mule Deer	*Odocoileus hemionus*	2.0 (25)	6.4 (81)	1.5 (19)	1.7 (21)	7.1 (90)	--	--
Mouse	--	1.5 (19)	2.1 (27)	3.9 (49)	3.4 (43)	11.0 (138)	3.2 (39)	0.3 (39)
Yellow-bellied marmot	*Marmota flaviventris*	--	--	0.1 (1)	--	0.1 (1)	--	--
North American porcupine	*Erethizon dorsatum*	--	0.1 (1)	--	--	0.1 (1)	--	--
Desert cottontail	*Sylvilagus audubonii*	0.2 (3)	0.4 (5)	2.3 (29)	0.6 (8)	2.4 (30)	--	--
Raccoon	*Procyon lotor*	0.3 (4)	0.5 (6)	0.1 (1)	0.5 (6)	1.3 (16)	--	--
Red Squirrel	*Sciurus vulgaris*	--	--	0.1 (1)	--	0.1 (1)	--	--
Ringtail	*Bassariscus astutus*	0.5 (7)	0.2 (2)	0.2 (2)	0.4 (5)	1.3 (16)	0.5 (6)	0.0 (6)
Rock Squirrel	*Otospermophilus variegatus*	3.6 (46)	1.0 (13)	3.4 (43)	5.3 (67)	13.4 (169)	2.2 (27)	0.2 (27)
Snake	--	0.1 (1)	--	--	--	0.1 (1)	--	--
Striped skunk	*Mephitis mephitis*	0.3 (4)	--	0.3 (4)	0.3 (4)	0.9 (11)	--	--
Wild Turkey	*Meleagris gallopavo*	0.1 (1)	0.2 (2)	0.1 (1)	0.1 (1)	0.4 (5)	--	--

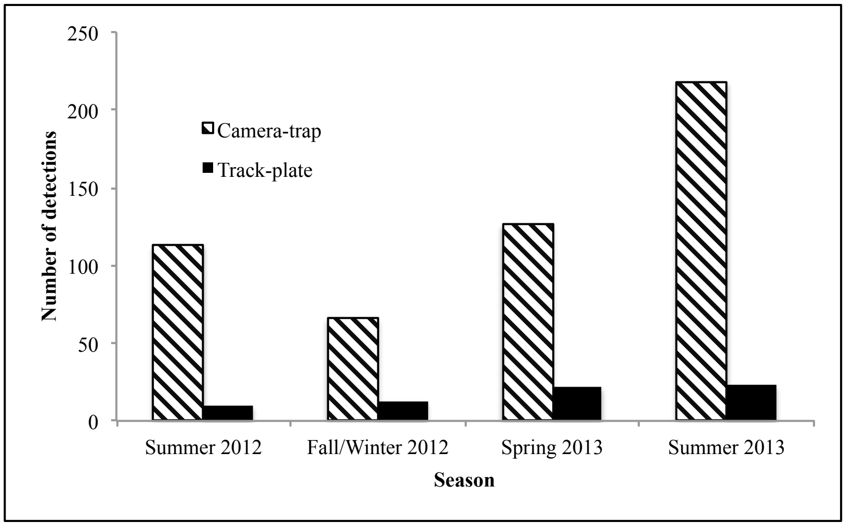

Figure 2-3. Total number of detections of ringtails (*Bassariscus astutus*), chipmunks, (*Neotamias* spp.), and rock squirrels (*Otospermophilus variegatus*), using camera-traps and track-plates in Zion National Park, Utah, May 2012 - August 2013.

Motion-triggered cameras captured ringtails 16 times during the 1260 trap nights (capture rate /TN = 1.3%). During 1220 available trap nights for the track-plates, ringtails were detected 6 times (capture rate /TN = 0.5%). To compare these two capture rates, I concatenated the camera detections throughout a trap interval to provide either a present or absent for each site for each season. 164 of these 7-day intervals were included for analysis; camera-traps detected ringtails 9 times (capture rate/interval = 5.5%) and track-plates detected ringtails 6 times (capture rate = 3.66%; $F_{1,275}$=35.33, $P < 0.0001$). Cameras were more successful detecting ringtails than track-plates ($F_{1,275} = 35.34$, $P < 0.0001$), and ringtails were detected at a lower rate in Fall/Winter 2012 than any other season ($F_{3,275} = 26.17$, $P < 0.0001$), with no recorded track-plate detections (Fig. 2-4).

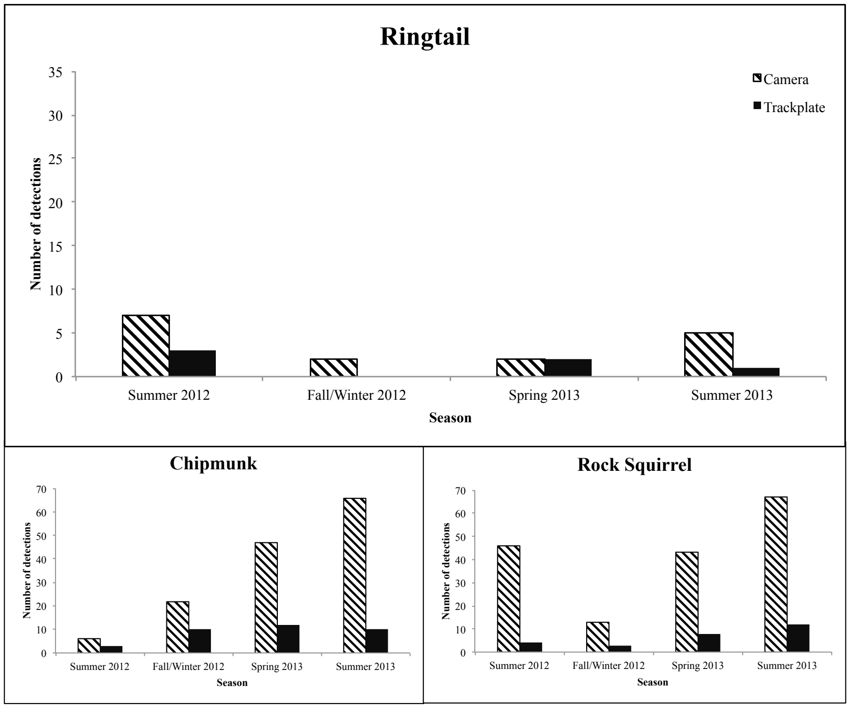

Figure 2-4. Number of noninvasive detections of ringtails (*Bassariscus astutus*) and two comparable species using camera-traps and track-plates in Zion National Park, Utah, May 2012 - August 2013.

Most detections (13 of 15) were in Zion Canyon, while 1 track-plate occurrence and 1 photo occurrence were in the Kolob Terrace region in Summer 2012 (Fig. 2-5). All ringtail detections within Zion Canyon were within 1 km to a permanent water source. The average distance to the nearest open water source was 92 m (range: 2 m – 230 m).

The two additional species included here to validate the combination and use of two noninvasive detection methods, chipmunks and rock squirrels, showed slightly different patterns than ringtails. Chipmunks were not detected at different rates among season ($F_{3,275}$ = 1.97, P = 0.1187) or method ($F_{1,275}$ = 1.39, P = 0.2394). Rock squirrels detections were lower in Summer 2013 than the other 3 seasons ($F_{3,275}$ = 14.96, P < 0.0001), and higher with camera-traps than with track-plates ($F_{1,275}$ = 13.60, P = 0.0003; Figure 2-4). Both species were detected throughout the park and at nearly every location sampled, independent of water presence.

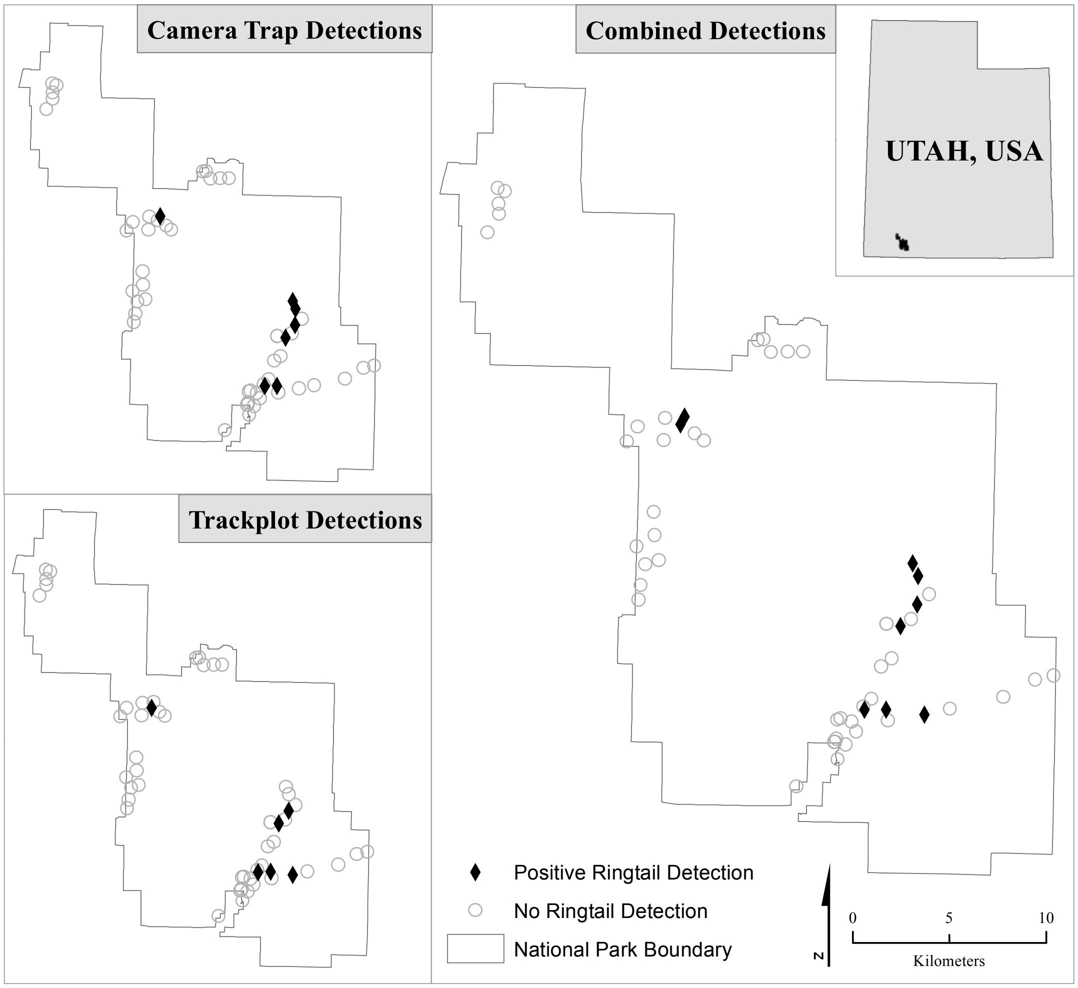

Figure 2-5. Map of successful ringtail (*Bassariscus astutus*) detections using both track-plates and camera-traps in Zion National Park, Utah between May 2012 and August 2013.

Probability of Detection and Occupancy

There is little evidence that detection rates (*p*) differed between camera-trap only and camera-trap combined with track-plate data. The top model explaining the variation in ringtail data was the null model {p(•); $\Delta AIC_c = 6.37$, $\omega_i = 0.957$; Table 2-2; Table 2-3} for both camera-trap data alone {p(•); $\Delta AIC_c = 6.37$, $\omega_i = 0.96$} and the combined dataset {p(•); $\Delta AIC_c = 2.05$, $\omega_i = 0.63$; Table 2-2; Table 2-3}. The occupancy rate provided by this model for the camera-only data ($\psi_{cam} = 0.268$, SE = 0.129, 95% CI = 0.091, 0.571) and the combined dataset ($\psi_{both} = 0.270$, SE = 0.092, 95% CI = 0.130, 0.480), did not improve with the addition of the track-plate. Because the null model was the best fit for the ringtail data, but did not include seasonal variation, the probability of detection was not estimated for ringtails for each season separately. This resulted in a single probability of detection for ringtails throughout the entire sampling period ($p_{cam} = 0.113$, SE = 0.129, 95% CI = 0.091,0.571; $p_{both} = 0.120$, SE = 0.092, 95% CI = 0.130, 0.480; Fig. 2-6).

For the two validating species, seasonal variation among the sampling intervals was the most explanatory variable for the camera-trap only data for chipmunks {p(t); $\Delta AIC_c = 10.33$, $\omega_i = 0.99$} and rock squirrels {p(t); $\Delta AIC_c = 11.46$, $\omega_i = 1.00$}, as well as for the combined data for chipmunks {p(t); $\Delta AIC_c = 15.28$, $\omega_i = 1.00$} and rock squirrels {p(t); $\Delta AIC_c = 17.48$, $\omega_i = 1.00$; Table 2-2; Table 2-3}. Using the model incorporating season as a covariate, the occupancy estimate of chipmunks using just the camera-trap data ($\psi_{cam} = 0.68$, SE = 0.077, 95% CI = 0.516, 0.812) and the combined data ($\psi_{both} = 0.73$, SE = 0.069, 95% CI = 0.573, 0.841) showed a slight increase in occupancy, although overlapping confidence intervals make the increase negligible. The rock squirrel data provided a similar increase in occupancy estimation from camera-only data ($\psi_{cam} = 0.759$, SE = 0.074, 95% CI = 0.589, 0.875) to the combined data ($\psi_{both} = 0.807$, SE = 0.065, 95% CI = 0.648, 0.904), but again without significance.

Table 2-2. Selection criteria for models estimating species occupancy incorporating variation over daily time (Sampling Intervals) and seasonal time (Season) using only camera-trap data in Zion National Park, Utah, May 2012 - August 2013.

Species	Model	AIC_c	ΔAIC_c	ω_i	Parameters
Chipmunk	Season	304.56	0.00	0.99	5
	Sampling Intervals	314.90	10.33	0.01	9
	Null	323.56	19.00	0.00	2
Ringtail	Null	89.21	0.00	0.96	2
	Season	95.58	6.37	0.04	5
	Sampling Intervals	100.47	11.26	0.00	9
Rock Squirrel	Season	337.70	0.00	1.00	5
	Sampling Intervals	349.16	11.46	0.00	9
	Null	358.92	21.22	0.00	2

Table 2-3. Selection criteria for models estimating species occupancy incorporating variation over daily time (Sampling Intervals), seasonal time (Season), and track-plate efficacy using camera-trap data combined with track-plate data in Zion National Park, Utah, May 2012 – August 2013.

Species	Model	AIC_c	ΔAIC_c	ω_i	Parameters
Chipmunk	Season	466.71	0.00	1.00	5
	Null	481.99	15.28	0.00	2
	Track-plate	484.29	17.58	0.00	3
	Sampling Intervals	485.59	18.88	0.00	13
Ringtail	Null	133.18	0.00	0.63	2
	Track-plate	135.23	2.05	0.22	3
	Season	136.03	2.85	0.15	5
	Sampling Intervals	150.16	16.98	0.00	13
Rock Squirrel	Season	476.53	0.00	1.00	5
	Sampling Intervals	494.01	17.48	0.00	13
	Track-plate	499.03	22.50	0.00	3
	Null	503.25	26.73	0.00	2

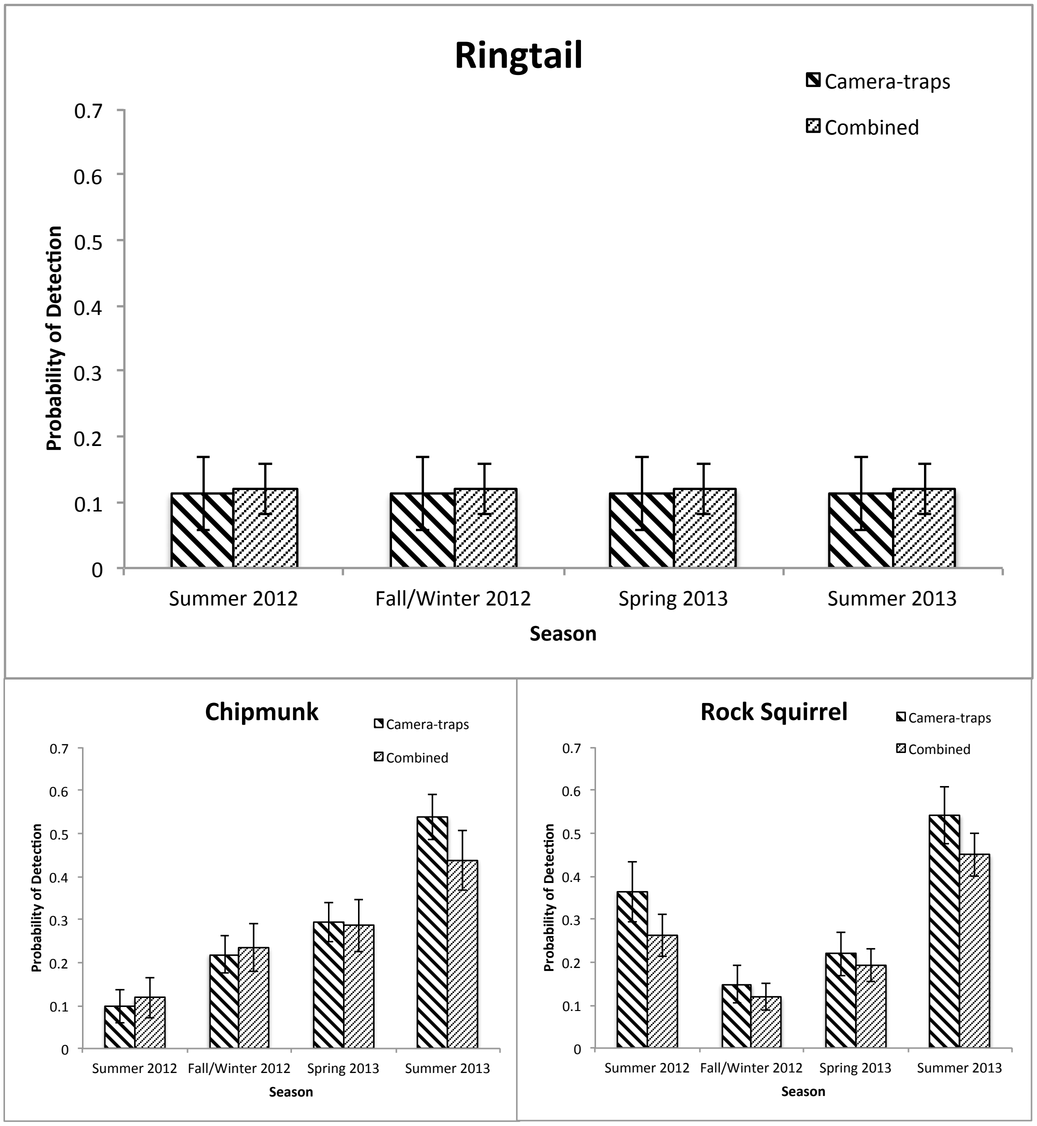

Figure 2-6. Probability of detection for ringtails (*Bassariscus astutus*) and two supporting species of comparable body size [chipmunks (*Neotamias* spp.) and rock squirrels (*Otospermaphilis variegatus*)] across four sampling seasons (May 2012 – August 2013) in Zion National Park shown with standard error bars.

