Mountain Lions and Bobcats of the Tucson Mountains:
Monitoring Population Status and Landscape Connectivity

Final Report—June 2010

Investigators
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From the University of Arizona authors:

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The study was funded by Pima County's Starr Pass Wildlife Enhancement Fund and was augmented by the National Park Service through the Desert Southwest Cooperative Ecosystem Studies Unit.

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Executive Summary

With this report we summarize results from a project in which we used infrared-triggered “trail” cameras to monitor mountain lions and bobcats in the Tucson Mountains, Arizona, from January 2008 through May 2010. We placed cameras at 65 sites both within the Tucson Mountains and in possible corridors surrounding the mountain. We obtained 36 photographs of mountain lions (and assembled an additional 16 lion photos from previous monitoring efforts) at seven camera sites. In a subset of 21 lion photos from a three-month period in 2009 we identified two age classes: adult and subadult. It is possible that we had an adult female, a young female, a young male, and a subadult male, however given the inherent difficulties in classifying gender, we can only conservatively state that there were the two age classes in this defined time period. In 2010 we photographed what is most likely an adult male, which may have been one of the subadults classified in 2009. We could not identify specific individuals and therefore were unable to estimate population size. At 34 camera sites we obtained 267 bobcat photos. In a subset of bobcat photos, we used unique spot patterns to identify individuals, either multiple times at specific sites, or at multiple sites, or both.

We monitored potential wildlife corridors, both in relation to the Starr Pass Resort Development, and in potential landscape linkages surrounding the Tucson Mountains, including the designated wildlife crossings of the Central Arizona Project canal. None of these camera sites documented mountain lions, but the cameras photographed bobcats and a variety of other wildlife in these potential corridor zones.

As a significant additional benefit to the study, we collected over 12,000 photographs of other wildlife documenting at least 21 mammal species (plus humans), 16 bird species, and two reptile species. Humans were most commonly photographed, followed by mule deer, coyotes, foxes and other species. In a subset of the total 227 photographs of skunks, we identified three species: common hog-nosed, Western spotted, and hooded skunks. We documented a new range-extension of the subspecies of Virginia opossum native to Sonora, Mexico, and a new winter record of the Mexican long-tongued bat in the Tucson Mountains.

Background and Need

The Tucson Mountains, located on the west side of metropolitan Tucson, Arizona, is a relatively small island of habitat (~250 km^2) utilized by mountain lions and bobcats. Two agency landowners administer the majority of the range. The National Park Service administers Tucson Mountain District of Saguaro National Park (SNP-TMD), comprising 96 km^2 in the north half of the range. Pima County Natural Resources, Parks and Recreation (PC-TMP) administers Tucson Mountain Park, comprising 114 km^2 in the south half of the range. In the surrounding areas, a mix of landownership, primarily low-density residential homes, comprises approximately 40 km^2 of additional habitat.

Wildlife in the Tucson Mountains face increasing segregation from surrounding habitat due to urban development and road construction around its perimeter (Shaw 2000). Human homes and roads, including Interstate 10, lie to the north and east of the mountains, and the Central Arizona Project (CAP) canal and additional homes and roads lie west and south of the range. As development increases and movement corridors are cut off, mountain lion and bobcat populations have and will become increasingly isolated (Shaw 2000).

Preservation of resident mountain lions and bobcats in the Tucson Mountains and maintenance of historical dynamics among these and neighboring populations will require proactive efforts by federal and state park personnel, conservation scientists, and concerned citizens. The mountain lion population in this area is already facing greater geographic constriction than other lion populations deemed genetically isolated and ultimately unlikely to survive (Beier 1996). Development of conservation tactics will require ongoing monitoring and an understanding of the population dynamics and spatial distribution of both cat species residing there (Shaw 2000).

Pima County, Arizona is facing one of the fastest urban growth rates in the United States. At the same time the county is embarking on one of the most comprehensive land-planning efforts for conservation ever attempted in the U.S.—the Sonoran Desert Conservation Plan. A key element to that plan is conservation and protection of Critical Landscape Connections. These linkages are particularly important for the Tucson Mountains. This mountain range is the most endangered of all the “sky islands” in Pima County. The range is small and is increasingly surrounded by human development and is therefore a top priority for conservation.

The fact that two wild cat species, the mountain lion and bobcat, still exist in this small mountain range is testament to its ecological value in this remarkable and diverse bioregion. Large carnivores, especially wild cats, are ecologically critical and serve as focal species for conservation due to their large home range sizes, low population densities, slow reproductive rates, and long-range dispersal distances (Crooks 2002, Hunter et al. 2003). It is these characteristics that make them most vulnerable to urban-related threats. Therefore it is imperative that scientists and managers have specific data regarding both cat species in the Tucson Mountains to maintain that mountain range’s place in an ecologically functioning landscape in perpetuity.

