Inventory of Terrestrial Mammals in the Rincon Mountains Using Camera Traps

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***Abstract**— The Sky Island region of the southwestern United States and northwestern Mexico is well-known for its diversity of mammals, including endemic species and species representing several different biogeographic provinces. Camera trap studies have provided important insight into mammalian distribution and diversity in the Sky Islands in recent years, but few studies have attempted systematic inventories of one or more mountain ranges with a repeatable, randomized study design. We surveyed medium and large terrestrial mammals of the Rincon Mountains within Saguaro National Park, and compared the results with previous surveys of the Rincons. We sampled in random locations in four elevational strata from May 2011 through April 2012. We detected 23 native species of mammals and estimated species richness to be 24.8 species. We failed to detect four native species documented by other methods during 1999-2012, as well as five species (bighorn sheep, grizzly bear, jaguar, gray wolf, and North American porcupine) documented during 1900-1999 that may be extirpated from the Rincons. Advances in camera trap technology, as well an expanding use of this technology by educators and the public, suggest this method has the potential to be a cost-effective and reliable method for both inventory and long-term monitoring of terrestrial mammals of Sky Island region.*

Introduction

The Sky Island region of the southwestern United States and northwestern Mexico is known for exceptional biological diversity, including species from the Sierra Madre, Rocky Mountain, Sonoran Desert, and Chihuahuan Desert biogeographic provinces (Swann and others 2005) and as many as 15 mammals on the edges of their biogeographic range (Warshall 1995). Southeastern Arizona, in particular, has been characterized as possessing the greatest mammalian diversity in North America north of Mexico (Turner and others 1995) including species with more northern affinities such as black bears (*Ursus americanus*) and tropical species such as ocelots (*Leopardus pardalis*), jaguars (*Panthera onca*), coatis (*Nasua narica*), and others. Several high profile species have been extirpated, including grizzly bear (*Ursus arctos*) and Mexican gray wolf (*Canis lupus*), while others such as jaguars, ocelot, bighorn sheep (*Ovis canadensis*), and pronghorn (*Antilocapra americana*) are considered highly vulnerable.

Species inventories, or verified lists of species that occur in a particular area, have value for many reasons (Sidner and Stone 2005) including studies of biogeography (Newmark 1995; Lomolino and others 1989), determining environmental change (McDonald and Brown 1992), and determining status of sensitive species. In addition, repeated inventories may provide data for monitoring long-term changes in plant and animal communities if conducted using a randomized, repeatable study design that allows estimates to be made of measures such as native species richness (the number of native species that occur in an area). Loss of biodiversity is one of the world's greatest environmental concerns (Wilson 1988) and detecting changes in diversity can be accomplished through repeated inventories conducted in a framework for drawing inference about variation in species richness over time (Nichols and others 2011).

Because of the significance of the Sky Island region, taxonomic inventories of its individual mountain ranges have been conducted for over a century (Swarth 1904) and remain a principal focus of biologists to this day. Recent inventories of reptiles (Flesch and others 2010), vascular plants (Van Devander and Reina 2005; Bowers and McLaughlin 1996), and other taxonomic groups exist for many prominent Sky Islands but inventories of mammals have generally lagged behind (Koprowski and others 2005). Although older surveys exist for selected ranges (Cahalane 1939; Hoffmeister and Goodpasture 1954; Lange 1960) mammals as a group are generally less well-studied and a recent paper (Koprowski and others 2005) identified a "dearth of data" on the mammals of the region. In addition, although medium and large mammals have a higher profile with the public than smaller mammals and bats, past inventories (Hoffmeister and Goodpasture 1954) have tended to focus on the latter groups because more of those species can be easily captured using a single method such as live-trapping and mist-netting. Inventory methods for larger mammals include collection of specimens by trapping and shooting, but these techniques are generally discouraged today. Other methods include use of sightings, tracks, and other sign, but these approaches have the disadvantage of not always being verifiable by other researchers. In addition, the probability of detection varies widely among species, habitats, and time. Many mammals are very elusive, rare, or both and may be present at a site but not detected during even a multi-year study (Tobler and others 2008).