DISCUSSION

Historically, few studies have used multiple detection methods in tandem to conduct occupancy surveys. Recently, however, the combination of methods is becoming more prevalent in analyses with the growing computing abilities available to handle the data (Mattfeldt and Grant 2007, Nichols et al. 2008). The combination of the methods allows for a broad spectrum of habitats and species to be sampled. This study displays the success of two different noninvasive methods for the detection of ringtails in a desert environment across varying habitat types. Both camera-traps and track-plates successfully detected the species, but the camera-traps had a higher detection rate of ringtails based on detection interval.

More ringtail detections occurred in the main Zion Canyon than other areas of the park. This area was most heavily sampled due to the apriori knowledge of ringtail conflict with humans near structures. This area had the greatest researcher access, however, the detections in Zion Canyon were all associated with riparian areas and running water, as shown in previous ringtail literature to be a driving factor in habitat selection. The detection instances in Kolob Terrace were not in an area of known running water, but the low number of detections in this area could be reflective of dispersing individuals in search of territories outside of Zion Canyon. There were no detections of ringtails in Kolob Canyons, but the researcher access to the potential habitat in this region was much more limited.

The detection of ringtails was more common during the summer months when the animals are more active and foraging for food. Their activity in the winter is reduced, as expected based on the anecdotal knowledge of the ringtails entering the buildings in the winter and denning down for long periods of time. During Fall/Winter 2012 when the detections were lowest, this is potentially the time of year when ringtails are finding dens and reducing movement, therefore being less available for detection using these two methods. However, during this study, the locations sampled near and around buildings did not see an increase in activity just before this denning down period despite the belief of increased ringtail presence near these structures in winter. It is still unclear what the dispersal patterns and shifting season habitat uses are for this species. So, while a standard sampling effort across seasons was used for this study to eliminate potential bias towards any one season, there is much to be learned about the detailed movement patterns of ringtails.

In 3 instances, the ringtail in the photo investigated the tunnel from the outside or entered the tunnel just with head and forepaws, but did not venture far enough to register a print on the contact paper. In this case, a tangible reward such as food bait, rather than a scent lure, may entice the ringtail entirely into the tunnel, but may bias this technique towards “trap-happy” individuals.

Of the two species used to validate the analysis of the ringtail data, the rock squirrel is the closest in body size. There was a significantly higher number of captures of rock squirrels using cameras than trackplates, but rock squirrels are quite abundant throughout the park and almost always were photographed foraging or investigating the general area of the detection set up, not the tunnel specifically. Both rock squirrels and chipmunks hibernate, as opposed to ringtails, so using these species as comparative measures to ringtail biology certainly has limitations. However, due to the specialized nature of the ringtail within this ecosystem, they were the two closest species of similar body size with which to validate the combination of these detection methods. Despite their differences, the analysis of these two species using these two methods confirmed that the lack of improvement based on the combination of methods is not isolated or unique to ringtails, but is consistent across species.

In some instances, an animal left footprints inside the tunnel but was not captured through either camera that was set up at the site, either inside the tunnel or outside. This is partly why some animals that are too small may not be detected from a camera with a field of view that is too broad, however, the camera isolated inside the tunnel would have enough sensitivity to detect an animal entering the tunnel if it had a proper triggering setting. One hypothesis regarding missed camera trapping events is that the temperature gradient in Zion during certain sampling periods (particularly the summer) was not wide enough to detect the body heat of the animal and therefore interfered with the motion-triggering mechanism involved. When temperatures are high, the infrared sensor on the camera has difficulty detecting a warm-bodied animal (Trolle and Kery 2003). In Zion, the ambient temperature may have been so high through the evening, as well as radiant heat from nearby sandstone features, as to cause a disruption to the infrared sensors of the cameras. It is unclear exactly how wide of a temperature difference is necessary for the camera to properly function for an animal the size of a ringtail. Although, for the sake of example, given a 10° F difference required, for the ringtail with an active body temperature of 99.7° F (Chevalier 1984, Mugaas et al. 1993), any time the ambient temperature was between 89.7° F and 109.7° F, the camera likely would not trigger consistently. During the sampling period between May 2012 and August 2013, 90 days were above 99.7° F, and 18 days averaged higher than 89.7° F (NPS 2014). The temperature data available are only for mid-day measurements, but on extremely hot days, such as those significantly above 99.7° F, even the evening cooling phase did not always reduce the ambient temperature more than 10 or 15 degrees (NPS 2014), therefore potentially falling into a range in which the camera may have malfunctioned. In this situation, relying on camera traps to detect ringtails might not be an effective method. As was shown here, the addition of a track-plate can protect against those instances in which a camera may give a false negative.

In this study, the track-plates were used solely as a bolstering measure for the camera-trap grid. While effectively increasing the information available to the camera data, the results of the track-plates alone cannot be used to build an occupancy model unless they are checked repeatedly throughout their deployment. If the camera is placed appropriately, the camera will record the date and time of the animal's visit to the track-plate without requiring multiple visits to monitor the track-plates. It is possible that with some modifications this design could be used for future information of the internal events of a track-plate tunnel.

Probability of Detection and Occupancy

When estimating occupancy of ringtails, or the probability that a given sample site is occupied by a ringtail at the time of sampling, the addition of the track-plate data increased the occupancy estimation but the difference was slight. The overlapping confidence intervals limit the inference that can be made from this difference. There does not appear to be a difference in the ringtail occupancy modeled across seasons. While ringtail interactions with humans increase in the winter as ringtails attempt to find suitable food and shelter sources in buildings, this activity did not influence their detectability.

The other species measured in comparison with the ringtails all displayed a significant influence of time in their occupancy estimations, as they are all hibernating species. Summer 2013 data had the lowest detection rate across all 3 of these species; however, this is likely due to the necessary learning curve and sample protocol modification implemented partially through the sampling season. While the incorporation of the track-plates increased the occupancy rate slightly for these species, the difference between the 2 detection methods was not significant. However, there is a trend toward a more accurate occupancy model with the addition of the track-plate data; perhaps with a more robust dataset one might detect a significant improvement with the addition of this method.

MANAGEMENT IMPLICATIONS

These findings confirm that ringtails are concentrated in the riparian areas of Zion National Park, mainly in Zion Canyon. While a few isolated captures occurred in the Kolob Terrace region during this study, these were not repeated. Because of the ringtail concentration within Zion Canyon and because the population is believed to be at a much lower density than in other areas of suitable habitat throughout the southwest, it is important to protect this habitat as much as possible going into the future. Most of the riparian habitat within Zion Canyon that is being used by ringtails is also in close proximity to the areas of human use of the national park, so the potential for human-wildlife interaction is high. Because ringtail occupancy of these areas does not shift seasonally, this is a year-round issue for managers. While the addition of track-plates to the camera trap method did not improve the detection rate of ringtails, it did allow for a wider range of sites to detect ringtails. This is useful to managers for monitoring ringtail presence around buildings in this area because they can equally use either method to measure the presence of ringtails nearby and be proactive in excluding ringtails from buildings while educating the public about protecting the ringtail habitat near human use.

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CHAPTER 3

USING DERMATOGLYPHICS TO IDENTIFY INDIVIDUAL RINGTAILS

ABSTRACT

Accurate noninvasive identification of unique individuals allows for the gathering of critical population demographic data to inform management and conservation decisions for wildlife. The patterning of the phalangeal skin of many mammals creates a unique fingerprint, which can be used to identify individuals. Noninvasive techniques such as photography can be used to estimate densities when individuals have unique pelage, ornamentation, or scale patterns, however when photographs are not sufficient to capture the individual characteristic, another method is necessary. I used charcoal track-plates paired with the Interactive Individual Identification System (I^3S) software to assess if different individual ringtails (*Basssariscus astutus*) can be reliably identified using the pattern of the dots and patterns formed by the papillae and ridges of the footpad. I also investigated the ability of human researchers to accurately identify individuals without the assistance of a computer program. I found that ringtails' footpad prints consistently generated unique pattern that were readily recognizable by humans using simple visual analysis and by a computer-aided analysis of the prints in a database. This result represents a significant development in the identification of ringtails because the procedure is repeatable throughout the life of the individual, all ages of individual can be marked despite the difference in footpad size throughout growth, and it provides an economical, noninvasive method to detect and identify this elusive omnivore.

INTRODUCTION

When assessing any population of animals with little established ecological knowledge, the primary information of interest is often the abundance of individuals. Gathering the data to make this assessment can be a significant challenge in rugged habitat or when the species of interest is elusive or trap shy (Jackson *et al.* 2005). While certain abundance information can be gathered by live-trapping, this can be invasive, labor intensive, expensive, and stressful to the animals. As a result, there are many emerging noninvasive methods to gather equally or more robust data to conduct quantitative analyses. Not only do noninvasive methods have the potential to increase the temporal and spatial scale available, they can decrease the labor, expense, and animal stress necessary to obtain accurate abundance estimates (Harrison, Barr & Dragoo 2002; Gompper *et al.* 2006; Kelly & Holub 2008). To accurately perform such estimates, the identification of individuals must be unambiguous and repeatable (Otis *et al.* 1978).

To date, two methods have commonly been used to “capture” individuals non-invasively: collect a small piece of genetic material such as hair, blood, or skin cells in feces, or collect a photograph of an animal with a unique skin or fur pattern. The first method can require significant laboratory time and potentially significant finances to build a database. The second method has become increasingly popular across a multitude of taxa, but requires the animal to be unique in pelage or skin patterning. For example, cameras are being used remotely to document populations of animals with stripes and spots (e. g. Karanth and Nichols 1998; Kelly & Holub 2008; Jackson *et al.* 2005) and cetacean spots, scars, and fluke patterns (Langtimm *et al.* 2004; Stevick *et al.* 2004; Marshall & Pierce 2012). While only recently used in conjunction with cameras, blotch and scale shapes in reptiles (Sacchi *et al.* 2010), spots in amphibians (Leland & Gee 2014), and whisker patterning in polar bears (Anderson *et al.* 2007) all appear to be unique to individuals and may be used in individual identification in the future.

Advances have been made in the field of pattern recognition using computers to recognize humans using facial features in recent decades (Baron 1981), and the use of computer-aided wildlife pattern recognition is beginning to make use of this technology. Pattern recognition algorithms use spot identification through automated systems (Gamble *et al.* 2008) or user-interactive computer programs to successfully build databases of individuals of many different species, including, for example, reticulated giraffes (*Giraffa camelopardalis reticulate)*, spotted raggedtooth sharks (*Carcharias taurus*), and marbled salamanders (*Ambystoma opacum*; Gamble *et al.* 2007; Van Tienhoven *et al.* 2007; Bolger *et al.* 2012). Herzog *et al.* (2007) showed that individual fishers (*Martes pennanti*) could be identified by researchers from the spot patterning left behind on track-plates from the papillae on their feet. This method of identification is similar to that of hominid fingerprinting (e.g., Roddy & Stosz 1997; Pakanti *et al.* 2002), which has been conducted on humans (*Homo sapiens*), chimps (*Pan troglodytes*), gorillas (*Gorilla beringei*), and other ape species, although human fingerprinting relies more on the bifurcation and combination of whorls than the unique placement of dots (Herzog *et al.* 2007).

Despite its known presence throughout southwestern North America, current scientific knowledge of the ringtail (*Bassariscus astutus*) is limited. This small house-cat sized member of Procyonidae is strictly nocturnal and occurs at low densities (Trapp 1978; Harrison 2012) making detection difficult unless an active den or latrine is found.

Therefore, the creation of a passive, individually identifiable method of detecting animals would greatly assist studies of the population distribution of this species. The footpad of the ringtail is exposed from fur (Poglayen-Neuwall & Toweill 1988) and the epithelial ridges and papillae patterning of their metacarpal pads (i.e. the "footprints") lend themselves to the possibility of unique identification through dermatoglyphics.

This study tested the uniqueness of ringtail footprints and the use of dermatoglyphics (the study of fingerprints) as a potential method for field studies of ringtail populations. My objective was to determine if footprints were unique and if so, was the identification method repeatable by researchers via a simple training process.

STUDY AREA

I conducted fieldwork using ringtails from 2 distinct study areas: Zion National Park in southwestern Utah and the Sutter Butte mountains of northern California (Fig. 3-1). Zion National Park hosts a huge range in elevation (1100m-2600m), a vast plant community (>900 species), extreme temperature variations (-12º C to 48º C), and seasonal precipitation variability (Gregory 1950). The main feature of this park is the steep canyon formed in the Navajo sandstone by the Virgin River. On the floor of the canyon, near this river, riparian and deciduous forest prevails with Fremont's cottonwood (*Populus fremontii*), velvet ash (*Fraxinus vlutina*), bigtooth maple (*Acer grandidentatum*), and Gambel oak (*Quercus gambelii*). Arid grasslands and desert shrubs predominate at lower elevations away from the canyon floor representing a northern extension of the Sonoran Desert. Pinyon-juniper communities (*Juniperus osteosperma*, *Pinus edulis,* and *P. monophylla*) are most common at intermediate elevations and at the highest elevations one will find ponderosa pine (*Pinus ponderosa*) forests with Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) present in cooler, moister areas (Nelson 1976).

In contrast, the Sutter Buttes in California's northern Central Valley are an isolated eroded volcanic dome complex related to the Coast Range volcanoes. They are Pleistocene in age and Andesitic to Dacitic with pyroclastic debris in composition. The highest of these buttes sits at 650m and the entire range encompasses 195 km^2 (Williams & Curtis 1977). Prominent outcroppings of volcanic rock intermingle with a wooded habitat of blue oak (*Quercus douglasii*) and chaparral vegetation. The majority of the land is held privately and is used for livestock grazing.

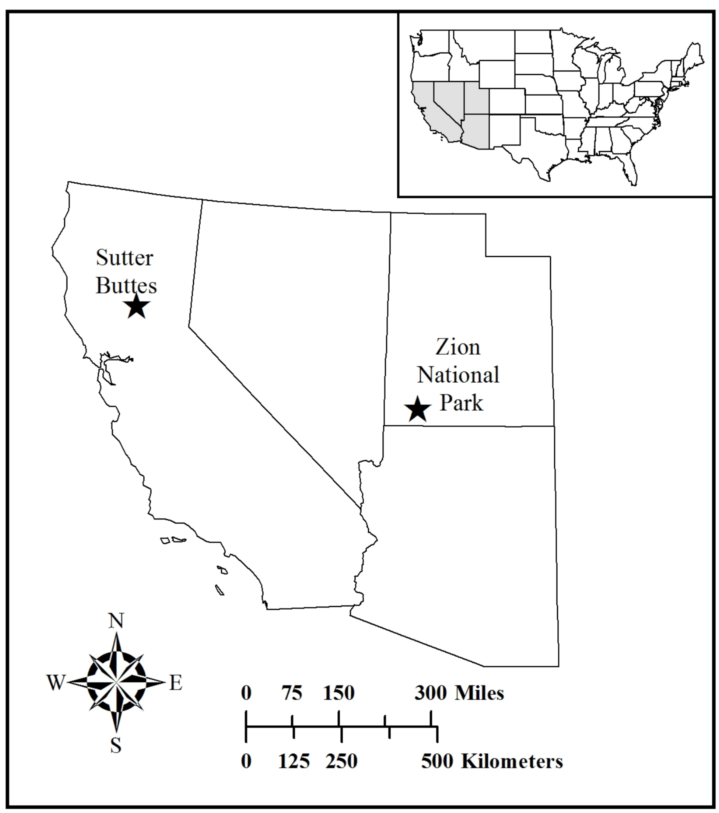

Fig. 3-1. Two study sites where ringtails (*Bassariscus astutus*) were captured and footprinted between November 2012 and November 2013.