One non-invasive technique used to gather data on wild cat species are animal-triggered cameras. In the past decade the use of animal-triggered cameras, also known as camera traps or trail cameras, has increased dramatically. These cameras have been especially useful to researchers who study nocturnal, cryptic, and sometimes rare or low-density species, such as wild cats. If individual animals can be uniquely identified by spot patterns, stripes or other variation in pelage and/or other physical characteristics, biologists can estimate abundance and density with classic mark-recapture analysis (with the “capture” being a photograph rather than physical capture). Biologists have used this technique to study tigers (Kranth 1995, Kranth and Nichols 1998), cheetahs (Kelly 2001), and jaguars (Silver et al. 2003), among others. Heilbrun et al. (2003) found that automatically triggered cameras could be used to identify individual bobcats. Mountain lions are more problematic in that they are relatively uniform in color and pelage, however Kelly and Camblos (2004) and Kelly et al. (2008) used camera traps and mark/recapture analysis to determine puma densities in Central and South America. They used two opposing cameras at each site to document both sides of every puma photographed and then oftentimes identified subtle but unique pelage or morphological differences in each individual.

In 2000, based on recommendations by Shaw (2000), SNP biologist Don Swann and mountain lion researcher Lisa Haynes initiated a 5-year assessment of mountain lions in SNP-TMD using primarily track surveys. We observed a general downward trend in mountain lion sign, which may have been confounded by rain in some years, and we noted a paucity of tracks or sign from adult males or kittens (Haynes and Swann 2003). As part of the SNP-TMD project, we experimented with camera traps to document presence and distribution of mountain lions and bobcats. We obtained 37 photographs of bobcats and nine photographs of mountain lions, including one photo in January 2005 of a female lion and kitten, thus documenting reproduction (Hackl et al. 2006).

Given the urgent need to understand and conserve the wild felids in the Tucson Mountains, we initiated a collaborative research project funded by Pima County that used trail cameras to assess the population status of mountain lions (and to some degree bobcats) and to determine if there is connectivity with populations outside the mountain range. Therefore, the Objectives of this project were to:

I. Assess the status and distribution of mountain lions and bobcats in the entire Tucson Mountains
II. Assess wildlife use of corridors associated with the Starr Pass Resort Development
III. Assess corridors, landscape linkages, and connectivity with surrounding populations with respect to mountain lions, bobcats, and other wildlife.

This project was focused more on mountain lions than bobcats, because lions are at a higher risk of extirpation in the mountain range and because it would take more camera stations to estimate bobcat population density. However, additional information from bobcat photos in this phase adds to our ongoing data collection and to an overall assessment of bobcats in the Tucson Mountains (Haynes et al. 2007, Haynes et al. 2009). We also expected several ancillary benefits such as gathering information on other wildlife species, and engaging citizen volunteers to participate in the project and thereby gain an understanding of and commitment to these conservation issues.

The study was funded by Pima County's Starr Pass Wildlife Enhancement Fund and was augmented by the National Park Service through the Desert Southwest Cooperative Ecosystem Studies Unit.

Methods

Objective I – Assess status and distribution of mountain lions and bobcats in the Tucson Mountains

Cameras – We initiated an intensive camera trapping effort following methods outlined by Kelly and Camblos (2004) and Kelly et al. (2008) to determine mountain lion density in the Tucson Mountains. This involves distributing cameras throughout the study area so that each resident mountain lion has a high probability of being photographed, i.e. cameras are distributed so that no holes, or areas larger than a minimum home range size, exist. The smallest documented average home range for female lions in a similar desert habitat (San Andres Mountains, NM) is 77 km^2 (Logan and Sweanor 2001). Based on this figure, an estimated 3.2 female lions live in the Tucson Mountains and the same number of camera sites, at minimum, was needed. (However, this estimate may be high, given that our study area is drier, hotter, and smaller than the San Andres Mountains.)

To estimate mountain lion numbers in the Tucson Mountains, we initially proposed distributing camera traps at 10 sites, two cameras per site, over two 15-day periods over two successive years (Kelley and Camblos 2004). However, because mountain lions are so elusive, to maximize the possibility of first photographing lions, we determined early on that it would be more effective to initially set camera traps at more sites to detect lions rather than double-up cameras at fewer sites. We thus placed cameras sites either within the mountain range itself or in washes at the base of the mountain that possibly lead to corridor crossings (Fig.1). Some cameras were also moved to different sites within the project period. We placed cameras in washes and on ridgelines (plus near a couple of water sources) to maximize opportunities to photograph mountain lions.

We purchased Cuddeback "Expert" digital trail cameras for this project. We also purchased "bear" (human) proof boxes that protected the cameras from human vandalism or tampering. In most cases, we used large cables and locks to attach cameras to trees, rocks, or immovable objects. We also labeled each camera with our University of Arizona contact information, stated that it was for wildlife research, and asked that the cameras not be disturbed.

Once the cameras sites were established, we checked them approximately every six weeks. We then entered the photo data into a Google Docs group spreadsheet so that staff and volunteers could continuously enter and analyze data.