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Infrared-triggered cameras, also called camera-traps, represent an important newer technology in mammal studies and are now used widely to study animal behavior (Bridges and Noss 2011), estimate abundance (Karanth and others 2011), and inventory mammals and monitor communities (Tobler and others 2008; O'Brien and others 2011). Camera-traps have a great advantage over observational studies in that they provide a record of each species, similar to a voucher specimen, which can be viewed by independent observers. They are relatively inexpensive to operate and can be left alone to gather data for long periods. Most importantly, camera-traps provide data that can be used to estimate the detection probability of individual species in different habitats, camera settings, time periods, and other factors that are known to influence detectability (O'Connell and others 2006; O'Brien and others 2011). In recent years, camera-traps have made a significant contribution to our knowledge of jaguars, ocelots, and other tropical cats of the Sky Island region (McCain and Childs 2008) while providing important information for conservation and management of mammals in small reserves (Crooks and others 2008; Swann and others 2010). However, most of these studies were in a relatively small area over a short time-frame.

We conducted an inventory of medium and large mammals in both districts of Saguaro National Park from May 2011 through June 2012. Our goals were to use a randomized study design to collect photos of all mammals that could be detected by our cameras, and to use these data to estimate species richness, as well as detectability and percent occupancy for common species. In addition to providing baseline monitoring data, we wanted to compare our results with a similar study during 1999-2005 (Swann and Powell 2006) and historic data (Davis and Sidner 1992; Swann 2011) to determine if species richness or distribution has changed significantly during the past decade and past century. Finally, we hoped to use photographs to interpret wildlife in the park through social media outlets while also providing opportunities for service learning and citizen science. Here, we present partial data (May 2011-March 2012) for the park's Rincon Mountain District.

Study Site

Saguaro National Park is located in Pima County, Arizona, and consists of two disjunct districts separated by the city of Tucson (fig. 1). The park includes 37,005 ha, of which 28,694 ha (78%) are designated Wilderness. The Rincon Mountain District covers a large portion of the Rincon Mountains, a northern Sky Island range adjacent and biologically connected to the Santa Catalina Mountains. The portion of the Rincon Mountains within the park ranges in elevation from 814-2,614 m. Biotic communities include Sonoran desertscrub, semi-desert grassland, oak savannah, oak pine-oak forest and woodland, and mixed conifer forest. The Rincon Mountains also contain riparian forest and riparian woodland in canyon bottoms, scattered wet and dry meadows at higher elevations, and perennial springs and spring-fed rock pools (*tinajas*).

Methods

We used a stratified random design with four elevational strata: 814-914 m (hereafter "low elevation"), 914-1,524 m ("low-medium"), 1,524-2,134 m ("medium-high"), and 2,134-2,641 m ("high elevation") (fig. 2). Previous studies (Davis and Sidner 1992; Swann and Powell 2006) suggested that mammal distribution in the Rincon Mountains varies among these strata, which may be associated with differences in soil type, vegetation, and climate. We divided the park into 1-km plots, deleting any that were >50% outside the park boundary and then randomly selected 15 plots (from a total of 60 plots). If a selected plot included two strata, it was assigned to the strata with the greatest amount of area. We established a minimum distance of 200 m between points.

Within in each plot we placed four Cuddeback Capture camera-traps (Non Typical Inc., Green Bay, Wisconsin). We set cameras at four random points generated for each plot but occasionally used an alternative random point if we determined that a point was not safe