MATERIALS AND METHODS

Capture and Footprint Collection

From June - September 2013, I live-captured ringtails using four double-door Tomahawk wire box-traps (15 x 15 x 60 cm; Tomahawk Live Trap Company, Hazelhurst, WI) rotated through eight trap lines in likely ringtail habitat in the Zion study area (Roadman 2014). Additionally, 20 traps were deployed for 3 consecutive nights in November 2012 and again in November 2013 in the Sutter Butte study area. These traps were deployed along four trapping lines at sundown and checked and removed the following sunrise. Bait consisted of small fresh apple slices, a tablespoon of peanut butter, a tablespoon of strawberry jam, and 6-8 raisins trailing into the trap opening. A small tin can contained the bait to keep the trap clean, to require the ringtail spend more time in the trap, thus ensuring a capture, and to prevent bait theft.

Captured ringtails were transported to a quiet, safe location for handling. I injected a dosage of 0.1 ml/1kg body weight of Ketamine Hydrochloride intramuscularly to provide sufficient sedation to safely handle the ringtail for approximately twenty minutes. I recorded full morphometrics (skull width, skull length, weight, total body length, tail length, ear length, sex, and age) and collected a full individual record of footprints of the ringtail using a non-toxic, washable ink in a 4x4 replicate of each foot to capture the pattern created by the papillae of the footpad (Fig. 3-2). Full recovery occurred within one hour of administration. Once a ringtail recovered from sedation, it was released either at the capture location or a pre-designated relocation site (Roadman 2014).

Digitization

Every footprint collected with ink during ringtail handling was digitized at 2400 dots per inch (dpi) using a desktop scanner. The prints were then loaded into the Interactive Individual Identification Software (I^3S Pattern v.4.0.1; www.reijns.com/i3s; Van Tienhoven *et al.* 2007) and annotated using the program's design. To begin annotation, three reference points were located on every footprint image. At the center of each dorsal pad, there exists a central pattern in which the concavity and convexity of the epithelial ridges meet to form a neutral line or centroid. This central pattern is usually an oblong shape, and the lateral center of this area was selected as the reference point for each of the main pads of the foot (left, middle, right; Fig. 3-3). These reference points were used to properly align and adjust comparative images. After the reference points were selected, the region of interest was highlighted (Fig. 3-2) and I^3S automatically annotated the "key points" of the photo, which were entered into the database as the identifying values for that particular footprint (Fig. 3-3). Using this software, 3-6 prints of every foot of every individual were loaded into the comparative database. A database was built for each of the four ringtail feet to ensure only other right hind feet were compared to right hind feet, for example. I used the program's evaluation tool to subsample the resulting database and conduct iterative tests to measure the successful matching of each image. In this test, one print within the database was removed and compared back to the remaining portion of the database for a match. This process was repeated for each print until all prints were tested once. The resulting percentages explain the number of prints from within the database that were tested and properly identified in the top 1, 2, 3, 5, and 10 matches. After the top matching images were provided, a visual comparison was necessary to confirm the proper match between two print images. To assist in visualizing the match, every pairing of images received a point cloud overlaying the matching or mismatching key points (Fig. 3-4). The score associated with this point cloud is a numerical representation of the distance between matching points, and it the factor used to calculate the likelihood of a match (Fig. 3-4).

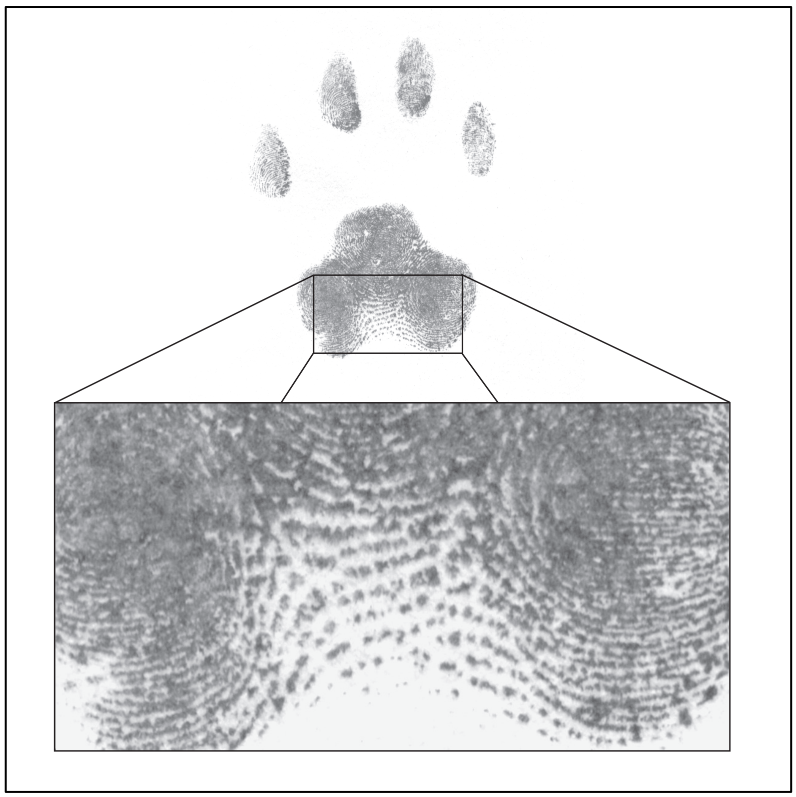

Fig. 3-2. Rear right footprint from male ringtail (*Bassariscus astutus*) showing area of individual comparison prior to selection for annotation; figure created April 2014.

Fig. 3-3. Right rear ringtail (*Bassariscus astutus*) footprint with annotations for individual identification using I^3S: reference points in blue, region of identification interest in green, and key points in red, created May 2014.

Volunteer Matching Test

To measure the ability of humans to visually match footprints without a computer program's assistance, I tested the impact of various training levels on the successful matching of footprints by volunteers. Two rounds of testing were conducted: a naïve session in which the volunteers received limited instruction prior to the test with moderate explanation half-way through, and a trained session in which the volunteers began with a moderate level of explanation and received formal training half-way through. In each round, the participant began by reading their introductory explanation of the desired outcome with their set of instructions. Then the participant opened an electronic image of a ringtail footprint labeled with the foot identified (i.e. right front, left front, etc.) and compared this footprint to a database of potential reference footprints. The participant attempted to find the most accurate match to the sample print, recording the corresponding ringtail's identification code, with "no match" as an option. The volunteer repeated this procedure for three distinct footprints. After completion of this first subset, the volunteer either received moderate instructions for the naïve session, or watched a twenty minute instructional video for the trained session. This training video was created by the researcher, explaining in greater detail the proper method of matching prints. The completion of this training video represented the "training session." After this explanation period (moderate or trained), the volunteer repeated the matching process with three new footprints and the same pool of reference prints. In both sessions, the participant entered an assessment of the quality of each print (1, 2, or 3), their personal confidence in every match (1-10), and the time required to find every match.

There exist gender differences in spatial pattern recognition (Fahle 2004, Brandner & Devaud 2013), so I analyzed the researcher scores between sex and the levels of training using a general linearized mixed model (GLMM; Royle *et al.* 2009) with binomial error distribution and logit link using the statistical software SAS (version 9.4, SAS Institute Inc., Cary, NC).

All data was collected in accordance with approved procedures as indicated by the Utah State University Institutional Animal Care and Use Committee (permit #2032).

Field Validation Trial

Every individual captured for footpinting was released through a constructed tunnel using mock field collection methods to imitate the tracks that are possible through a long-term noninvasive rack sampling study. The track-plate tunnel was a collapsible corrugated plastic (Coroplast ®, Dallas, TX) tunnel measuring 30.5 cm x 30.5 cm x 91.4 cm with overhanging lips to protect from rain and sun (Gompper *et al.* 2006). This rectangular tunnel enclosed a 0.32 cm thick aluminum plate (Clinton Aluminum, Clinton, OH) coated in charcoal (Gompper *et al.* 2006). A 30.5 cm x 91.4 cm plate of either aluminum or corrugated plastic lay on the bottom of each track-plate tunnel. At one end of the track plate, I placed plain white adhesive drawer lining paper (Con-Tact Brand®, Pomona, CA) to cover 30 cm of the end of the plate. This was attached with tape so that it was adhesive side up on the plate with the protective paper removed. In place of the traditional sooted aluminum plate method using an acetylene torch (Herzog *et al.* 2007), I designed and implemented a new method for this study. Using a 1:6 concentration of black powdered artist's charcoal (General's, Jersey City, NJ) and 70% isopropyl alcohol to create a charcoal slurry, I painted the remaining length of plate beyond the adhesive paper. The alcohol quickly evaporated, leaving a thin, even layer of charcoal lightly adhered to the plate. As a ringtail walked out of the trap and into the tunnel, the ringtail's footpads picked up this fine charcoal and deposited it as a positive footprint onto the adhesive paper to be saved for analysis. The adhesive pages were sprayed with a thin layer of an artist's graphite sealant and placed into plastic sheet protector sleeves. All charcoal prints were then scanned and digitized in the same manner as the ink prints. Each print was recorded for ringtail individual as well as the particular foot the print came from. The prints were anonymously labeled and compared for a match in the reference databases for the appropriate foot (e.g. Left Hind Foot Database).

RESULTS

Over the entire trapping period, 8 female and 10 male ringtails were footprinted with ink, 9 from the Utah population (5 female, 4 male) and 9 from the California population (3 female, 6 male).

Digitization

Fifteen individual ringtails were included in the footprint database. Three individuals captured were footprinted with an alternative ink, but their footprints did not yield results detailed enough to include in the database. When the evaluation tool within I^3S was run to establish the likelihood of print matching within the database, the print from the right hind foot was the print most often correctly matched by the I^3S algorithm. The hindfeet were more likely to be correctly matched than forefeet (Table 3-1). Within the settings of the program, there is the ability to modify the number of key points necessary to accurately represent the pattern present in the image. Multiple values were tested between 20 and 50, but the software's automatic setting of 35 key points annotated provided the highest percentage of correct matches.

Volunteer Matching Test

I conducted a generalized linear mixed model to compare results based on training level and to determine the influence of the volunteer's sex on their ability to correctly match ringtail footprints. Eighteen human volunteers were tested (5 males, 13 females).

There was no significant difference in the volunteers' scores based on the provision of training at any level ($F_{1,3}$=0.88, P=0.4185). There also was no difference in the overall scores between the naïve session and the trained session ($F_{1,3}$=1.33, P=0.3321). The sex of the volunteer did not influence their ability to correctly match prints ($F_{1,3}$=3.70, P=0.1501). Volunteers reported an average search time for a match to be 3.5 minutes (range: 30 seconds to 10 minutes).

Field Validation Trial

Thirty-one individual footprints were collected during ringtail releases that were high enough quality to test against the reference prints collected in ink. These charcoal prints were individually compared to the appropriate database of reference ink prints for all ringtails sampled. Nine percent of the prints analyzed had the correct individual offered as the first match.

Table 3-1. Percentage of successful individual ringtail (*Bassariscus astutus*) footprint matches using I^3S Evaluation Tool; based on individuals sampled in Zion National Park, Utah and California's Sutter Butte region between 2012 and 2013.

Foot	% Match				
	Top 1 Print	Top 2 Prints	Top 3 Prints	Top 5 Prints	Top 10 Prints
Right Hind	74.2	81.8	86.4	87.9	93.9
Left Hind	53.5	67.2	70.7	77.6	93.1
Right Fore	49.0	61.2	71.4	81.6	91.8
Left Fore	67.3	85.5	87.3	89.1	90.9
Forefoot Average	58.1	73.3	79.4	85.4	91.4
Hindfoot Average	63.8	74.5	78.5	82.74	93.5

I^{3}S provided the correct individual within the top two matches for 22% of prints analyzed, 53% had a correct match in the top five prints, and 66% had a correct match in the top ten prints offered.

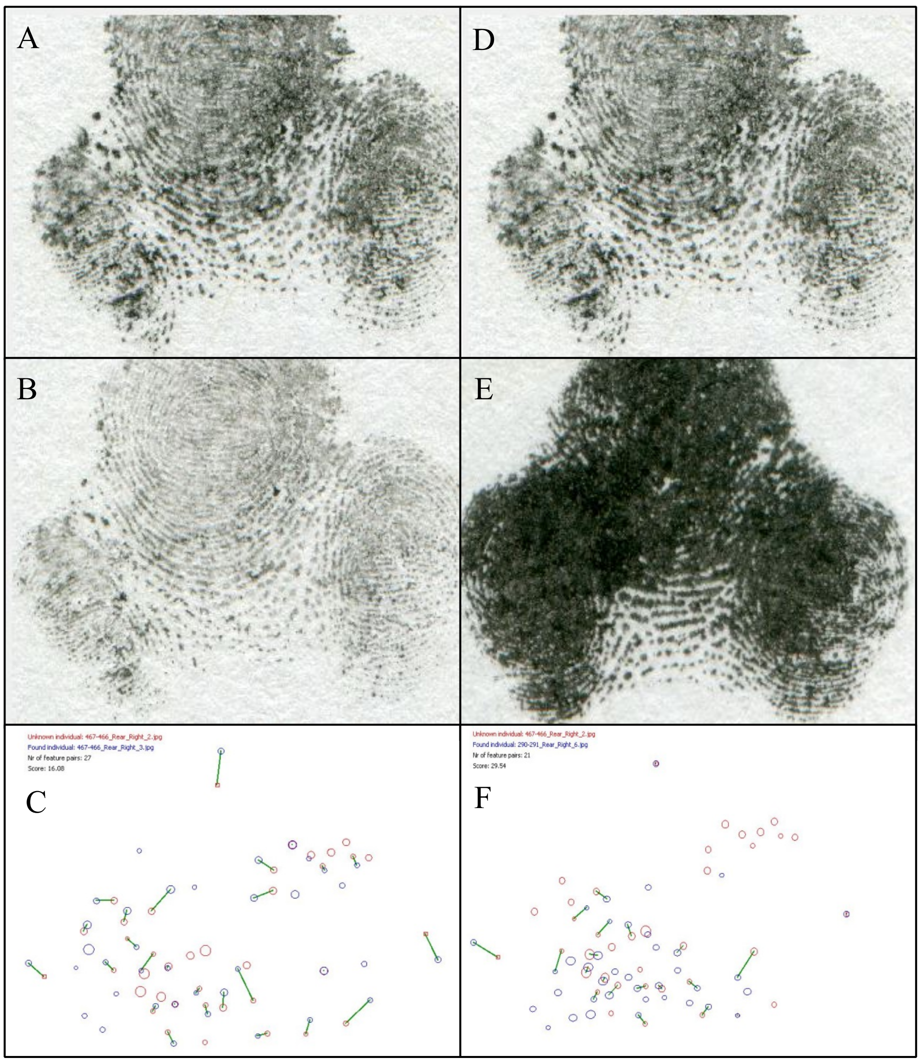

Fig. 3-4. Two matching ringtail (*Bassariscus astutus*) footprints (A, B) with the associated point cloud (C) and two mismatching prints (D, E) with the associated point cloud (F), created May 2014.

DISCUSSION

This study confirmed that ringtails can be identified by the shape, placement, and relative arrangement of papillae on a ringtail's metacarpal pad. These patterns can be isolated and analyzed with the assistance of a computer program, or by human comparison. However, the successful automation of the program supplying likely images to pair with the researcher's matching skill greatly reduces the time and error involved with searching unassisted. In general, the greatest limitation to photographic comparison is the amount of time required to compare pictures in a given sample, which rises exponentially with each additional individual. For ringtails, though, the populations are commonly at a low density and this limitation would have little influence.

My results demonstrated that the application of I^3S to the footprints of ringtails is extremely time-efficient despite the final visual confirmation necessary from the researcher. When volunteers were tested on their matching ability, the average footprint took 3.5 minutes to find a match. This was in a greatly constricted database of only five reference prints and the time necessary to make a match would most likely increase with a higher number of footprints to choose from in a true study. In comparison, I^3S was able to provide an extensive listing of potential matching prints in a matter of seconds. The final match is decided by the researcher, so the time required is increased from seconds, but much much faster than without the computer assistance.

My analysis showed that the three reference points required for each print were easy to find on a clear print, but may create a bias if inputting an incomplete print. The dimensions of these three reference points may be the most important factor in distinguishing between individuals, as opposed to the patterning of the papillae. The I^3S

program was initially designed for use identifying whale sharks (Van Tienhoven et al. 2007) and in that application the reference points were used as a way to scale and adjust the photograph measurements to account for photos of individuals at multiple distances and angles. In my footprint data, however, each footprint was scanned and saved as a file at the exact same dimensions. As a 2D visualization, this reduced one potential source of error: the roll and yaw of the individual being photographed. The reference points are still extremely useful in orienting comparative images. The placement of the whorl patterns on the three portions of the metacarpal pad from which the reference points are selected are distinct between individuals, and therefore the measurement between the centers of those whorl patterns may be the driving identifying factor.