Genetics—As part of several related studies, we have been conducting ongoing genetic analysis of mountain lions and bobcats at SNP-TMD, and also of bobcats across the Tucson basin. Our goals in these related studies were to identify individuals, examine relatedness among individuals, and assess gene flow. In this study we proposed augmenting those data sets, if suitable scat or tissue samples could be collected.

Objective II – Assess the use of corridors, identified in the Starr Pass Resort Development Plan, by bobcats, mountain lions, and other wildlife.

Cameras – A system of wildlife corridors were incorporated into the Starr Pass Resort design to mitigate some of the effects of the development on wildlife. We placed 10 camera sites in corridors and surrounding areas near the Star Pass development to assess wildlife use of this area. Due to limited access and respect for the privacy of Starr Pass residents, we placed most of the cameras on the periphery of the development (Fig. 2). However, we were confident that the sites adequately assessed the use of the corridors and open space associated with Starr Pass. Camera 37 was stolen shortly after installation, therefore, nine cameras functioned as Starr Pass cameras.

Objective III – Assess connectivity and landscape linkages that allow wild cats and other wildlife connect with populations outside the Tucson Mountains

Cameras – We conducted site visits and field reconnaissance at locations (identified from maps, aerial photographs, GIS analysis, and previous studies) as being potential wildlife linkages. We established camera stations where there was a likelihood that mountain lions and/or bobcats would use the linkage and where it was logistically feasible to place and check cameras. We viewed linkages as (a) potential routes to and from the mountains (i.e. site 24, in a major wash leading to the Santa Cruz River, and site 30 next to a culvert in Robles Pass), (b) potential routes near or under Interstate-10 (sites 50 and 51), and (c) potential routes across the Central Arizona Project (CAP) canal (sites CAP 1 through 10). Another camera, number 31, was placed in a potential linkage in the Santa Cruz River, but it was stolen shortly after its installation.