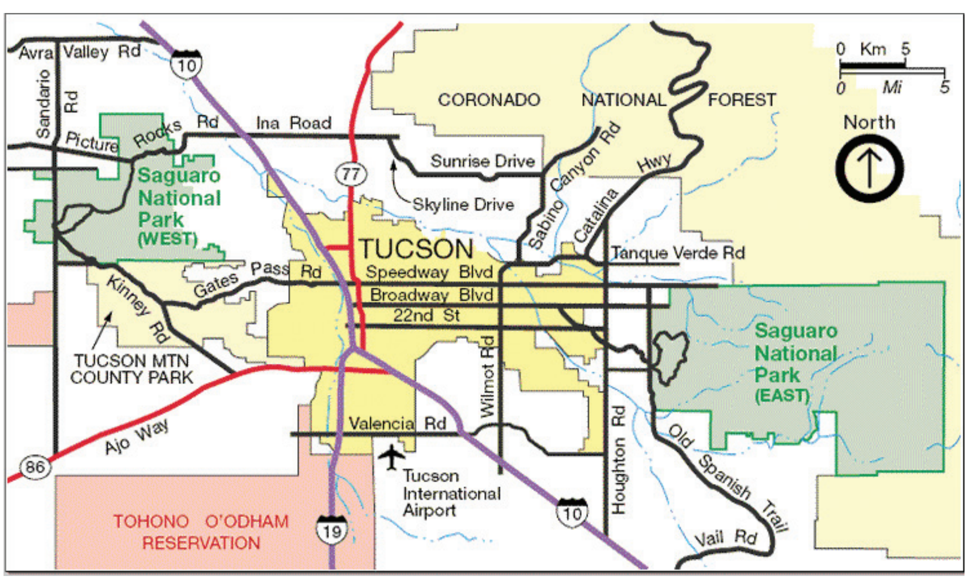

Figure 1—Location map for the Rincon Mountains, east of Tucson, Arizona.