Many different transfer substrates were used in the collection of ringtail prints, such as commercial inkpads, official fingerprinting pads, and a charcoal track-plate. While an ink choice is the most effective for retaining detail, the type of ink used is important. Three different ink types were used throughout this study. One, an official fingerprinting inkpad designed for human fingerprinting use, collected sufficient detail, but did not retain the color contrast over enough time to preserve the print. Those samples were not included in the analysis because their characteristics were too faint to be identified by I^3S. Charcoal, such as that used for field printing, is sufficient to collect detail, but caution must be paid to ensure that the detail is not destroyed during collection, transport, or storage of the adhesive paper. Artist's charcoal spray was used to great effect in this study to retain the detail of the prints, seal the adhesive paper, and protect the patterning without yellowing, aging, or smudging.

The "field" prints collected with the mock field setup using charcoal upon ringtail release provided lower concentrations of correct matches than the prints collected using just ink, however with 66% of the prints analyzed being correctly matched within the top 10 prints offered and 22% in either the top print or second print, this implies this is a viable practice for field collected prints. In all cases, human researchers still confirm the definitive match. In one case, the researcher visually matching the prints caught a mistake in the database. The charcoal print was mislabeled in the transfer between paper copy and digital file, but the analysis in I3S provided an opportunity to rematch this individual with reference prints. The program provided the correct individual match in the top 2 prints and the file was accurately identified, checked against the initial collection datasheet, and relabeled. When preparing to collect prints in the field with this method, care must be taken to ensure that the concentration of charcoal to alcohol is neither too high nor too low resulting in prints that are either to dark or too light, respectively. When care is also taken to ensure the detailed nature of the print is preserved and stored properly during removal from the field, the prints remain just as detailed as when the prints are first deposited by the ringtail. While not failsafe as a method, this novel way to identify individual ringtails adds to the toolbox of field method options by providing a definitive measure for identifying ringtails noninvasively throughout their life.

The results of the volunteer test show that while some individuals are better at identifying patterns than others, extensive training or experience is not necessary for the effective use of dermatoglyphics. Dermatoglyphics is useful for a couple of reasons. First, the patterning on the individual's foot is set during development in utero (Kücken & Newell 2005); therefore as the animal grows, the fingerprint will remain static in design even as it changes in size. With the assistance of the interactive computer program, this size can be accounted for with the reference points. This allows for this method to be used on all ages of individuals present in the population and is not limited to adults, as many marking techniques are. Second, this method is economical and easy to implement. When extended to a potential field application of the protocol, many years of data can be recorded on that individual without requiring a physical recapture. With a permanent database available and a freeware option, wildlife managers can use this tool to identify problem individuals into the future.

MANAGEMENT IMPLICATIONS

This study indicates that the collection and analysis of footprints is an effective technique for identifying individual ringtails. This could be further developed to use at a large scale to assess a population in a mark-recapture framework. It is important to have detailed and accurate prints, which can be achieved with some simple training and care during set up. With proper precautions and protection of the track-plate from the elements, this method is possible to use as a field method. Developing these noninvasive survey methods for the ringtail population will improve future efforts to gather information about ringtails in target areas or throughout a population range. Ideally, the development of this method could result in a way to obtain a population estimate in remote areas and without direct contact with the study animal.

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CHAPTER 4

INFLUENCE OF ANTHROPOGENIC RESOURCES ON RINGTAIL DIET IN ZION NATIONAL PARK, UTAH

ABSTRACT

Current scientific knowledge of the ringtail (*Bassariscus astutus*) is relatively limited. Ringtails in Zion National Park, Utah are rarely seen, but are involved in increasing occurrences of negative interactions with park visitors and employees such as food theft and denning in buildings, interactions which are harmful to both parties. Of the past research conducted, ringtail diet has been a central focus of many studies, but these projects focused on wild populations, while providing no information on populations in direct contact with humans. I measured the influence of available anthropogenic resources on ringtail diet in Zion National Park by examining 146 total ringtail scats, 128 collected from buildings and areas of high human activity in the park (directly-influenced) and 18 opportunistically in ringtail habitat with low human activity (minimally-influenced). Activity rates of high and low were determined via personal communication with park biologists. In the subset collected in areas of high human visitation, insects (33.2%) and mammals (26%) were the most relatively frequent food items. Anthropogenic items were present across 32.8% of scats sampled, most of which were non-digestible items such as trash. In the minimally-influenced scats collected in areas of low human activity, insects were most common (53.3%), but plant material was second most relatively frequent (23.3%) with anthropogenic items present in 11.1% of scats. While insect prey is dominant in both subsets, the higher density of rodent

populations in and around buildings is reflected in the higher presence of mammal remains in the ringtail feces found in human-inhabited areas. Ringtails actively modify building entry points to gain access; therefore, a constantly monitored rodent and ringtail exclusion practice is likely the most effective long-term method of preventing ringtail entry.

INTRODUCTION

Determining the dietary needs of a population can provide critical information on the population's stability, but becomes complicated when wildlife populations coexist in landscapes with people that bring anthropogenic resources (e.g. human food and trash) and make them available to wildlife (Conover, 2002; Woodroffe et al., 2005). Historically, diet information was obtained via analysis of whole digestive tracts, but more recently the analyses of fecal contents has produced comparable results while remaining non-invasive and not necessitating the death of the organism (Orr et al., 2003).

Using scat content analysis to draw conclusions about diet and thereby extrapolate ecological information about an animal can be useful (Putnam, 1984), but certain practicality measures must be considered when drawing conclusions from food item presence in scat. Differing rates in digestion can create biases when determining the true importance of a particular food item. An item with low digestibility may appear to be more common in the diet, while soft-bodied food items or items with high moisture content will be underestimated (Wyatt, 1993). For example, ringtails (*Bassariscus astutus*) have been seen consuming agave nectar, which is entirely digestible and would not be represented visually in scat (Kuban and Schwartz, 1985). Therefore, when only solid objects are recorded, both volume and occurrence of food items should be considered (Wyatt, 1993).

Ringtails are small members of the Procyonidae family with an average weight of 0.7-1.8 kilograms (Poglyen-Neuwall and Toweill, 1988; Ackerson and Harveson, 2006). They occur along the western coast of North America from southwestern Oregon to southern Mexico extending east to Colorado, Nebraska, Arkansas, Oklahoma, Texas and Louisiana (Bradley and Hansen, 1965; Hall, 1981; Wozencraft, 2005). Ringtails make use of their short, semi-retractable claws (Hall, 1981) and 180°-rotatable hind feet (Schmidly, 2004) to skillfully climb trees, ascend nearly-vertical rock walls, and foray into extremely narrow rock crevices (Trapp, 1972).

Ringtails are an important meso-carnivore in the Southwest; they depredate and help control populations of rodents, insects, and reptiles. Ringtails are omnivorous and their specific diet shifts with food availability (Nelson, 1918; Taylor, 1954; Alexander et al., 1994); they will consume fruit, nectar, and various plant materials (Kuban and Schwartz, 1985; Poglayen-Neuwall and Toweill, 1988). Ringtails are also able to conserve water when water-stressed as dietary or freestanding water becomes scarce or absent (Chevalier, 1984). This water constriction leads to extremely concentrated urine and potentially extremely dense fecal material (Chevalier, 1984).

Both male and female ringtails will use urination and defecation to mark their territory (Taylor, 1954; Barja and List, 2006). Defecation marking is sometimes done with a single deposit, often near the center of the territory, but is also commonly done in latrines (Trapp, 1978). Latrines usually consist of 2 to 19 feces (Trapp, 1978; Barja and

List, 2006), although some massive latrines have been observed in buildings consisting of dozens of feces (A. Roadman, USU, personal observation).

Traditionally, the ringtail was an elusive creature of the Southwest, but more commonly campers and hikers are seeing these small omnivores in campsites and at trailheads in national parks (Claire Crow, NPS, personal communication, 2012). One potential reason for these sightings is the increase of ringtail foraging for human foods and trash. One place that is experiencing significant conflict with ringtails is Zion National Park in southwestern Utah. In this national park, the ringtails are not only interacting with people at trailheads and in campgrounds, but are entering offices, restaurants, lodges, and maintenance sheds year-round in search of food and shelter (C. Crow, NPS, personal communication, 2012). The resultant damage from this entry causes monetary loss as well as negative impressions of ringtails to the people working, living, and traveling in the park. Additionally, their activities may be potentially dangerous to the ringtails. Before one can determine methods to alleviate negative interactions between humans and ringtails, the extent of the damage must be assessed. Of particular concern to biologists are the potential negative impacts of incorporating human-sourced food into the ringtail diet.

The objectives of this study are to determine food habits for ringtails in areas of high and low human activity in Zion National Park, Utah, and to determine the extent to which anthropogenic foods are incorporated into their diets.

STUDY SITE

I conducted research in the main canyon of Zion National Park, Washington County, Utah, U.S.A. (hereafter 'Zion'). This area of the national park sees more than 2 million human visitors each season, heavily overlapping with the habitat for hundreds of species of flora and fauna. As part of the western portion of the Colorado Plateau, the landscape is primarily composed of terraces and vertical walls. The two major geologic features of this region are the more southerly Uinkaret Plateau and the northerly Kolob Terrace (Gregory, 1950). Elevation varies throughout the park from approximately 1100 m in the SW corner to as high as 2600 m in the NW corner. From this surface of the plateau, the canyon walls form a vertical descent to the North Fork of the Virgin River. This river continues to create the principal canyon via downcutting through the Navajo sandstone plateau from a northeasterly bearing.

The Virgin River flows continuously, although in the hot, dry summer months, the tributary drainages throughout the study area tend to dry or become intermittent, exposing long stretches of dry streambed. The freestanding and flowing water available in the canyon is restricted and isolated to the main canyon.

Vegetation throughout the park varies with the elevation. A northern extension of the Sonoran Desert is represented with predominately desert vegetation at lower elevations. Piñon-juniper communities (*Juniperus osteosperma*, *Pinus edulis,* and *P. monophylla*) are most common at intermediate elevations. At the highest elevations, ponderosa pine (*Pinus ponderosa*) forests with Douglas fir (*Pseudotsuga menziesii*) are predominant and white fir (*Abies concolor*) grows in cooler, moister areas (Nelson, 1976). On the floor of the canyon, near the Virgin R., a deciduous forest prevails with

Fremont's cottonwood (*Populus fremontii*), velvet ash (*Fraxinus vlutina*), bigtooth maple (*Acer grandidentatum*), and Gambel Oak (*Quercus gambelii*).

MATERIALS AND METHODS

Scat Collection

I collected scat from areas with known low human-activity (hereafter 'minimally-influenced scats') and areas with known high human-activity (hereafter 'directly-influenced' scats). Areas with low human-activity were at least a quarter mile away from trails and reached opportunistically by the researcher. Areas with high human-activity included an attic system in the Zion Lodge Complex in the main Zion Canyon, housing structures throughout the park, and NPS maintenance buildings. The known presence of the latrines in the attics from a pilot study in the fall of 2011 led researchers to sample those specific attics. I collected each scat individually in a small paper envelope labeled with an identification number, the date, a Universal Transverse Mercator (UTM) coordinate, the latrine identification, and any pertinent information about the scat. If the scat was not solitary and was touching other fecal matter in the latrine, I treated each major segment as a solitary scat because ringtail scats are almost exclusively deposited in single segments (Trapp, 1978). If the scat could not be identified as confidently belonging to a single individual, I did not collect it. If the scats were adhered together and could not be sufficiently divided, I did not collect them. I collected all scats that were safely within reach to the access walkways of the attic. I sealed each dried scat in a collection envelope and kept it in an airtight container out of sunlight in a cool, dry place until it could be placed in a freezer. Additional scats classified as directly-influenced came opportunistically throughout the study season from locations such as housing, maintenance sheds, and near dumpsters.

I collected the minimally-influenced scats using the same protocol. To find these scats, I sampled opportunistically in known ringtails habitats. I differentiated ringtail scats from other species by size, shape, smell, location, and the number of segments. Ringtail scats are mild-odored, single-segmented, and have a mean diameter of 9.6 mm and a total average length of 75.7 mm (Trapp, 1972; Poglayen-Neuwall & Toweill, 1988). If the sample appeared too degraded or damaged for analysis, I did not collect it.

Scat Processing

A small (<5%) portion of the scat sample was removed from the exterior of the scat for future genetic analysis, and the sample was weighed. The dry sample was placed in a glass beaker containing 200 mL of distilled water, heated on a hot plate to 95°C, stirred with a glass rod to break up the sample, and then poured through a Büchner funnel containing a 90mm medium fast filter paper to retain all medium and fine particulates (4-7 micron). The sample was picked through while still wet with static-resistant forceps to arrange the contents evenly on the filter paper and then allowed to air-dry completely before covering. The sample was again weighed and preserved in a 90mm glass petri dish for visual analysis.

I compiled multiple reference materials in preparation for the analysis of these dried samples, including hair, teeth, bone, seed, and insect collections of potentially occurring species from the riparian regions of Zion National Park. Six categories for food items were created: plant, mammal, bird, invertebrate, reptile, and anthropogenic. Many non-food items, such as trash, were also categorized as anthropogenic. I compared and identified seed and plant material samples using the Intermountain Flora database and a personal compilation of reliable seed photographs.

I identified insect samples using both the Audubon Society Field Guide to North American Insects and Spiders (Milne, 1980) and the Kaufman Field Guide to Insects of North America (Eaton and Kaufman, 2007). Items unidentifiable by the above sources were classified to the lowest level possible and then pooled. When possible, the item was listed to species, but if necessary, the sample was only identified to order.

Comparison slide mounts were prepared from hair samples obtained from the Utah State University mammal reference collection in the Department of Wildland Resources Museum. I identified mammalian remains using bone fragments identified with Roest's skull and jaw key (1986). I identified hair samples by examining, size, length, and coloration and referencing Moore et al. (1974). Particularly, the medulla was examined for cell pigmentation and patterning under a stereo-microscope. For many mammal species, the external structure of teeth is diagnostic for identification and was used for the identification of many of the scat contents of this analysis. All birds were placed in the class Aves.

Scat Analysis

Item identification included a visual volume estimation of food items based on a decile percentage scale in increments of 10 % (Trapp, 1973). Trace amounts of items were identified but only included as trace.

To determine the extent of difference between the two categories of ringtail diet: directly-influenced and minimally-influenced, an MRPP (Multi-response Permutation Procedure) was run using the software package R (R Development Core Team 2014). This nonparametric procedure tests the hypothesis of no difference between and within the two groups of scats (directly-influenced and minimally-influenced) by comparing the proportional composition across all food categories of the scats in these two groups. If the groups were truly different (e.g. in their food item composition), then the average of the compositional dissimilarities within a group will be less than the average of the dissimilarities between two random collections of scat samples drawn from all the scats collected. The *A* statistic reports the chance-corrected within-group agreement; A=1 when all items within groups are identical and A=0 when within-group heterogeneity is equal to the dissimilarity expected by chance. (Mielke and Berry, 2001; McCune and Grace, 2002).

RESULTS

I collected 146 scats between April and September 2013; 18 minimally-influenced (low human-activity) and 128 directly-influenced (high human-activity). I found 256 food items in the 146 scats: 44 anthropogenic items, 11 avian items, 94 insect items, 66 mammal items, 34 plant items, 5 reptile items, and 11 unidentifiable items (Table 4-1).

In the directly-influenced scats, the three items with the highest relative frequency (RF) were beetles (Coleoptera; RF=15%), crickets and grasshoppers (Orthoptera; RF=12%), and mice (*Peromyscus* sp.; RF=8%). The item with the next highest relative frequency was paper at 6%. All other items fall below 5% relative frequency (Table 4-2).

In the minimally-influenced scat samples, Orthoptera (23%), Coleoptera (RF=20%), and indeterminate insect parts (RF=10%) were the top three most common food items (Table 4-2).

By relative volume, in the directly-influenced fecal samples, rope (4%) and Pocket Gophers (*Thomomys* sp.; 4%) were highest, with foil candy wrapper (3%), plastic candy wrapper (3%), Long-tailed Pocket Mouse (*Chaetodipus formosus*; 3%), maple seed shell (3%), and Golden-mantled Ground Squirrel (*Spermophilus lateralis*; 4%) occurring next most voluminously (Table 4-3). The rest of the samples were equivalently low. In the minimally-influenced samples, the highest relative volume food item was Prickly Pear (*Opuntia* sp.; 12%), with Long-tailed Pocket Mouse (11%), Net-leaf Hackleberry (*Celtis laevigata var. reticulate*; 11%), and voles (*Microtus* sp.) (11%) equally second.

The weighted volume (WV), an average of the relative volume and the relative frequency of each food item, describes the influence of a particular food item within the collection of items consumed. Within directly-influenced scats analyzed, beetles (Coleoptera; WV=9%), crickets and grasshoppers (Orthoptera; WV=7%), mice (*Peromyscus* sp; WV=5%), and paper (WV=4%) were highest by this measure. The highest WV values in the minimally-influenced scat samples were crickets and grasshoppers (16%) and beetles (14%; Table 4-3).