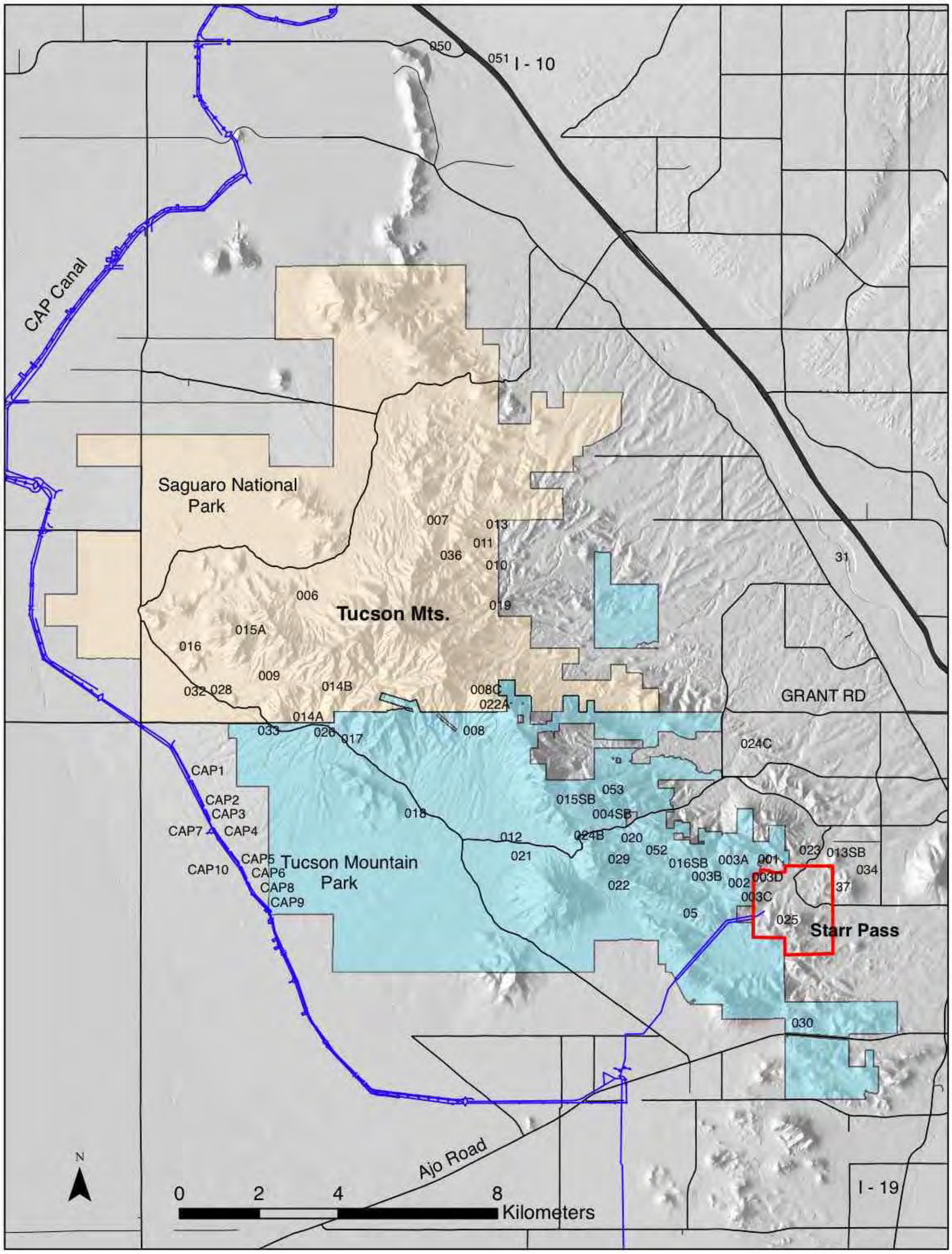

Figure 1. Infrared-triggered "trail" camera sites located in and around the Tucson Mountains, AZ from 2008-2010.

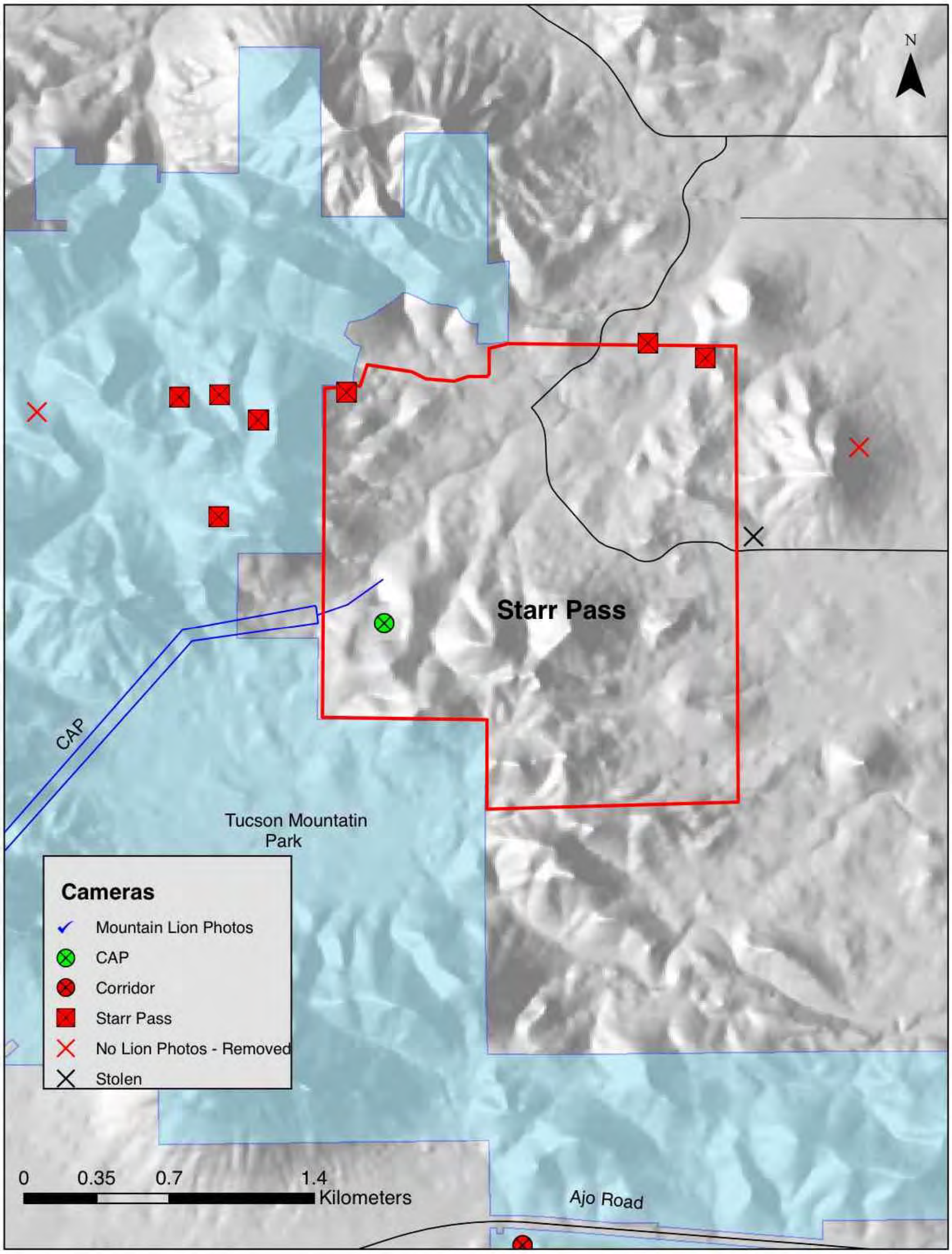

Figure 2. Infrared-triggered "trail" camera sites associated with Starr Pass Resort and Development. In our analysis, the green CAP camera at this location is actually considered a Starr Pass camera. (The GIS program designated it as a CAP camera due to its association with the CAP water system.)

Ancillary Objectives and Benefits

Felid Sign – We attempted to note all mountain lion “sign”, i.e. tracks, scat, kills and scrapes (territorial marks made by male bobcats and mountain lions), and we noted bobcat sign as much as logistics allowed.