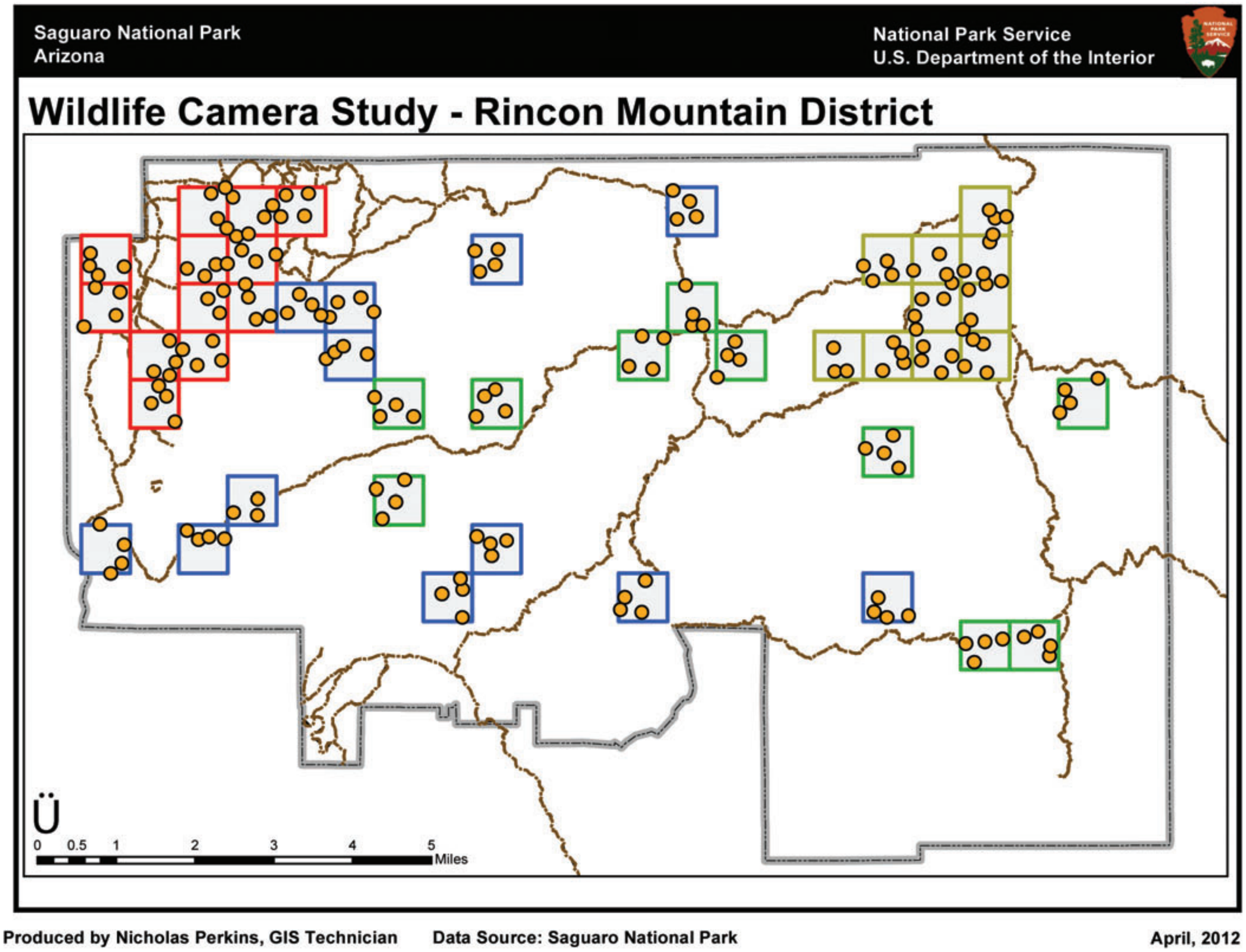

Figure 2—Study design for camera trap placement in Rincon Mountain District of Saguaro National Park. Four camera traps were placed randomly in each randomly located plot for 6 weeks, with all four strata being sampled from May 2011-March 2012.

for technicians to place a camera (e.g., on a cliff). We navigated to each point using a Garmin GPSmap 76 GPS unit (Garmin International, Olathe, Kansas) and recorded the actual camera location. We set cameras as close to the random point as possible (within 20 m), choosing the closest location that had a sufficiently open field of view to provide the potential to detect an animal if it was present. We made an effort to reduce technician bias in setting cameras through training, but we suspect that some bias on this small scale (e.g., setting cameras where a scat was present) crept in. We set cameras 30-60 cm above ground to detect both larger as well as relatively small mammals, although ground height typically varied within the detection zone. We targeted all terrestrial mammals that were squirrel-sized or larger (>80 g), except for nocturnal rodents and pocket gophers due to the difficulty in identifying them to species level. We did not provide bait or any attractants.

We left cameras in place for 6 weeks. We typically kept two plots active in each of the four strata (total of 32 cameras), although this routine was altered by an extreme fire danger closure of Saguaro National Park in June 2011, a major event (the BioBlitz) in October 2011, and by occasional weather or logistical concerns. We checked plots at least once (but typically twice) during each 6-week interval to change batteries and verify that cameras were working properly. On each visit we replaced the camera memory card and also downloaded photos and viewed them in the field using a MP3 player.

We downloaded memory cards back in the office and placed photos in digital computer folders arranged by location and named by camera placement date and a unique camera ID. We examined each photo and identified all mammals to species. We independently confirmed all identifications using local experts and sent questionable identifications to taxonomic specialists. We entered all photo data in Excel spreadsheets using a separate spreadsheet for every camera location. We independently checked all data entry. To organize and analyze photo data, we created a file geodatabase with shapefiles for study plots, random points, active camera locations, and other information associated with each camera location. For statistical analysis, we imported a master Excel file that contained all photo records into a GIS (Arcmap) project and added attributes such as geographic coordinates and plot name, and then summarized the records by species to identify misspellings and other errors. We used ArcGIS-based models created for the project to build tables summarizing photo records of species by district and strata.

To calculate species richness of native mammals, we converted these tables to binary data, and used the species richness program EstimateS (http://viceroy.eeb.uconn.edu/EstimateS) that computes a variety of biodiversity functions, estimators, and indices for biotic sampling data (Colwell and others 2012). We used the Jack1 estimator in EstimateS; Jackknife estimators perform well when there is heterogeneity in capture probabilities among species as would be expected with camera-traps and past studies have indicated that Jack1 provides the most reliable estimates for large number of camera nights (Tobler and others 2008). For purposes of species richness estimation, we assumed that Abert squirrels (*Sciurus aberti*), which were introduced into the Santa Catalina Mountains in the 1940s and first observed in the Rincons in 1959 (Davis and Sidner 1992), are now "native" and that all cottontails found above 2000 m are eastern cottontails (*Sylvilagus floridanus*), although a specimen is needed to confirm identification of this species.