TABLE 4-1—Food items observed in 146 ringtail (*Bassariscus astutus*) scats collected from April-September 2013 in Zion National Park, Utah.

Food Item	Common Name
Anthropogenic	
Aluminum Foil	---
Apple skin	---
Canvas	---
Fabric	---
Foil Candy wrapper	---
Hard plastic	---
Hard Unknown	---
Paper	---
Plastic	---
Plastic candy wrapper	---
Rope	---
Sunflower seed shell	---
Bird	
Feathers	---
Insect	
Coleoptera	Beetle
Insect (indeterminate)	---
Odonata	Damselfly, Dragonfly
Orthoptera	Cricket, Grasshopper
Mammal	
Chaetodipus formosus	Long-tailed Pocket Mouse
Microtus sp.	Vole (Long-tailed or Montane)
Neotamias dorsalis	Cliff Chipmunk
Neotamias minimus	Least Chipmunk
Neotamias sp.	Chipmunk (Cliff, Least, or Uinta)
Neotamias umbrinus	Uinta Chipmunk
Peromyscus crinitus	Canyon Mouse
Peromyscus maniculatus	Deer Mouse
Peromyscus sp.	Mouse (Brush, Canyon, Cactus, Deer, or Piñon)
Rodent indet.	---
Sorex palustris	American Water Shrew
Sorex sp.	Shrew (Merriam's, Montane, or American Water)
Spermophilus lateralis	Golden-mantled Ground Squirrel
Sylvilagus audubonii	Desert Cottontail
Thomomys sp.	Pocket Gopher (Botta's or Northern)
Plant	
Amelanchier sp.	Serviceberry
Arctostaphylos sp.	Manzanita
Celtis laevigata var. reticulata	Net Leaf Hackberry
Fruit skins	---
Maple seed shell	---
Opuntia sp.	Prickly Pear
Plant (indeterminate)	---
Ribes sp.	Wild Currant or Gooseberry
Reptile	
Scales	---
Scales and bones	---
Other	
No identifiable items	---
Sand	---
Unknown	---

TABLE 4-2—Frequency of 265 food-items observed in ringtail (*Bassariscus astutus*) scats collected April-September 2013 in Zion National Park, Utah. Frequency (F)=(# scats in which item occurs)/(total # scats sampled). Relative Frequency (RF) = (F of item)/(total of F values of all items). F and RF are expressed as percentages. *n*=number of food item occurrences.

	Directly-Influenced (128 samples)			*Minimally-Influenced (18 samples)*		
Food Item	F	*(n)*	RF	F	*(n)*	RF
Anthropogenic						
Aluminum Foil	0.078	(10)	0.040	---		---
Apple skin	---		---	0.11	(2)	0.067
Canvas	0.008	(1)	0.004	---		---
Fabric	0.042	(5)	0.022	---		---
Foil Candy wrapper	0.008	(1)	0.004	---		---
Hard plastic	0.008	(1)	0.004	---		---
Hard Unknown	0.008	(1)	0.004	---		---
Paper	0.108	(13)	0.056	---		---
Plastic	0.050	(6)	0.026	---		---
Plastic candy wrapper	0.008	(1)	0.004	---		---
Rope	0.017	(2)	0.009	---		---
Sunflower seed shell	0.008	(1)	0.004	---		---
Bird						
Feathers	0.092	(11)	0.047	---		---
Insect						
Coleoptera	0.292	(35)	0.151	0.33	(6)	0.200
Insect (indeterminate)	0.100	(12)	0.052	0.167	(4)	0.100
Odonata	0.025	(3)	0.013	---		---
Orthoptera	0.233	(28)	0.121	0.389	(7)	0.233
Mammal						
Chaetodipus formosus	0.008	(1)	0.004	---		---
Microtus sp.	0.067	(8)	0.035	0.111	(2)	0.067
Neotamias dorsalis	0.017	(2)	0.009	---		---
Neotamias minimus	0.008	(1)	0.004	---		---
Neotamias sp.	0.033	(4)	0.017	---		---
Neotamias umbrinus	0.008	(1)	0.004	---		---
Peromyscus crinitus	0.017	(2)	0.009	---		---
Peromyscus maniculatus	0.008	(1)	0.004	0.056	(1)	0.033
Peromyscus sp.	0.150	(18)	0.078	0.056	(1)	0.033
Rodent (indeterminate)	0.042	(5)	0.022	---		---
Sorex palustris	0.008	(1)	0.004	---		---
Sorex sp.	0.067	(8)	0.035	0.056	(1)	0.033
Spermophilus lateralis	0.050	(6)	0.026	---		---
Sylvilagus audubonii	0.017	(2)	0.009	---		---
Thomomys sp.	0.008	(1)	0.004	---		---
Plant						
Amelanchier sp.	---		---	0.056	(1)	0.033
Arctostaphylos sp.	0.008	(1)	0.004	0.111	(2)	0.067
Celtis laevigata var. reticulata	0.023	(3)	0.012	0.056	(1)	0.033
Fruit skins	0.086	(11)	0.045	0.056	(1)	0.033
Maple seed shell	0.008	(1)	0.004	---		---
Opuntia sp.	0.039	(5)	0.020	0.056	(1)	0.033
Plant (indeterminate)	0.039	(5)	0.020	0.056	(1)	0.033
Ribes sp.	0.008	(1)	0.004	---		---
Reptile						
Scales	0.016	(2)	0.008	---		---
Scales and bones	0.023	(3)	0.012	---		---
Other						
No identifiable items	0.039	(5)	0.020	---		---
Sand	0.008	(1)	0.004	---		---
Unknown	0.039	(5)	0.020	---		---

TABLE 4-3—Relative volume (RV) and weighted volume (WV) of food items observed in ringtail (*Bassariscus astutus*) scats collected April-September 2013 in Zion National Park, Utah. RV=(average volume of item)/(total of all average volumes of all items). WV=(Relative Frequency +Relative Volume)/2.

	Directly-Influenced *(128 samples)*		*Minimally-Influenced* *(18 samples)*	
Food Item	RV	WV	RV	WV
Anthropogenic				
Aluminum Foil	1.5%	2.8%	---	---
Apple skin	---	---	6.7%	6.7%
Canvas	2.7%	1.6%	---	---
Fabric	2.2%	2.2%	---	---
Foil Candy wrapper	3.5%	2.0%	---	---
Hard plastic	1.9%	1.2%	---	---
Hard Unknown	2.3%	1.4%	---	---
Paper	2.0%	3.8%	---	---
Plastic	1.0%	1.8%	---	---
Plastic candy wrapper	3.5%	2.0%	---	---
Rope	3.9%	2.4%	---	---
Sunflower seed shell	0.4%	0.4%	---	---
Bird				
Feathers	1.6%	3.2%	---	---
Insect				
Coleoptera	2.1%	8.6%	7.1%	13.6%
Insect (indeterminate)	1.6%	3.4%	5.3%	7.6%
Odonata	1.8%	1.6%	---	---
Orthoptera	1.8%	6.9%	8.5%	15.9%
Mammal				
Chaetodipus formosus	3.5%	2.0%	---	---
Microtus sp.	2.9%	3.2%	11.0%	8.8%
Neotamias dorsalis	3.3%	2.0%	---	---
Neotamias minimus	1.9%	1.2%	---	---
Neotamias sp.	3.1%	2.4%	---	---
Neotamias umbrinus	1.9%	1.2%	---	---
Peromyscus crinitus	2.9%	1.9%	---	---
Peromyscus maniculatus	3.1%	1.8%	9.7%	6.5%
Peromyscus sp.	2.5%	5.1%	11.0%	7.1%
Rodent (indeterminate)	0.6%	1.4%	---	---
Sorex palustris	3.1%	1.8%	---	---
Sorex sp.	2.2%	2.8%	1.2%	2.3%
Spermophilus lateralis	3.5%	3.1%	---	---
Sylvilagus audubonii	2.9%	1.9%	---	---
Thomomys sp.	3.9%	2.1%	---	---
Plant				
Amelanchier sp.	---	---	7.3%	5.3%
Arctostaphylos sp.	1.5%	1.0%	4.3%	5.5%
Celtis laevigata var. reticulata	1.0%	1.1%	11.0%	7.1%
Fruit skins	1.5%	3.0%	2.4%	2.9%
Maple seed shell	3.5%	1.9%	---	---
Opuntia sp.	1.6%	1.8%	12.2%	7.8%
Plant (indeterminate)	1.5%	1.7%	2.4%	2.9%
Ribes sp.	0.8%	0.6%	---	---
Reptile				
Scales	1.5%	1.2%	---	---
Scales and bones	2.4%	1.8%	---	---
Other				
No identifiable items	3.8%	2.9%	---	---
Sand	2.7%	1.6%	---	---
Unknown	3.2%	2.6%	---	---
Total	100.0%	100.0%	100.00%	100.00%

The frequencies and relative frequencies across the individual food items were pooled to draw conclusions about the types of food, rather than individual food items. In the scats influenced by human resources, insects were the most frequent food category (F= 61%, RF= 33%), mammals were second (F = 48%, RF = 26%), and anthropogenic items were third (F = 33%, RF = 18%) (Fig. 4-1). In the minimally-influenced scats, the insect category was also most commonly found (F = 89%, RF = 53%), plants were second most frequent (F = 39%, RF = 23%), and mammals were third (F = 28%, RF = 17%) (Figure 4-1).

The most common food type for directly-influenced scats, measured by relative volume (RV) category, is the “other” category, including unidentifiable items (RV = 23%). The second highest category is mammals (RV = 17.2%) and third is reptiles (RV = 13.8%). However, insects had the highest weighted volume (WV = 22.9%), mammals are second (WV = 21.6%), and anthropogenic items were third (WV = 15.2%). In the minimally-influenced scats, insects represented the highest proportional volume of items found (RV = 30.1%), plants were categorized as the next highest relative volume (RV = 25.1%), and anthropogenic items were third (RV = 23.0) (Fig. 4-2). By weighted volume, insects were highest (WV = 41.7%), plants second (WV = 24.2%), and mammals third (WV = 19.1%) (Fig. 4-2).

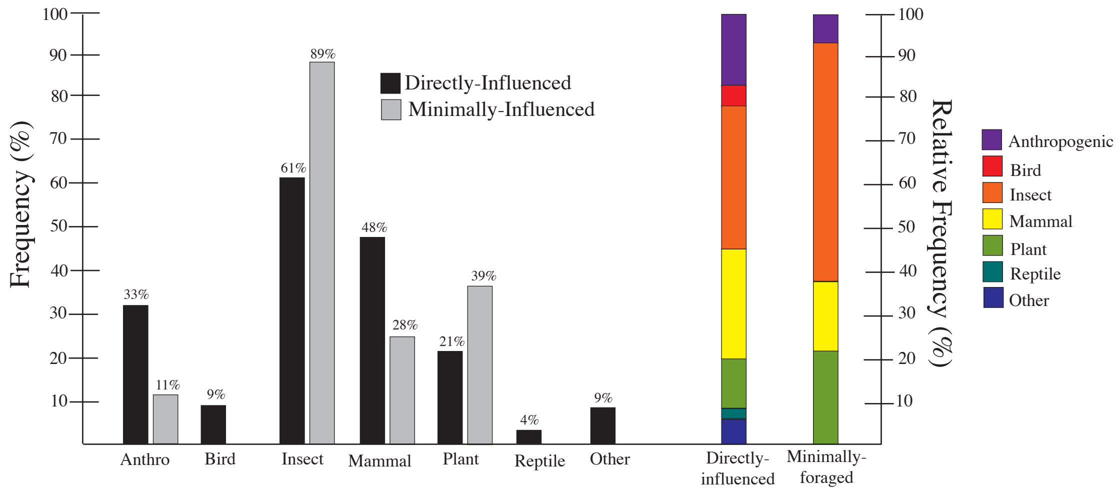

FIG. 4-1—Frequency of occurrence of food categories observed in ringtail (*Bassariscus astutus*) scats collected April-September 2013 in Zion National Park, Utah. Frequency (F)=(# scats in which item occurs)/(total # scats sampled). Relative Frequency (RF) = (F of item)/(total of F values of all items).

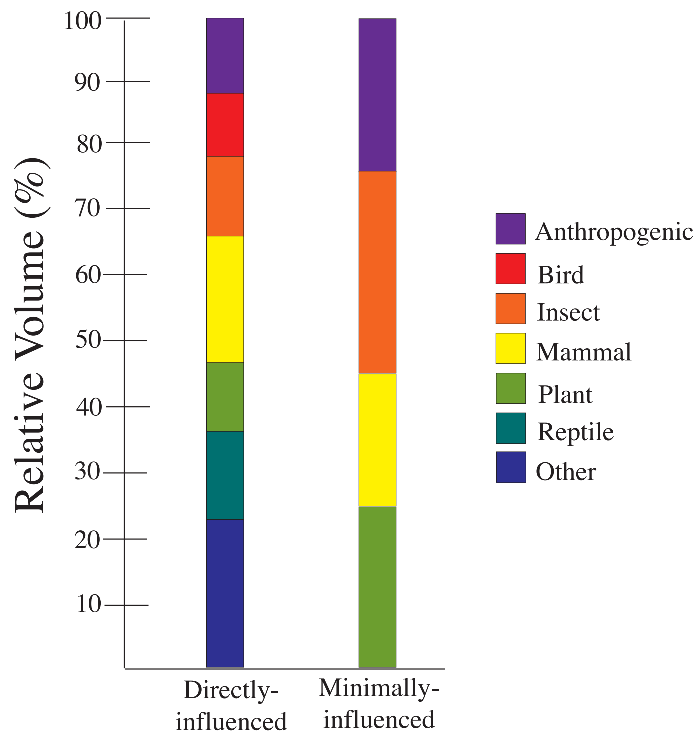

FIG. 4-2—Relative Volume (RV) of food categories observed in ringtail (*Bassariscus astutus*) scats collected April-September 2013 in Zion National Park, Utah. RV=(average volume of item)/(total of all average volumes of all items).

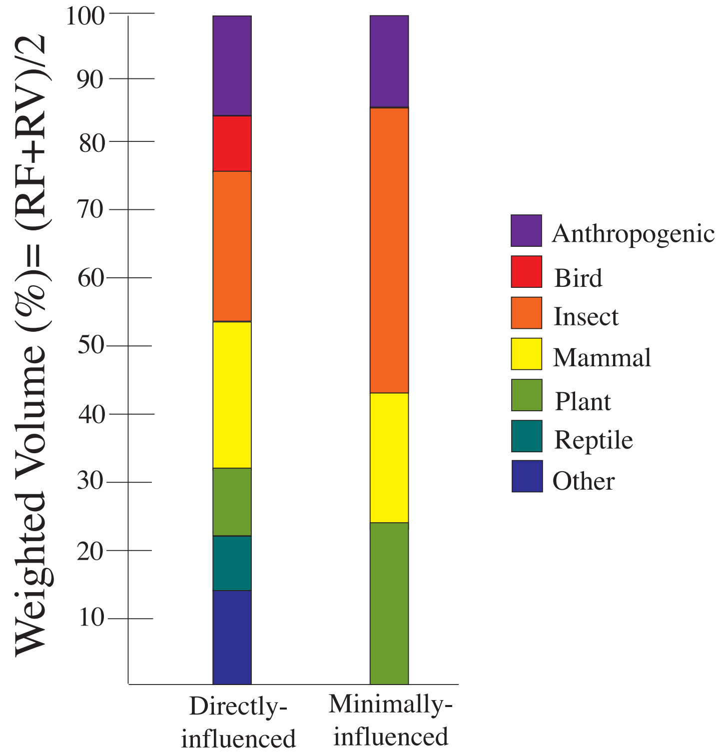

FIG. 4-3—Weighted Volume (WV) of food categories observed in ringtail (*Bassariscus astutus*) scats collected April-September 2013 in Zion National Park, Utah. WV=(Relative Frequency+Relative Volume)/2.

The compositions of all scats sampled were compared between the directly-influenced group (n=128), and the minimally-influenced group (n=18) using a Euclidean distance measure. A significant difference was detected between the observed compositions of these two subsets of scat ($p<0.001$, A=0.07536, observed $\delta=112.3$, expected $\delta=121.4$).

DISCUSSION

Minimally-Influenced Diet

The results of this study indicate that insects, mammals, and plants are the dominant wild food sources for ringtails in Zion Canyon, as would be expected for omnivorous mammals of this size. The types of food consumed by ringtails in this study are similar to many of the results found in previously published studies, aside from the anthropogenic items (Nelson, 1918; Taylor, 1954; Kuban and Schwartz, 1985; Poglayen-Neuwall and Toweill, 1988; Wyatt, 1993; Alexander et al., 1994), but there is a higher detection of insect prey than the previous studies. The relatively common presence of Coleoptera and Orthoptera, for both directly-influenced and minimally-influenced subsets, is likely a factor of the density and diversity of insect life that is prevalent along the large, permanent Virgin River.

The frequency of mammalian remains present in the directly-influenced samples, particularly *Peromyscus* sp., supports the known ecology of ringtails as successful “mousers”. Their success at depredating small rodents led to a long history of humans keeping them as pets in gold mining camps in the southwestern U.S. (Poglayen-Neuwall and Toweill, 1988). The higher density of rodent populations in and around buildings was reflected in the higher presence of mammal remains in the ringtail feces found in human-inhabited areas. However, it is difficult to assess whether these rodents are being caught inside or out of the buildings without a more rigorous sampling protocol.