Other Wildlife – The remotely-triggered cameras photographed a wide variety of wildlife in addition to mountain lions and bobcats. All photo data were curated on duplicate external hard-drives and logged into the Google Docs spreadsheet, which was then converted into MS Excel files.

Volunteers – Involving members of the public in hands-on activities is one of the best mechanisms for fostering commitment to conservation. “Citizen science” is a rapidly expanding technique for engaging and educating the general public. We engaged a core group of very committed and dedicated volunteers who conducted a majority of the camera checks and logged in a majority of the data.

Results

Objective I -- Assess status and distribution of mountain lions and bobcats in the Tucson Mountains

Cameras: MOUNTAIN LIONS – We placed cameras at 65 sites within the Tucson Mountains and in possible corridors surrounding the mountain (Fig. 1). Some cameras were moved to different sites during the course of the project. Out of over 12,000 photographs of wildlife (and humans) 36 were of mountain lions at seven sites during the project period (Fig. 3 and 4). At site 6 in SNP-TMD—a site that has been monitored with a digital camera since 2006—we obtained an additional 16 lion photos from 2006-2007. (We did not include previous photos from a film camera that monitored that site from 2004-2006.) Only two of the seven camera sites that documented mountain lions were in Pima County’s Tucson Mountain Park. The remaining five were in Saguaro National Park.

For a variety of reasons, we were not always able to set a second camera at each lion photo site (to obtain concurrent left and right sided views of the animals). We did establish paired cameras at two sites, 8C-22A and 11-36. In only one instance for each site were we able to photograph both sides of the mountain lion in the same photo event. Unfortunately in several instances, one of the paired cameras would fail to photograph the lion that was “captured” by the other camera. Also, our original protocol called for analyzing mountain lion photos over two 15-day periods over the course of two successive years. Unfortunately, lion photos were not concentrated in any 15-day period. A revised protocol by Kelly et al. (2008) recommended analyzing mountain lion photos within a three month period to assess population dynamics, since coat color and size does not change considerably within that time frame. Therefore, we assembled a subset of 21 mountain lion photos taken from May through early August 2009 to attempt to provide at least a rough estimate of population demographics. An additional benefit was that this was during the summer when there was a was maximum opportunity to identify unique characteristics or anomalies in the cats’ sleeker summer pelage.

We conducted pairwise comparisons of the 21 lion photos to narrow the possibilities down to those that might represent different individuals or age classes. This resulted in five left-sided and five right-sided photographs for this time period (with only one R-L pair of concurrent photos). In addition, two photographs were selected from May 2010 (the other R-L pair), which we believe represented another category based on size. We then asked for assistance from two experts who are highly experienced with mountain lions and who have cumulatively handled over 300 lions.