Results

During May 2011 to March 2012, we sampled for approximately 7,837 camera nights (tables 1 and 2). The cameras functioned during most but not all camera-checks and so the number of actual operational camera nights is fewer and unknown. We sampled at 173 points: 47 in the low elevation strata, 47 low-medium, 40 in medium-high, and 39 in high in elevation. We obtained 1,943 photos containing medium-to-large mammals that could be identified to species, as well as many photos of nocturnal rodents, birds, reptiles, humans, and other non-target species. We detected a total of 23 native species during the study period, including 17 in low elevation, 18 in low-medium, 12 in medium-high, and 10 in high elevation (table 1). We estimated the native species richness of the Rincon Mountains to be 24.8 species (SD = 1.2).

The most commonly photographed species were desert cottontail (*Sylvilagus audubonii*), white-tailed deer (*Odocoileus virginianus*), and antelope jackrabbit (*Lepus alleni*) (fig. 3). Five species were photographed less than 6 times during the study period: mule deer (*Odocoileus hemionus*), Abert's squirrel (*Sciurus aberti*), round-tailed ground squirrel (*Spermophilus tereticaudus*), Western spotted skunk (*Spilogale gracilis*), and American badger (*Taxidea taxus*). We did not detect any species that had not been previously documented for the Rincon Mountains, although we did photograph one species (American badger) that had not been previously documented by camera-traps. We failed to detect two species (Virginia opossum [*Didelphis virginiana*] and Northern raccoon [*Procyon lotor*] that were detected in the Rincon Mountains by non-randomly placed cameras during the same study period (Saguaro National Park, unpublished data). We also failed to detect one species (cliff chipmunk [*Tamias dorsalis*]) that was confirmed by numerous reliable observations and one species (Arizona gray squirrel [*Sciurus arizonae*]) that was detected during the inventories in 1999-2005. We did not detect five species, including grizzly bear, jaguar, gray wolf, bighorn sheep, and North American porcupine (*Erethizon dorsalis*) that were confirmed either by specimen or very reliable historical record to be present in the Rincon Mountains at some time during the period between 1900 and 1999 (Swann 2011). We did not detect free-ranging, non-native domestic dogs (*Canis familiaris)*, domestic cat (*Felis catus*), or cattle (*Bos taurus*), which are known to occur in the Rincon Mountains at times (Swann 2011) but probably not in established populations.

Discussion

Our study demonstrates some advantages and limitations of using infrared-triggered camera-traps to inventory and monitor medium and large mammals, where we define the term *inventory* as the development of a species list for an area and *monitoring* as a method to determine changes in a measure such as species richness over time. Camera-traps have some major advantages over traditional inventory and monitoring methods for larger mammals. These methods include kill-trapping and hunting which provide reliable identification but raise ethical issues and have the potential to impact populations; live-trapping, which provides reliable identification but is expensive and has safety issues for animals and researchers; visual identification of scat and sign, which is non-invasive but the results cannot be verified to prevent false identification; genetic identification of scat and hair, which is growing in its potential as a non-invasive, reliable method, but can be expensive and incomplete due to DNA degradation of scat in a field environment (Piggot and Taylor 2003); observation records, which are inexpensive to gather but produce results that cannot be independently verified (Giordano and others 2011); and collection of voucher specimens of roadkills and other dead animals, as well as collection of vouchers photographs by citizen scientists, which are inexpensive and verifiable but require a very long effort in time due to species avoidance of humans and raise complicated study design issues.

One advantage of camera-traps for inventory and monitoring is that the results can be independently verified. The results of some classic papers in conservation biology (Newmark 1995) have been questioned due to their use of unverified observational records (Parks and Harcourt 2002). In addition, camera-traps can be easily deployed in a repeatable study design. Our study demonstrates that cameras placed at random locations, as opposed to only at water holes, game trails, and other locations known to attract certain species, will detect large numbers of species present in an area even if no bait or other attractants are used. Baiting camera-traps for a study of multiple

Table 1—Summary data on effort and results of camera trap study in the Rincon Mountains, May 2011-March 2012.