Directly-Influenced Diet

The occurrence of anthropogenic items in the scats is a concern. While the relative frequency of individual items is low, ringtail use of the category as a whole is significant. The types of items present in the samples are almost all non-digestible items, so this could lead to a higher weighting in the calculation of importance factor, but the fact that these animals are ingesting non-digestible items in an attempt to eat human resources is a concern. The anthropogenic item of highest frequency, paper, is likely due to the ringtails ingesting paper napkins while foraging in open human trash containers. Whether the napkins have digestible items on them to begin with, or they just smell tempting, is unknown. The impact all these non-digestible items, including plastic, are having on the internal digestive tracts of these animals is also unknown. These items are often disproportionately large in size (e.g. rope) and health complications may result in some individuals. The presence of some anthropogenic items in the minimally-influenced samples, such as apple skins, is also interesting to note. The apple skin was introduced by a human visitor, deposited within park boundaries, but away from human buildings, and found, eaten, and digested by a ringtail. It is possible that the animal collected the fruit in an area of high human activity, and then moved to an areas of low human activity to eat it. This illustrates that the interface between humans and wildlife certainly is not delineated solely by the locations of the buildings or trails in Zion.

One important thing to consider about the statistical significance in the difference of these two groups of scats is the wide variance in sample size. The statistical procedure used is very good at discerning differences categorically between groups, but there is the possibility that certain data will display significance with a small p-value even though the “effect size” (*A*) is small. This may be the case in this study because one sample group was so much larger than the other and therefore had a wider variety of items by sampling nature, as opposed to ecological significance. However, the possibility of a wider variety of foods being available to ringtails that utilize buildings and trashcans is a key factor to consider. Despite the smaller sample size of the minimally-influenced scats, the food items available are more limited, leading to more narrow scat composition.

The definition of human-wildlife conflict is any interaction between human and wildlife that causes harm to one party. However, in almost every case, the harm occurs to both humans and wildlife, independent of the unit of measure. In this case, the human users of the national park are frustrated with the ringtails entering and damaging buildings; however, the ringtails are being directly affected by their exposure to and use of accessible human resources.

Ringtails, as omnivores, are able to utilize many different food sources, and are exploiting the resources of the human visitors of the park. Anthropogenic resources impact the ringtails’ diet via physical objects (e.g. trash), but also via a shift in the prey available to the ringtails. The high rodent population in and around buildings will continue to draw in the ringtails, as seen in scat evidence that they are targeting this prey base more heavily than in areas of low human density.

MANAGEMENT IMPLICATIONS

This study illuminates some of the influences that anthropogenic resources are having on the ringtail population within Zion National Park. This wild population of animals continues to enter human structures through access holes to take advantage of human food items and increased rodent density. Knowing that the ringtails will return to buildings to utilize the human food and rodents available presents two available options to forestall future conflicts: management of human trash and management of the rodent population. Better trash receptacles, cleanup protocols, and human food storage practices will reduce directly-influenced food availability. Excluding rodents from a building is a difficult task, however, the dimensions of holes often targeted during rodent exclusion will also contribute to ringtail exclusion. The preservation of the ringtail population as a park resource is part of the National Park Service's mission. Human visitors are there to enjoy the park and its resources, but not at the expense of the stewardship of natural resources.

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CHAPTER 5

SUMMARY AND CONCLUSIONS

The ringtail (*Bassariscus astutus*) is an understudied mesocarnivore throughout the southwest. Specifically, ringtails in Zion National Park, Utah, are rarely seen, but are involved in increasing occurrences of negative interactions with park visitors and employees such as food theft and denning in buildings, interactions which are harmful to both parties. To manage this conflict, updated general knowledge about the condition of the population was required. This study has added to the growing scientific knowledge of the ringtail and displays the importance and impact of ringtail-human interactions in a small region of their overall distribution.

The first objective of this research was to confirm ringtail use of known habitat types. Using a combination of two noninvasive techniques, I confirmed ringtail association with riparian habitat within Zion National Park, specifically focused on Zion Canyon using both camera-traps and track-plates. Previously, a reliable noninvasive detection method for ringtails was not well documented; but this study confirms both track-plates and camera-traps are equally effective for detecting ringtails.

The second objective of my research was to review detection methods of ringtails and assess population presence. The two successful detection methods tested were used to build an occupancy estimate of ringtails as well as an estimated probability of detection. The addition of the track-plate to the camera trap did not improve the occupancy model, however, it did increase the number of sites at which an animal was detected if there was a camera malfunction. Through the use of the track-plates to detect ringtails, a study was established to individually identify ringtails noninvasively using their footprints. I used the Interactive Individual Identification System (I^3S) software to assess the reliability of identifying individuals using the pattern of the dots and patterns formed by the papillae and ridges of the footpad. I found that ringtails' footpad prints consistently resulted in a unique pattern that was recognizable by humans using simple visual analysis and by a computer-aided analysis of the prints in a database. This pilot study provided groundwork for developing a dermatoglyphic field technique as a noninvasive individual identification method. This result represents a significant development in the identification of ringtails since i) this procedure is repeatable throughout the life of the individual, ii) all ages of individual can be marked despite the difference in footpad size throughout growth, and iii) it provides an economical, noninvasive method to detect and identify this elusive carnivore.

The third objective of this study was to determine impact of human conflict on ringtail biology. The ringtails in close proximity to humans that entered buildings were examined for the impact on their diet through consumption of directly-influenced food sources. The diet of ringtails using human structures was significantly different from that of the ringtails foraging away from human development. I measured the influence of available anthropogenic resources on ringtail diet by examining 146 total ringtail scats collected from buildings throughout the park and opportunistically in areas of low human activity. In the directly-influenced subset, insects (33%) and mammals (26%) were the most relatively frequent food items. Anthropogenic items were present across 33% of scats sampled, a majority of which were non-digestible items such as trash. In the minimally-influenced scats, insects were most frequently detected (53%), but plant material was also frequent (23%), and anthropogenic items were present in 11% of scats. Until the availability of human food and a high rodent resource is controlled, ringtails will continue to return to buildings in search of them. Ringtails actively modify building entry points to gain access; therefore, a constantly monitored rodent and ringtail exclusion practice is likely the only long-term effective method of preventing ringtail entry. The ringtail population in Zion National Park exists at relatively low densities, but certain individuals are repeat users of human structures, therefore to manage for this human-wildlife conflict, it is necessary to manage the holes in the buildings in conjunction with managing the ringtails.

Overall, this study greatly added to the current scientific knowledge of the ringtail and provides significant findings to help support the management decisions of Zion National Park. While humans and ringtails continue to co-exist in Zion National Park, there will be the potential for overlap and interaction, therefore, I hope that this information will be used to better monitor this population into the future and limit the adverse effects that human presence can have on ringtail biology.

APPENDIX

Ringtail Relocation in Zion National Park using an Adaptive Resource Management Strategy: Final Report

August 7, 2014

Prepared by:
Adrian A. Roadman, M.S. Candidate
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INTRODUCTION

Despite its abundance throughout southwestern North America, current scientific knowledge of the ringtail (*Bassariscus astutus*) is relatively limited (Ackerson and Harveson 2006). In contrast with their wide range, the studies that have been conducted have been located in only a small portion of their overall range, resulting in a fragmented understanding of their ecology, spread across many decades of methodological and technological advancement (Alexander et al. 1994). To date, a number of studies investigated the diet of this small desert omnivore (Wood 1954; Taylor 1954; Alexander et al. 1994; Trapp 1972; Chevalier 1984; Wyatt 1993; Roadman 2014), a few studies focused on movement patterns, home ranges, and activity patterns (Trapp 1978; Toweill and Teer 1980; Lacy 1983; Ackerson and Harveson 2006; Montacer 2009), and assorted other studies explored topics such as helminth load, disease prevalence, and behavioral trends (Winkler and Adams 1972; Richards, 1976; Pence and Willis 1978; Willey and Richards 1981; Krebs et al. 2003; Gabriel et. al 2008; Myers 2010; Harrison 2012).

This small house-cat-sized omnivore belongs to the family Procyonidae, the carnivore family also encompassing the cacomistle (*Bassariscus sumichrasti*), the raccoon (*Procyon lotor*), and the white-nosed coati (*Nasua narica*). Ringtails are a small procyonid with an average weight of 0.8-1.1 kilograms (Poglyen-Neuwall and Toweill 1988; Ackerson and Harveson 2006) and total lengths of 616mm-811mm, with the males commonly becoming slightly larger than females (Gehrt 2003; Harrison 2012). Ringtails make use of their short semi-retractable claws (Hall 1981) and 180-degree-rotatable hind feet (Schmidly 2004) to skillfully climb trees, ascend nearly-vertical rock walls, and foray into extremely narrow rock crevices, often using a chimney-stemming climbing technique (Mandolf 1961; Trapp 1972). Their tails, with 7-8 alternating black and white stripes, are nearly as long as their bodies and provides excellent balance to combine with the rotatable ankle joints for extremely quick and agile change in direction while climbing (Trapp 1972).

Distribution

Currently in North America, ringtail distribution extends from Mexico along the western coast of the United States into southwestern Oregon and through the southwest to Colorado, Nebraska, Arkansas, Oklahoma, Texas and Louisiana (Figure 1; Hall 1981; Wozencraft 2005). Ringtails are widespread throughout southern Utah, but in low-density populations (Trapp 1978; Poglayen-Neuwall and Toweill 1988), making use of chaparral, pinon-juniper woodland, and various scrub vegetation communities (Trapp 1978). Ringtails display a preference for rough, rocky terrain independent of the vegetation community or presence of trees (Grinnel et. al. 1937; Davis 1960; Hall and Dalquest 1963) and this is frequently paired with an affinity for riparian areas (Trapp 1972). However, in both Texas and California, ringtails exploit nearly every available type of habitat within their range (Taylor 1954, Orloff 1988).

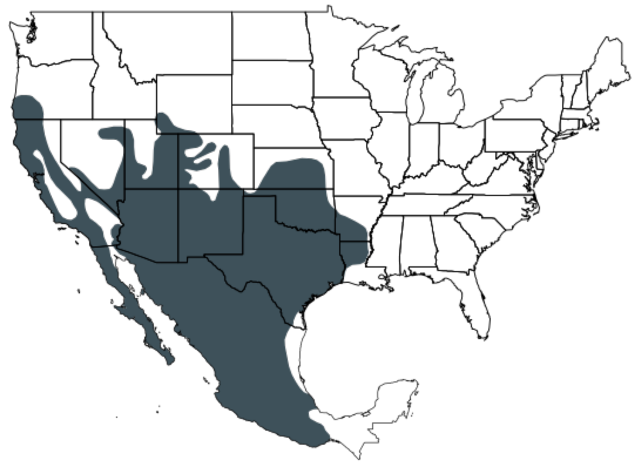

Figure A-1. Distribution of ringtails (*Bassariscus astutus*) throughout southwestern North America as of 2008.

Zion National Park Distribution

The main area of the park that harbors the habitat most likely to be used by ringtails–boulder-strewn riparian areas (Trapp 1972)–overlaps with the areas of highest human activity within the park boundaries. This overlap provides an avenue for an increase in the number of occurrences of ringtail conflict and damage. The majority of employee and visitor sightings of ringtails occur around human structures in the main canyon, implying at least a presence of ringtails in this area, perhaps even a distinct concentration (personal communication with Claire Crow 2008). Three main locations with the highest concern regarding ringtail conflict are: the Zion Lodge Complex, the National Park Service Headquarters Complex, and the National Park Service Maintenance Complex. Ringtails are able to enter any hole large enough to fit their skull, providing ease into buildings (Figure 2). Any access point or hole in a building that is larger than this width will allow a ringtail of this size (a large adult male) to pass into the building. Smaller ringtails could potentially utilize smaller holes. Because many of the buildings in Zion National Park are historic structures dating back to the 1920s and 1930s, many of which were built by the Civilian Conservation Corps, there has been a strong effort to preserve the buildings as originally built. The majority of these structures are constructed of stone and masonry with multitudes of crack and holes in the construction. The high volume of entry points, often in visually obstructed areas, present a major maintenance concern. Ringtails utilize these holes regularly.

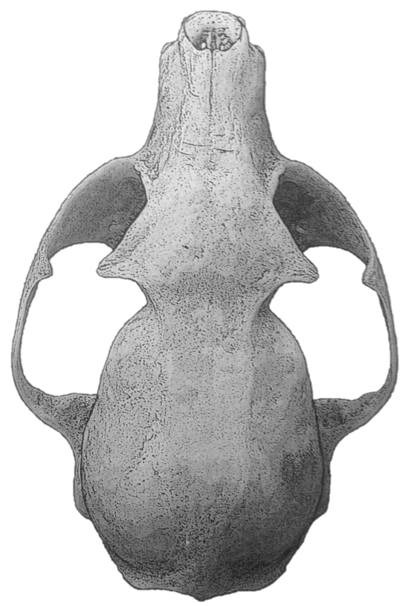

Figure A-2. Life-sized representation of a ringtail (*Bassariscus astutus*) skull displaying the maximum width of the skull between the zygomatic arches of an average adult male ringtail.

Home Range

Home ranges reported for ringtails vary greatly in the sparse number of studies that have been conducted to date, which parallels the vastly differing habitats in which these studies occurred (Table 1). The discrepancy across these home range sizes is likely a direct effect of the available of resources in certain habitats.

Table A-1. Ringtail (*Bassariscus astutus*) home range sizes (ha) from seven comparative studies.

Study	Location	N	$\bar{X}$ (range)	Male $\bar{X}$ (N)	Female $\bar{X}$ (N)
Trapp (1978)[a]	Utah	9	136 (49-223)	139 (7)	129 (2)
Toweill (1976)[b]	Texas	5	29 (16-52)	43 (2)	20 (3)
Koch and Brody (1981)[c]	California	4	221 (49-338)	221 (4)	---
Lacy (1983)[a]	California	4	9 (5-14)	9 (2)	8 (2)
Callas (1987)[b]	California	6	175 (68-349)	278 (2)	124 (4)
Yarchin (1990)[a]	Arizona	4	20 (16-23)	23 (2)	17 (2)
Wyatt (1993)[d]	California	8	12 (5-21)	16 (4)	8 (4)
Ackerson and Harveson (2006)[e]	Texas	5	42 (---)	47 (1)[f]	28 (4)[g]
Montacer (2009)[e]	Texas	4	---	ranged 36-81 (3)	3 (1)
Harrison (2012)[d]	New Mexico	13	302 (5)	806 (6)	152 (7)

[a] minimum area polygon - atypical habitat elimination method
[b] minimum polygon encompassing all known den locations
[c] harmonic mean
[d] minimum area polygon - 95% minimum convex polygon and atypical habitat elimination method
[e] minimum area polygon - 100% minimum convex polygon
[f] winter range
[g] summer range only

Diet

Ringtails are an important meso-carnivore in the southwest; they depredate and help control populations of rodents, insects, and reptiles. Supplementary to their efficient predation, ringtails are omnivorous, allowing them to exploit hot, arid habitats (Chevalier 1984); they will consume fruit, nectar, and various plant materials (Kuban and Schwartz 1985; Poglayen-Neuwall and Toweill 1988). Their specific diet content shifts with food availability (Alexander et al., 1994; Nelson, 1918; Taylor 1954). Ringtails are able to conserve water when water-stressed as dietary or freestanding water becomes scarce or absent (Chevalier 1984). This is particularly useful for lactating females, newly weaned young, and dispersing individuals. This water conservation leads to extremely concentrated urine and potentially extremely dense fecal material (Chevalier 1984).

As human presence in the national park increases, human-wildlife interactions involving ringtails are growing in frequency and intensity. The level of damage currently created by these individuals throughout the year has reached an intolerable level for the governing body of the park. Because of the lack of recent scientific information in Utah regarding ringtails, a controlled study to gather information was necessary to properly inform and formulate a ringtail management plan.

Study Objectives

1) Provide a ringtail population estimate for the main canyon.
2) Find a minimum relocation distance required to prevent conflict ringtail returns.
3) Measure return rates of relocated conflict ringtails.
4) Follow relocated individuals using radio telemetry to illuminate movement patterns.

METHODS

Study Site

Zion National Park is 590 square kilometers (229 mi^2) of land in Washington County, UT. There is some human development on the boundaries of the park, near the southern entrance, in the town of Springdale, UT and along the access road of State Route 9, but otherwise is largely surrounded by land managed by the Bureau of Land Management. The main portion of the park is the five-mile long Zion Canyon. The three main areas targeted for sampling for human-ringtail conflict were located in this canyon, at the Zion Canyon Lodge, NPS headquarters, and NPS maintenance yard. The Zion Canyon Lodge is complex of buildings within the main canyon, run by Xanterra Parks & Resorts, and is made up of 21 separate buildings including sheds, cabins, office complexes, and multi-level hotel buildings. The headquarters of the national park is just south of the main canyon's mouth and has two large buildings and a double-wide trailer, and the maintenance yard is west of the headquarters complex in Oak Creek Canyon and is made up of seven buildings of varying sizes and uses including offices and garages (Figure 3).