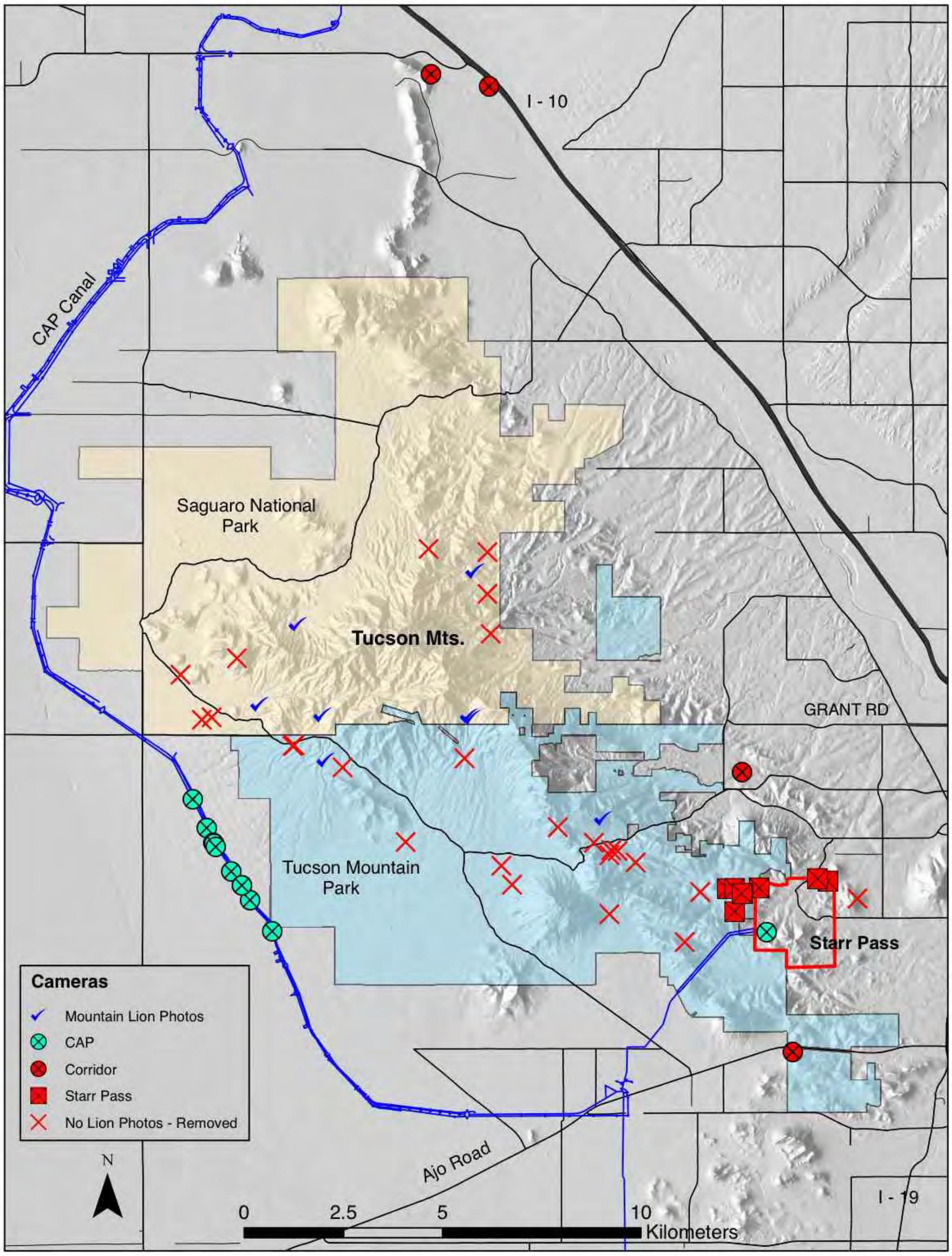

Figure 3. Designations of infrared-triggered “trail” cameras in and around the Tucson Mountains. Blue checks refer to cameras which photographed mountain lions and which will remain operating. Red X’s refer to cameras that did not photograph mountain lions and were removed from the study area. CAP are camera sites located in designated wildlife crossings of the Central Arizona Project canal (where it runs underground). Red boxes are Starr Pass sites, and red circles are sites in other potential wildlife corridors or landscape linkages. (In our analysis, the CAP camera within Starr Pass is considered a Starr Pass camera. The GIS program designated it as a CAP camera due to its association with the CAP water system.)