Strata	Elevation range	Area of sampling unit	No. of camera points	No. of camera nights	No. of photos	No. of species	Species richness estimate
	(m)	(ha)					(SD)
1	814-914	5,066	47	2,015	1,216	17	19.9 (1.9)
2	914-1,524	27,714	47	1,876	302	18	18.9 (0.9)
3	1,524-2,134	27,040	40	1,900	218	12	14.7 (1.9)
4	2,134-2,641	7,469	39	2,046	207	10	11.8 (1.2)
Total		67,289	173	7,837	1,943	57	24.8 (1.2)

Table 2—Species of terrestrial mammals, excluding nocturnal rodents and pocket gophers, confirmed for Rincon Mountain District, Saguaro National Park. Sources are (1) photo during this study, (2) photos or specimens collected during 1999-2010 (Swann and Powell 2006), and (3) photos, specimens, or very reliable record from 1900-1999 (Swann 2011), but no recent records. Source for names: Wilson and Ruff (2000).

Species	Photo this study	Confirmed 1999-2010	Confirmed 1900-1999 only
Marsupials			
Virginia opossum (*Didelphis virginiana*)	-[a]	X	
Rabbits and Hares			
Antelope jackrabbit (*Lepus alleni*)	X	X	
Black-tailed jackrabbit (*Lepus californicus*)	X	X	
Desert cottontail (*Sylvilagus audubonii*)	X	X	
Eastern cottontail (*Sylvilagus floridanus*)	X[b]	X	
Rodents – Squirrels and Porcupines			
Abert's squirrel (*Sciurus aberti*)[c]	X	X	
Arizona gray squirrel (*Sciurus arizonensis*)		X	
Harris's antelope squirrel (*Ammospermophilus harrisii*)	X	X	
Round-tailed ground squirrel (*Spermophilus teriticaudus*)	X	X	
Rock squirrel (*Spermophilus variegates*)	X	X	
Cliff chipmunk (*Tamias dorsalis*)		X	
North American porcupine (*Erethizon dorsatum*)			X
Carnivores			
Ringtail (*Bassariscus astutus*)	X	X	
Feral dog (*Canis familiaris*)[c]	-[a]	X	
Coyote (*Canis latrans*)	X	X	
Common hog-nosed skunk (*Conepatus mesoleucus*)	X	X	
Gray wolf (*Canis lupus*)			X
Mountain lion (*Puma concolor*)	X	X	
Feral cat (*Felis catus*)[c]		X	
Bobcat (*Lynx rufus*)	X	X	
Hooded skunk (*Mephitis macroura*)	X	X	
Striped skunk (*Mephitis mephitis*)	X	X	
White-nosed coati (*Nasua narica*)	X	X	
Jaguar (*Panthera onca*)			X
Northern raccoon (*Procyon lotor*)	-[a]	X	
Western spotted skunk (*Spilogale gracilis*)	X	X	
American badger (*Taxidea taxus*)	X	X	
Common gray fox (*Urocyon cinereoargenteus*)	X	X	
Black bear (*Ursus americanus*)	X	X	
Grizzly bear (*Ursus arctos*)			X
Hoofed mammals			
Domestic cattle (*Bos taurus*)[c]		X	
Mule deer (*Odocoileus hemionus*)	X	X	
White-tailed deer (*Odocoileus virginianus*)	X	X	
Bighorn sheep (*Ovis canadensis*)			X
Collared peccary (*Pecari tajacu*)	X	X	

[a]Recent photographs exist, but not from cameras at random points during this study.
[b]Eastern cottontails are presumed based on appearance and habitat, but it is not possible to confirm this species based on sightings or photographs without a voucher specimen.
[c]Non-native species.

species raises the potential for biasing results in studies of mammal communities (Kays and others 2011). We obtained a large number of photos of animals without using bait and without targeting water holes, game trails, or other macro-habitat features.