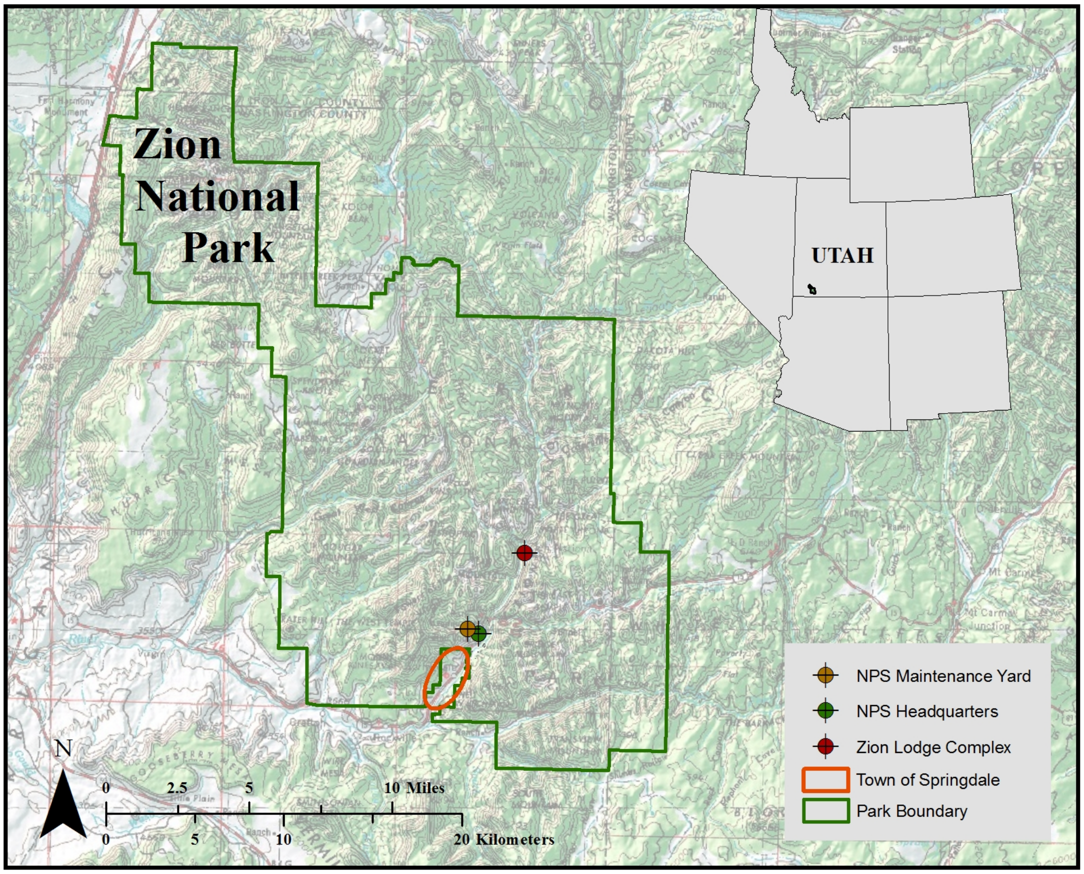

Figure A-3. Map of study area highlighting areas of interest for trapping and reference, created November 2013.

Data Collection

Trapping. — From October to December 2011 and June to September 2013, a rotating trapping scheme using double door Tomahawk wire box-traps (15 x 15 x 60 cm; Tomahawk Live Trap Company, Hazelhurst, WI) sampled various locations throughout the main canyon and building complexes. Each night of the trapping session, traps were deployed at sundown and checked and removed at sunrise. Traps were baited with a combination of small fresh apple slices, a scoop of peanut butter, strawberry jam, and raisins trailing into the trap opening. A small tin can contained the bait to keep the trap clean and to require the ringtail to spend more time in the trap, preventing bait theft.

Each morning, captured ringtails were carefully transported to a quiet, safe location away from visitor use areas for handling. During 2011, a dosage of ~0.5mg/1kg body weight of Xylazine was injected intramuscularly. The reversal agent Yohimbine was available during all captures. General body condition and health was assessed, an eartag was attached to each ear, and for full-grown adults, a very-high-frequency transmitting radio collar was carefully attached (Advanced Telemetry Systems, Isanti, MN). Due to health concerns for the ringtails, the use of only Xylazine was discontinued in spring 2013. Throughout summer 2013, we used Ketamine Hydrochloride instead, with no adverse reactions observed. Injected intramuscularly, a dosage of 0.1 ml/1kg body weight of Ketamine Hydrochloride provided sufficient sedation of ringtails to allow the researcher to safely handle the ringtail for approximately twenty minutes. Within this time, the researcher recorded full morphometric measurements (skull width, skull length, weight, total body length, tail length, ear length, sex, and age) and took footprints of the ringtail using non-toxic, washable ink in a 4x4 replicate.

All animal trapping and handling was done under the procedures and protocols specifically outlined in a permit approved by Utah State University's Institutional Animal Care and Use Committee (IACUC-2032).

Relocation. — During 2011, after sedation and collar attachment, ringtails were released in a scheme of varying distances based on recapture history. For a first time capture, the ringtail was released at the site of capture, but away from the building and in a safe location. For each subsequent recapture and release, the animal was released further away from the capture site (Figure 4) but never outside of park boundaries. Every release location was recorded using a handheld Global Positioning System (GPS) device. The animal was observed to make sure it made a full recovery before the researcher left.

Telemetry. — From May to August 2012, the individuals trapped and collared in winter 2011 were tracked using handheld and truck mounted radio antennae on at least a twice-weekly basis. When a signal was strong enough to track, it was triangulated as accurately as possible, once in the evening and again the following morning. If possible, the researcher located the ringtail daytime den or location on foot using the handheld receiver.

Data Analysis. — All spatial data collected using Global Positioning Systems (GPS) was uploaded and plotted using ArcGIS (version 10.0, Environmental Systems Research Institute, Redlands, CA). Telemetry triangulation information was input into the LOAS program (Location Of A Signal; Ecological Software Solutions, LLC) and locations estimated using a 95% maximum likelihood estimator.

RESULTS

Population Information

Between August 2011 and September 2013, 12 male ringtails, 6 female ringtails, and 6 juvenile ringtails of indeterminate sex were captured. All of these individuals were in good health and only one individual was observed to have ectoparasites, an adult female with a minor infestation of ear mites. One very large male had slightly tattered ears and minor tooth damage, but every other ringtail was in excellent body condition with healthy teeth. The weight of adult female ringtails (n=6) ranged from 775g to 1290g, averaging 943 ± 181g (SD). Male ringtails (n=11) ranged from 912g to 1490g with an average weight of 1013 ± 175g (SD). Standard morphometric data was also collected for a subset of the captured individuals (3 females, 3 males; Table 2). Two of the females captured during Summer 2013 were lactating at the time of capture.

Unfortunately, because of the inability to coordinate and control unauthorized trapping and relocation of animals beyond the researcher, the basic assumptions of a controlled capture-mark-recapture estimate were violated numerous times, and therefore a standardized scientific population size can not be estimated with any validity.

Table A-2. Adult ringtail (*Bassariscus astutus*) morphometric data from six comparative studies and two reference books.

Study	Location	N	Mean Weight (g) ± SD [range]		Mean Total Length (mm) ± SD [range]		Mean Tail Length (mm) ± SD [range]		Mean Ear Length (mm) ± SD [range]	
			♂	♀	♂	♀	♂	♀	♂	♀
Toweill and Toweill (1978)	Captive	9	---	1036 ± 77 [894-1139]	---	---	---	357 ± 21 [330-392]	---	58 ± 4 [43-57]
Kaufman (1982) - book	---				630-810[a]		305-438[a]		45-54[a]	
Wyatt (1993)	California	8	1120 ± 70	972 ± 149	780 ± 29	752 ± 28	373 ± 25	360 ± 24	47 ± 4	45 ± 2
Davis & Schmidly (1994) - book	---		[1000-1500][a]		802	714	410	350	55	---
Ackerson and Harveson (2006)	Texas	17	1200 ± 360 [700-1750][a]		---		---		---	
Montacer (2009)	Texas	19	1370 [800-1600]	990 [700-1200]	788 [650-875]	676 [392-780]	387 [325-440]	363 [330-410]	47 [35-56]	44 [33-52]
Harrison (2012)	New Mexico	18	1000 ± 100	900 ± 100	---		375 ± 21	367 ± 17	48 ± 3	47 ± 3
Roadman (2014)[b]	Utah	16	1013 ± 175 [912-1490]	943 ± 181 [775-1290]	743 ± 33 [708-773][c]	720 ± 37 [724-757][c]	377 ± 21 [353-393][c]	401 ± 103 [335-552][c]	---	36 ± 11 [24-44][c]

[a]Did not differentiate sexes

[b]This study

[c]n=3

Relocation

Twenty-four individuals were live-trapped throughout the duration of this study. Of this total, the recapture rate varied greatly. Throughout winter 2011/2012, when trapping was conducted exclusively in buildings, 9 individuals were only captured once, while one individual returned to the traps 7 times and another returned 8 times (Figure 4). Very few individuals were recaptured during summer 2013, but this trapping was conducted on free-ranging individuals, and not inside buildings.

The buildings that had the highest rate of capture were those located within the Zion lodge complex. The traps set in the main lodge building produced the highest capture rate of ringtails. The buildings in the maintenance yard of the National Park Service were second in overall capture events, and the headquarters complex saw the least activity of the three main conflict areas targeted with trapping (Figure 5).

Of the 24 individuals trapped throughout the study, 17 were trapped during winter 11/12 in the buildings, and 7 were trapped in the summer of 2013 outside of buildings. None of the summer 2013 individuals were relocated. Of the 17 ringtails trapped in buildings, six individuals fitted with radiocollars were progressively relocated. All relocations resulted in returns to initial capture site until the loss of the radio signal. No relocated individual established a new home range at the relocation site. The farthest distance returned by one individual occurred in February 2013 when M-000-190 was captured in the NPS headquarters building and moved 6.5 km. His signal was triangulated just east of the first tunnel four days later, having moved 3.8 km. He moved the remaining distance of 3.2 km back to NPS headquarters the following day and reentered the building. His total return time was 5 days for 6.5 km.

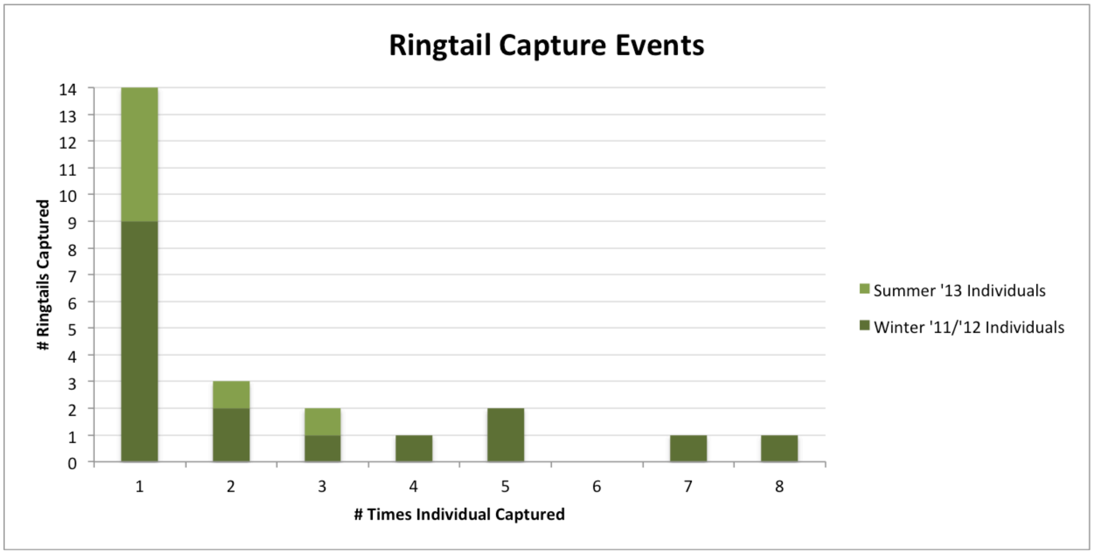

Figure A-4. Ringtail (*Bassariscus astutus*) recapture rates between August 2011 and August 2013 in Zi on National Park, Utah.

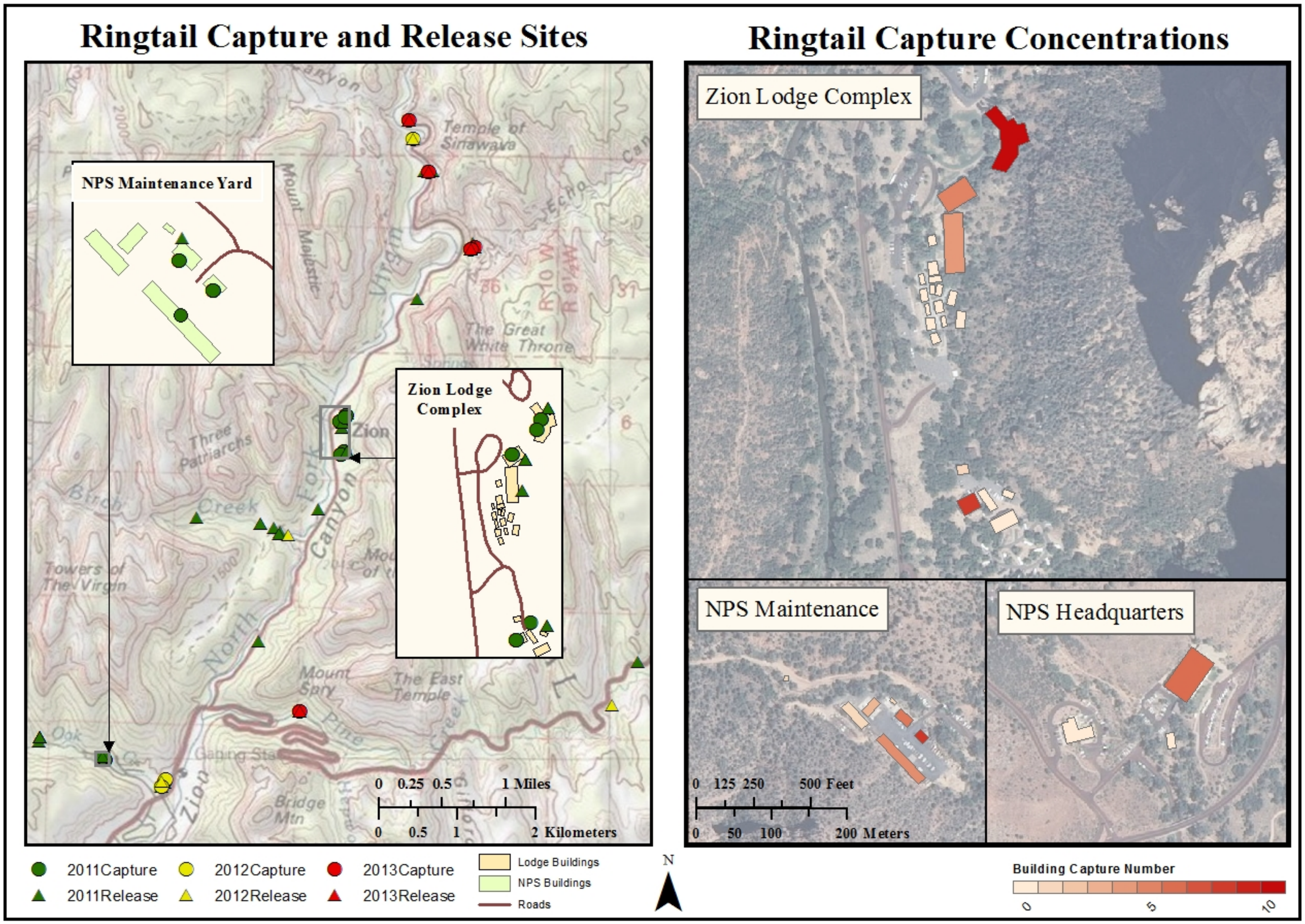

Figure A-5. Ringtail (*Bassariscus astutus*)capture and release locations throughout Zion National Park and the resulting concentrations in affected buildings.

Telemetry

After animals were captured and relocated, certain adults were fitted with very high frequency radio transmitters to track their movements and follow them throughout the season. Ten individuals were collared and tracked. The following short write-ups explain the extent of the information known about every animal that was collared throughout the study. The distances moved are listed in parentheses:

M-149-054. — This adult male was first captured on August 10, 2011 in the lodge's building A. He was fitted with radiocollar 149.054 and released just behind building A (0 km). He was recaptured in Building A on October 17, 2011 and released further up the hills behind the lodge complex (0.5 km). He was then recaptured on October 20, 2011 in the lodge basement (0.5 km) and released again along the Sand Bench Trail in Birch Creek canyon (1.5 km). He found his way back to the lodge basement (1.5 km) and was captured once again on October 24, 2011 and was released at the East Rim Trailhead (5.6 km) near the east entrance. His signal was triangulated once near the east entrance in July 2012, but was never found again afterwards.

M-149-033. — This adult male initially caught in the lodge Building A on August 10, 2011, fitted with radiocollar 149.033, and released just behind building A (0 km). He was never recaptured, and his signal was not heard again.