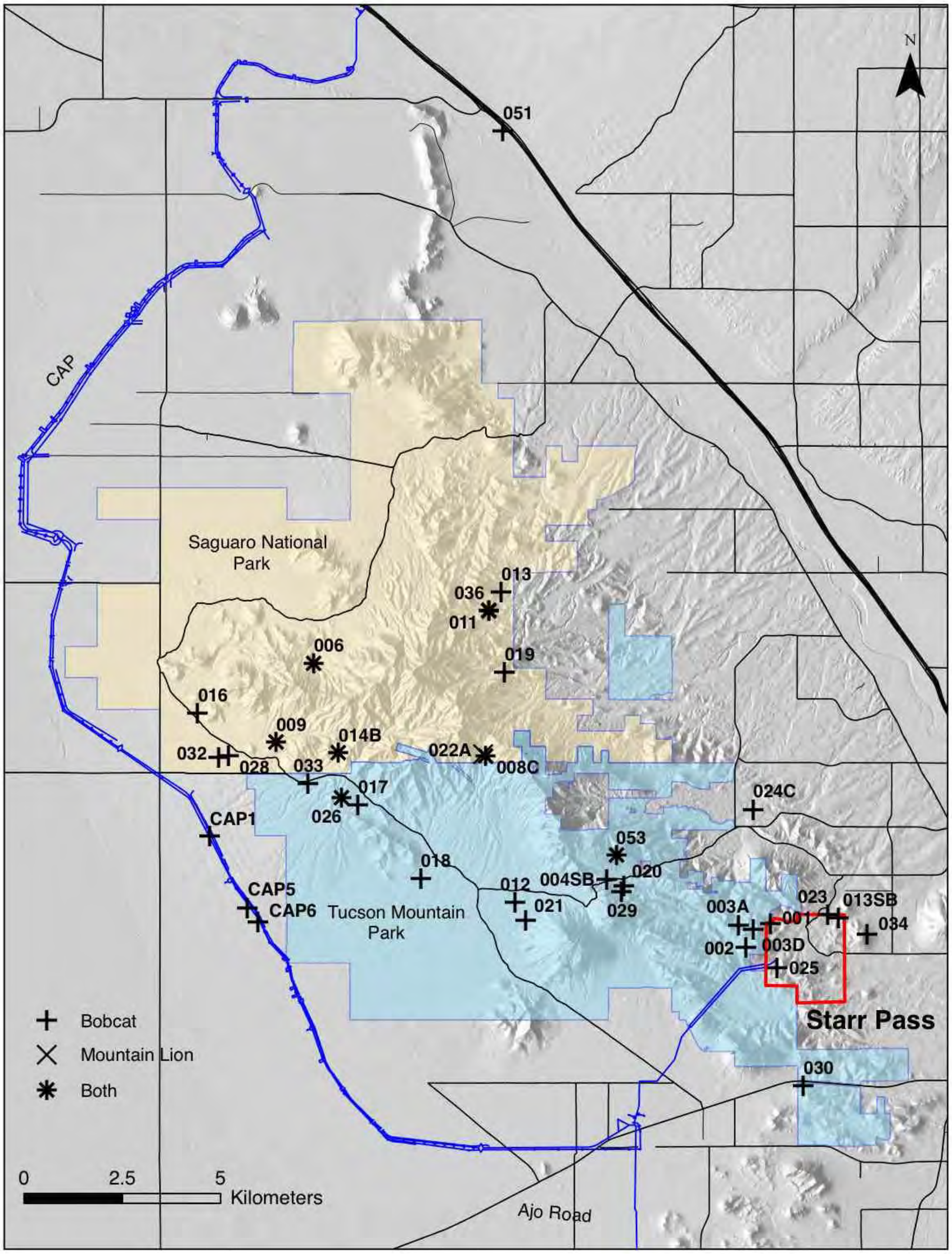

Figure 4. Infrared-triggered "trail" cameras that photographed mountain lions, bobcats, or both.

We asked these biologists to give us their assessments of lion demographics. According to one expert, the 2009 photographs represented a subadult male, a young adult male, a young adult female, and an adult female (Fig. 5). The other expert classified the cats as only age-categories 1 to 3 years old, 3 to 4 years old, and adult, with no gender classifications. Neither expert was comfortable identifying individual mountain lions. And both identified the two May 2010 photographs as an adult (most likely a male—which could have been one of the young males from the 2009 photo set—now one year older). Given that we were not able to identify individuals, we were unable to use the program CAPTURE to provide a more robust estimate of population size.

Cameras: BOBCATS – Of the 65 camera sites, 34 cameras photographed bobcats (Fig. 4) resulting in 267 photographs of bobcats. Given this large sample size we did not conduct an intensive assessment of individual bobcat identification. However, in a subset of photos we used unique spot patterns or markings to identify some individuals, either multiple times at one site, or at multiple sites, or both (Fig. 6). A more intensive analysis could possibly provide rough estimates of home range sizes. The photographs also documented a variety of bobcat behaviors such as playing (or possibly fighting), scent marking (spraying) and sniffing.

Genetics—As part of several related studies, we have been conducting ongoing genetic analyses of mountain lions and bobcats at SNP-TMD. Our goals in these studies were to identify individual cats, examine relatedness among individuals, and assess gene flow. Most of the samples have been scat (feces) collected opportunistically in the field. In addition, we analyzed a tissue sample from a lion carcass found near Wild Horse Mine in 2005, and experimented with hair snares to obtain hair samples from lions and bobcats. Hair snares have been developed as a method to survey endangered lynx (*Lynx canadensis*) across large areas in the northern United States (McDaniel et al. (2000). We found that hair snares were unsuccessful for a variety of reasons (Haynes and Swann 2003).

As part of a previous multi-national park analysis, we had analyzed 74 total scats from SNP-TMD that were field-identified as bobcat and lion (Hackl et al. 2006). Of those, 27 yielded DNA and 18 were identified as wild felid (2 lion and 16 bobcat). Of those, two bobcats were identified as individuals. In a different multi-park analysis, we had analyzed eight mountain lion scats; successfully extracted DNA from six; and identified one individual (from two scats) (M. Culver and E. Garding, pers. comm.). Scat DNA from the one individual matched the lion carcass, so we now know that that individual is dead. We did not find any additional mountain lion scat during the course of this project and therefore have no further elucidation on the genetic relatedness of mountain lions in the Tucson Mountains.

Regarding bobcats, as part of a different project (Haynes et al. 2009 AGFD U07013), we conducted an assessment of the genetic structure of bobcats across the Tucson basin, in which we identified two additional individuals from the Tucson Mountains. However, our citywide analysis showed little genetic segregation, suggesting few or no barriers to bobcat movement or gene flow across the Tucson landscape. However, our sample sizes were relatively small and we hope to continue this analysis over time.

Objective II – Assess the use of corridors identified as part of the Starr Pass Resort Development by wild felids and other wildlife.