A major issue in inventories as opposed to monitoring (see below) that cannot be resolved by camera-traps is that of incomplete detectability or the failure to detect species when they are indeed present. Camera-traps are like live-traps and other methods in that they vary in their ability to detect species, especially when they are set in a standard manner at random points. We expect that some individual animals may notice and avoid cameras, some may be attracted to them, and some may not be detected by cameras due to their small size or

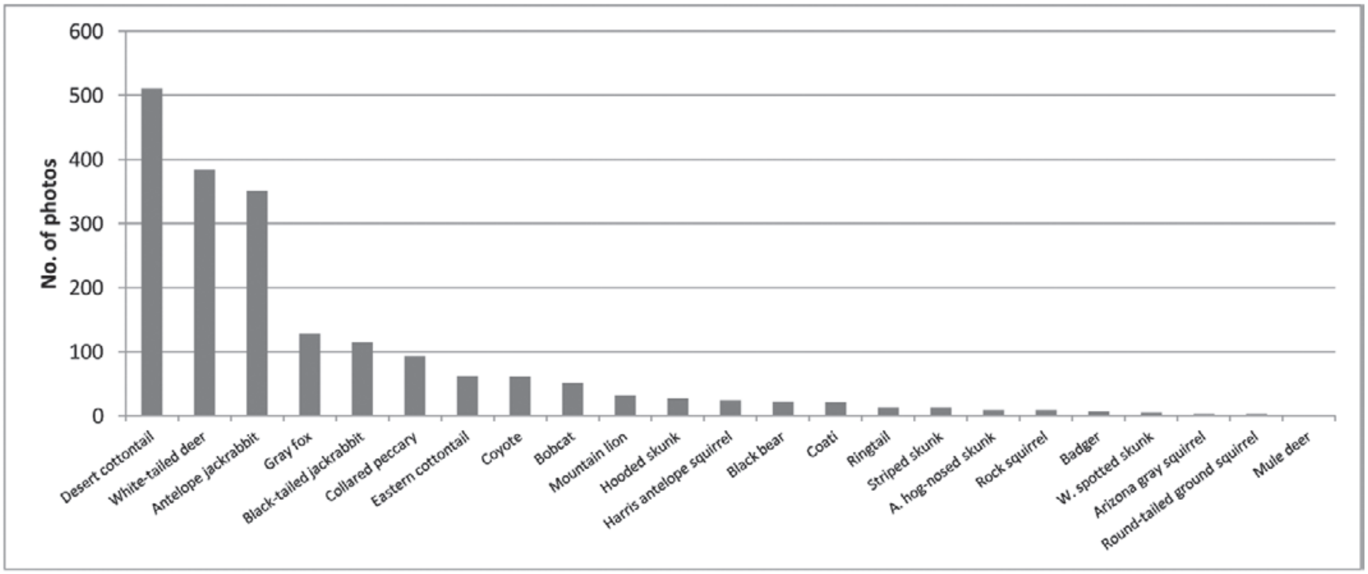

Figure 3—Number of photos for each of the 23 native terrestrial mammal species (excluding nocturnal rodents and pocket gophers) photographed by camera traps in the Rincon Mountains during May 2011-March 2012.

quick movements. Despite a large effort, we did not detect several species that were photographed in the Rincon Mountins during the past decade (Swann 2011). We suspect that these species were present in the park for at least part of our study but went undetected due to their relative rarity, small size (cliff chipmunk), or specific habitat needs (e.g., Arizona gray squirrels who occur mostly in trees). We believe we would detect more species with increased sampling effort, although this effort may need to be very large. Therefore, for a mammal inventory of an area to be as complete as possible, we recommend that some cameras be set in targeted habitats. For example, setting cameras at the base of oak trees to detect Arizona gray squirrels, a rare habitat specialist, may be the most efficient way to detect this species in the Rincon Mountains.