M-149-014. — This large adult male was first captured in the lodge basement on October 20, 2011. He was fitted with a radiocollar of signal 149.014. He was released in the hills behind the lodge (0.5 km). His signal was triangulated eight times at the beginning of summer 2012, all near the Court of the Patriarchs, but his signal disappeared after that and did not resurface. He was not recaptured.

F-149-073. — This female ringtail was large and healthy and captured initially on October 21, 2011 in the lodge's gift shop storage area. A radiocollar of frequency 149.073 was fitted and she was released off of the Sand Bench trail in Birch Creek canyon (1.7 km). She was recaptured in the Lodge Basement (1.7 km) three days later (October 24, 2011) and released near Weeping Rock (2.5 km). She was captured a third time in the lodge basement (2.5 km) on November 24, 2011 and released along State Route 9 towards the East Entrance (5 km), halfway between the first and second tunnel. Her signal was triangulated five times throughout summer 2012, two of these times the signal was weak and erratic. All of these locations were along the base of the main canyon between the lodge and the Court of the Patriarchs (5 km). After this, her signal never resurfaced.

M-149-063. — Another healthy, adult male ringtail, this individual was first captured on October 25, 2011 in the basement of the main lodge building. A radiocollar of frequency 149.063 was fitted and he was released in the hills behind the lodge building (0 km). Follow-up telemetry never returned another moving location on this male, but his slipped collar was recovered in May 2012 near Birch Creek hiking trail (1.6 km). Due to the low level of wear on the collar, it is unlikely the ringtail wore the collar for longer than a few weeks before it fell off.

M-149-043. — First captured on October 25, 2011 in the NPS warehouse in the maintenance complex, this ringtail was an adult male, and was fitted with a radiocollar of frequency 149.043 and was released just past the Court of the Patriarch's bus stop (4.2 km). He was then recaptured approximately a week later back in the NPS maintenance yard in the electrician's office on November 2, 2011 (4.2 km). His initial collar had come loose but had not fallen off, so he was fitted with a new collar of frequency 149.082, and released near the base of the Great White Throne (7.3 km). His signal was not heard again.

M-149-105. — This male ringtail was a very large and was first captured on November 1, 2011 in the lodge's gift shop storage area. He was fitted with a radiocollar of frequency 149.105 and released near the Menu Falls waterfall (3.4 km). No additional telemetry locations were received on this male, but his collar signal was present in the scree fields above the lodge complex for the entire season of 2012 without moving (3 km). Multiple attempts were made by the researcher and NPS employees to recover the collar, but it could never be reached and is believed to be in a crevice in the cliffs above the lodge.

M-000-190. — This healthy, well-sized adult male was first captured on March 11, 2012 in the NPS headquarters building just outside the communications center office. He was fitted with radiocollar 149.024 and metal eartag #190 and released just outside of the headquarters building (0 km). His signal was present throughout the summer of 2012 in the base of Pine Creek Canyon and is strongly believed to be the ringtail captured via motion-triggered camera in that area in May 2012 (2.5 km). He remained in Pine Creek until fall and was triangulated 16 times, always remaining in the Pine Creek drainage. He was captured by NPS employees in the headquarters building December 10, 2012 and released up Birch Creek Canyon (3 km). He was once again trapped by NPS employees on February 7, 2013 in the headquarters building (3 km) and released beyond the second tunnel towards the east entrance (6.5 km). His signal was located on February 11, 2013 near the first tunnel (3.8 km) and then found in the headquarters building again via his radio frequency on February 12, 2013 (3.2 km). He was not successfully trapped again until February 27, 2013. He was released in the parking lot outside of the headquarters building to attempt to find his access hole (0 km). Law enforcement unexpectedly attempted to trap him on March 8, 2013, but the individual they captured was a different, unknown individual that they released at the East Entrance (7.5 km). The final trapping of M-000-190 occurred on March 12, 2013 in the boiler room of the headquarters building and he was released in the parking lot (0 km) with a crew of employees watching to locate his "re-entry" hole. However, due to participant noise and lack of communication (e.g. individuals starting vehicles in the parking lot), he became startled and disappeared behind the Resource Management trailer. His signal never resurfaced.

M-000-177. — This young male was captured in the NPS roadhouse on March 16, 2012. He was fitted with a radiocollar of frequency 149.093 and metal eartag #177 and released in the drainage behind the maintenance yard (0 km). The researcher picked up his signal ten times throughout summer 2012, mainly in the Oak Creek drainage. One time the signal was triangulated in the main canyon, just north of Canyon Junction, but this is believed to be the result of severe signal bounce. No den site was found, and he was never recaptured. His signal was not found again after July 2012.

F-000-178. — This was a small adult female captured near the bathrooms at the Temple of Sinawava on August 8, 2012. She was fitted with a radiocollar of frequency 149.133 and metal eartag #178 and released in the hills behind the parking lot (0.1 km). An NPS employee witnessed her a week later foraging in trash containers at the bus stop, but we were unable to recapture her. Her signal was picked up intermittently at the end of the canyon road for a couple of weeks before disappearing and never resurfacing. The signal was never strong enough to triangulate.

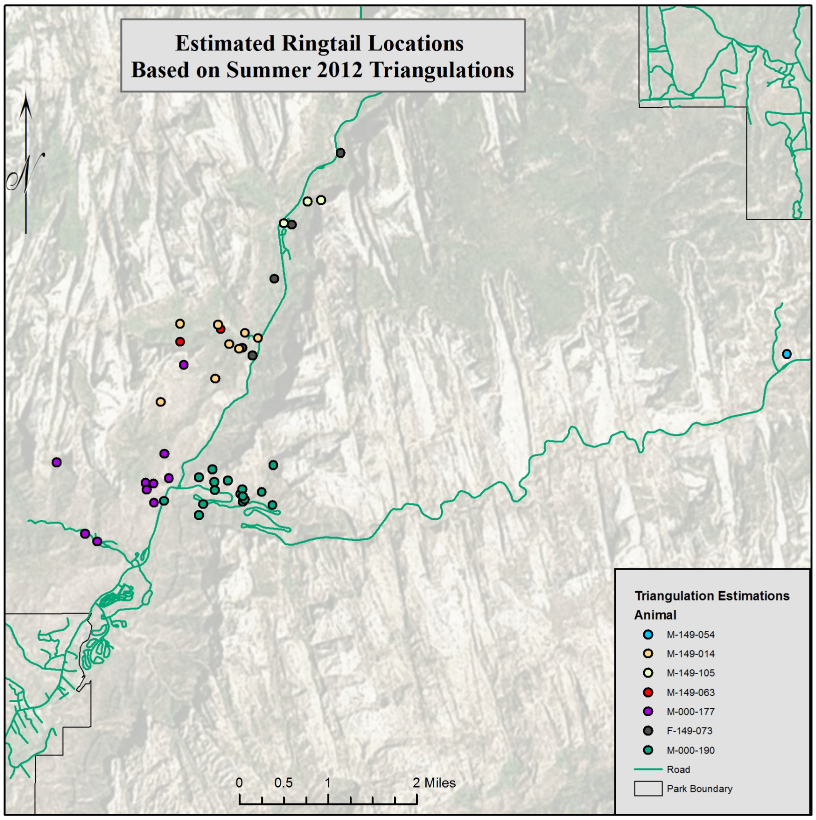

Figure A-6. Locations of individual collared ringtails (*Bassariscus astutus*) identified in the main canyon of Zion National Park, Utah.

DISCUSSION

Through the course of this research, the scientific knowledge of ringtail biology has increased in somewhat unexpected, but fascinating ways. The current status of the Zion National Park ringtail population has been assessed; knowledge about the efficacy of relocation as a management strategy has grown; and more details about ringtail movement patterns in canyon country have been gleaned.

Population Information

Despite the inability to mathematically estimate a ringtail population size, I was able to determine several interesting facts regarding the population of ringtails in Zion Canyon The ringtails in this area weigh less than most previously documented research. The population measured in New Mexico (Harrison 2012) is most similar, but is also a desert population. The largest ringtails reported are in Texas (Ackerson and Harveson 2006; Montacer 2009), and the ringtails studied in California are larger than those measured in Zion, but smaller than the Texas populations (Wyatt 1993). Although by weight the Zion ringtails are smaller, it is interesting to note that the mean tail lengths of females measured in this study are longer than any previously reported. Despite their lower weight, this increased tail measure is possibly a reflection of their canyon habitat. A longer tail would increase stability as individuals are climbing steep canyon walls and provide greater balance while pouncing and chasing prey. This is more pronounced in the female individuals, however, male ringtails in Zion have similar tail lengths to other studies, despite also having smaller body measurements, therefore leading to a higher tail to weight ratio than other studies.

All individuals captured and handled in this study were in prime condition with basically no ectoparasites, suggesting the population is very healthy. Two females were lactating at the time of capture and multiple juveniles were captured, so the population certainly is reproducing.

When using Xylazine as a sedative, ringtails required 2 to 3 minutes to be sedated, were down for 5 to 6 minutes and made a full recovery occurred within twenty to thirty minutes of administration. However, Xylazine resulted in erratic sedation, inconsistent response, unpredictable recovery, and on occasion, seizures. Based on these observations, we adjusted our methods to begin using Ketamine Hydrochloride in 2013. Using Ketamine Hydrochloride, after injection, the ringtail was immobilized within 1 to 2 minutes and was consistently sedated for fifteen to twenty minutes. Full recovery then followed within one hour of administration. No side effects were observed using Ketamine Hydrochloride beyond excessive salivation in one female. Although, it is important to note, this female also had excessive salivation on a recapture event in which no sedative was used.

Relocation

Of the individuals relocated, five of the six returned immediately, the sixth individual presumably slipped his collar or perished, as the collar never moved again. The five individuals that returned all did so within days of their initial relocation. Every ringtail continued to return at increasingly distant relocation point until finally, individuals didn't return from their most distant relocation, with every case at this furthest point resulting in the radiocollar signal disappearing. No individual established a new home range after relocation. The farthest one ringtail was moved was 7.3km, but this signal was then never heard again. M-000-190 did return from a 6.5km move, but after his next capture, his signal was never heard again.

Relocations were halted because of the belief that the relocations were detrimentally impacting the survival of the ringtails. The radio telemetry of these relocated individuals returned extremely low results due to the nature of the canyon, so the fate of the released ringtails largely remained unknown until the signal entirely disappeared. Once the signal entirely disappeared, I concluded it was largely due to the death of the individual in a place that prevented transference of the signal. The restrictions imparted within the study design allowed for a maximum distance possible to move the ringtails to remain within park boundaries. The individuals that were moved far enough to test this boundary still returned to their original capture location within a matter of days initially, but when relocated to a further distance, this often did not allow for appropriate ringtail habitat to be incorporated and may have led to fatal consequences for those individuals. The relocation is complicated to measure randomly because of the locations available to release a ringtail based on the nature of the canyon. Ringtails have extremely agile climbing skills and maneuverability so there is not the possibility of placing them in an area that is "geographically blocked" from returning, and yet they are still very small animals that have high metabolic and energetic requirements. Huge movements such as 3, 5, or 7 kilometers in a short span of time are massive commitments for these animals. The rate of return seen in these animals before relocations were halted showed that they were willing to invest huge stores of energy and take enormous risks to return to their sites of capture. Taking further steps as managers to place them in a location that will prevent their return is likely to be fatal. The impact on the survival of this valuable resource of the National Park becomes so high as to outweigh the human benefit of their relocation. Because of their pervasive nature, they will continue to return no matter the cost and no matter the distance. Therefore, the relocation is not a recommended option for ringtail management at this time.

The pattern of capture of these animals suggests that there may not be a large population in the main Zion Canyon. The same individuals continually were recaptured, and would return to the same place despite the relocation, without other individuals invading and taking their place. Another interpretation of this is that certain individuals are much more persistent in utilizing human resources. While it is clear some individuals live around the buildings without ever entering, such as those captured in Summer 2013, the individuals captured inside buildings consistently used the same buildings in the same part of the park. Perhaps these are individuals that were born in buildings and kept returning annually throughout their adult lives to overwinter.

It is important to note that throughout the tenure of this study, multiple unauthorized ringtail relocations occurred. It is likely that there were more incidents that went undocumented. Individuals that were relocated by individuals other than the researcher did not follow the study protocol. Because of the lack of scientific control over these relocations, my ability to draw conclusions about ringtail movement patterns or survival was compromised.

Movement Patterns

The majority of the ringtail activity within buildings was concentrated around cold winter months, in which food resources throughout the park are limited and shelter is a prime survival concern. Very little ringtail activity was reported in the buildings during the summer. The lack of radio signals present in the canyon during the summer suggests that the ringtails moved out of the main canyon, however the specific location of these summering areas remains unknown based on the lack of data return from the radiocollars. This is an area of great interest for future research, if the constraints of technology can be overcome. Telemetry is an extremely effective and robust method of individual and population data gathering for species of all forms and sizes, but is dependent upon the consistent reception of a signal from the collars deployed in the field. At the beginning of the study, despite the known potential for problems associated with radio telemetry in a stone canyon such as Zion, the belief was that these drawbacks could be overcome with extra effort put forth by the researcher based on the design laid out by Trapp in the late 1960's. The extreme distances moved by the ringtails were certainly unanticipated and the unique climbing patterns of the ringtails provided sufficient doubt as to the whereabouts of the study individuals. While the researcher was granted access to the entire park on foot, based on the signal's coverage of each collar, in this terrain, a boulder in the wrong placement, or the bounce of signal against a stone wall, which are exceedingly common, will drive a signal in a wild pattern down a canyon, sometimes miles off the true path. Whether the ringtails moved great distances or simply curled up into very deep crevices behind rocks through which the radio signals could not penetrate is unknown, but for extended periods of time the signals of the majority of the radio collars deployed were lost. These holes in the presence data of the ringtails makes any sort of habitat use or home range estimates impossible. While this seems a wasted effort, these problems are not insurmountable. However, in the case of this project, as a solitary researcher, with limited resources and no aerial support, the ability to search out lost collars once a signal went rogue was nil, and therefore hugely detrimental to the future of the telemetry portion of the investigations. Because this portion of the research became so time and cost intensive for such minimal data return, the deployment of collars was terminated in August 2012.

This outcome of the study certain is extremely unfortunate because of the apparent egress of ringtails from the main canyon witnessed during summer months. While some were still captured during the trapping done during the summer season, the densities are low and spread quite distant, this being quite distinct from those observed during the winter months. If aerial surveys had been allowed, a huge amount of information could have been gleaned about the areas of the park being utilized by ringtails during the summer months. The whereabouts of the ringtails and the habitats and areas utilized are critical pieces of information. Similarly, their social structure is still vastly understudied, but these topics fell outside of the capabilities of this project.

Alternative Management Options

Based on this knowledge that relocation is not a viable option for conflict management, an alternative management plan is necessary. This alternative is to control the buildings, as opposed to controlling the ringtails. Even though the buildings in the park are old and have many access points, it is possible to exclude ringtails. Not every building in the park that has human resources present inside experiences a ringtail influx. If the access points to the buildings are found and sealed, the ringatils will find alternative shelter and food sources. The entry points of each building can be maintained and monitored and up kept. Seasonally the building can be assessed and monitored for potential access points. Because a ringtail can fit through any hole that their head can pass, even small holes must be controlled. An adult male ringtail has a skull width of approximately 2” (Elbroch 2006). This means that any hole larger than this will allow an adult male ringtail. Holes slightly smaller than this could potentially allow access to smaller adults or juvenile ringtails. This is important to consider as entering buildings may very well be a learned behavior when the animal is young, and as they grow older, they will return to the same building and may begin to destructively create their own access points, thus a reason for multi-season checks of every building within the park boundaries. This small size of access points is much smaller than previous management concepts considered, so current practices should be modified to accommodate it.

MANAGEMENT IMPLICATIONS

Relocation as a management tool is currently ineffective for this species. The individuals relocated came back multiple times to the same building in a surprisingly short amount of time. A few individuals did not return after their relocation, however, these individuals rarely were found or heard from again, creating concern about their survival. While it is possible these individuals established a new territory and managed to survive in their relocated areas, based on the complete lack of radio frequency, it is equally or more likely that these individuals died as a results of their relocation. This end result does successfully keep that individual out of a building, but does not fall within the National Park Service's mission statement of conserving natural resources. In addition, once one offending individual is removed from the building, there becomes an available resource gap that will quickly be filled by an alternative ringtail. The ringtails are entering buildings in search of shelter (presumably based on season), food access in the form of human food and an increased rodent population around buildings (Roadman 2014), and possibly also as a learned behavior from previous generations. Since the ringtail is not a portion of this conflict equation that can be managed effectively by removing it, the result is to manage the buildings to prevent ringtail entry. Based on their small skull size and their ability to enter any crevice or hole large enough for their skull, all potential holes of this magnitude must be closed and maintained. Ringtails actively modify buildings to gain access by removing shingles, digging in walls, or removing chicken wire (personal observation), therefore regular vigilance and maintenance is required to keep them out of the buildings over time. If the buildings are made secure against the ringtails, these animals will move off and find their necessary energy and shelter requirements elsewhere. Until this is completed, they will continue to return to the buildings and use the resources available to them.

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