For monitoring, the problem of incomplete detectability is common to all wildlife monitoring studies and can be overcome through a design that quantifies the probability of detection and estimates the measure of interest. Species richness, particularly of native species, is often used to determine changes in biological diversity, and can be estimated from camera trap studies using a number of models and approaches (Tobler and others 2008; O'Brien and others 2011), including a fairly simple approach using program EstimateS, as we have done in this paper. Our estimated native species richness of 24.8 $\pm$1.2 for the Rincon Mountains seems to be reasonable, given that 27 native species have been detected by all methods since 1999.

As one the most northern and western of the Sky Islands, the Rincon Mountains might be expected to have a reduced number of mammals of tropical origin compared to more southern and eastern ranges such as the Chiricahua Mountains, Huachuca Mountains, and others. Compared to other Sky Islands, the Rincon Mountains have fewer reptile and amphibian species, and lack at least seven montane species found even as close as the nearby Santa Rita Mountains (Swann and others 2005). Medium and large mammals should be able to move among Sky Islands more easily than reptiles and some other taxa, and indeed a number of recent genetic studies have shown that larger mammals such as bears can be closely related among nearby sky islands (Varas and others 2005). We photographed opossums at non-random sites, a more southern species that appears to be expanding its range to the north (Babb and others 2004), but did not detect ocelots or jaguars. There are apparently no confirmed records of ocelots from the Rincons but at least four jaguars were confirmed (killed by hunters) in the Rincon Mountains during 1900-1932 (Swann 2011). Several other terrestrial mammals that occur in the area, such as kit fox (*Vulpes macrotis*), have never been documented in the Rincon Mountains.

At least five species that we did not detect are known to have occurred in the Rincon Mountains during the past century (Swann 2011). In addition to jaguar, these include grizzly bear (last record a hunter kill in the 1920s); Mexican gray wolf (last records from the 1950s); bighorn sheep (last records from the 1950s); and North American porcupine (last record a reliable observation in the 1990s). Of these five species, grizzly bear and Mexican gray wolf are extirpated from the region. Jaguars and bighorn sheep are probably extirpated from the Rincon Mountains, but both are wide-ranging species that could be expected to occur occasionally. Porcupines appear to be declining throughout Arizona, possibly due to the increase in predators, especially mountain lions (Brown and Babb 2009).

Management Implications

Despite the great interest in mammals of the Sky Islands, the need for regional monitoring and improvements in our ability to detect rare species such as jaguars, many Sky Islands still do not have basic inventories and the region does not have a current standardized monitoring plan. Camera-traps are an emerging technology that may provide opportunities to address these issues. Comprehensive monitoring need not be an expensive investment, due to volunteer efforts by groups such as the Sky Island Alliance (SIA), and because monitoring intervals can be widely separated in time, but it would require a coordinated effort. A great advantage of using camera-traps over other monitoring methods is that they provide interesting photos and videos that not only possess important scientific value but can be enjoyed by the public through a wide variety of social media. Photos and videos from our study have been made available through Facebook and a number of websites including Flickr, National Geographic Society, and Friends of Saguaro National Park.

The project described in this paper was initiated and inspired by the 2011 BioBlitz, a major biodiversity event that took place at Saguaro National Park in October 2011 and was supported by the National Geographic Society, Friends of Saguaro National Park, and many other organizations. The BioBlitz matched nearly 200 scientists and experienced naturalists in the field with more than 2,500 Tucson school children and adult volunteers to sample the park's biodiversity. As part of the BioBlitz, we developed a program with SIA, the National Park Foundation, AmeriSchools College Preparatory Academy, and others that enabled middle and high-school students to track wildlife with expert SIA trackers and download wildlife photos from camera traps that had been previously set by high school volunteers. The program provided a hands-on wildlife experience, with students succeeding in capturing a number of species on film including mountain lions (fig. 4) and coatis. The growing use of camera-traps by both biologists and educators has great potential to engage the public directly in the conservation of Sky Island mammals while also providing data useful for long-term conservation.

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Figure 4—Mountain lion (*Felis concolor*) photographed by a camera trap in the Rincon Mountains for the BioBlitz educational program in October, 2011.

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