Cameras – No mountain lions were detected with Starr Pass cameras, however a wide variety of other wildlife species were documented, including bobcats at seven of the of the Starr Pass sites (Table 1). In many of the low-density housing areas surrounding Tucson, wildlife officials often receive mountain lion sightings from the general public. However, if these sightings can be

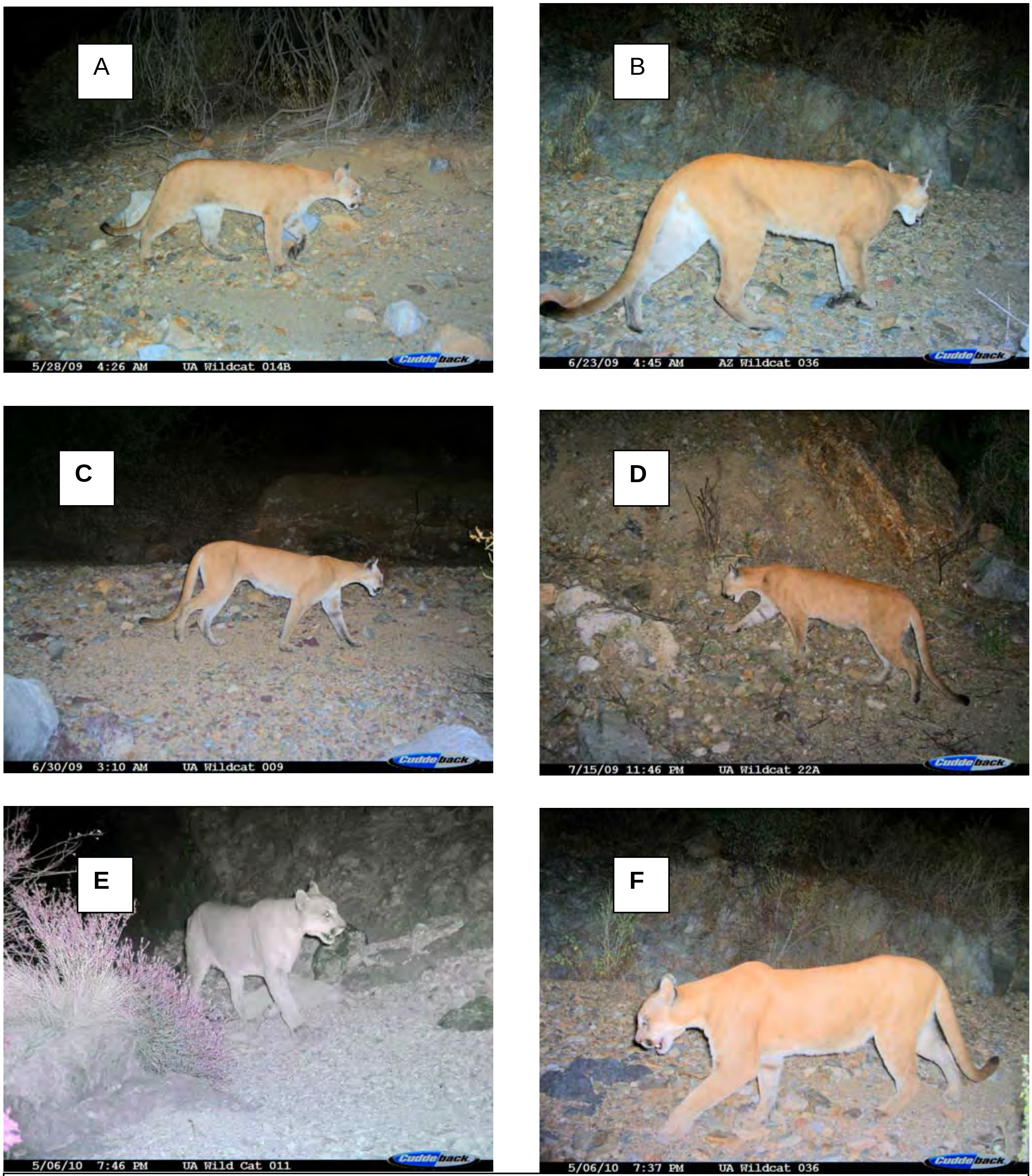

Figure 5. Representative photographs of mountain lions taken by infrared-triggered "trail" cameras located in and around the Tucson Mountains, AZ from 2008-2010 classified by two experts respectively as: A. young female/1-3 yrs, B. young male/1-3 yrs, C. adult female/3-4 yrs, D. subadult male/1-3 yrs, E. and F. adult male (note these are paired right-left photos of same event).

Figure 6. Bobcats photographed by infrared-triggered "trail" cameras located in and around the Tucson Mountains, AZ from 2008-2010, representing individuals identified by markings on inner front legs. Top Pair: same individual at different times at same site. Middle Pair: different individuals at same site. Bottom Pair: same individual at different sites.

documented by experienced observers, most of them turn out to be bobcats. There are few validated occurrences of mountain lions in foothill areas surrounding Tucson. However, this does rarely occur, so sightings should not be discounted out of hand. The data from our cameras indicates that the majority of lion locations occur in more rugged terrain or unpopulated areas.

Objective III – Assess connectivity and landscape linkages that allow wild cats and other wildlife to connect with populations outside of the Tucson Mountains

Cameras – The ten CAP canal cameras were only set on January 21 (and monitored through May), 2010, due to unforeseen delays in getting permits approved. No mountain lions were documented, however the presence of bobcats, coyotes, collared peccaries (javelina), mule deer, and a badger are encouraging evidence that the CAP wildlife mitigation corridors are functioning as such. On another positive note, one of our volunteers who is highly experienced with mountain lions, observed one crossing Sandario Road at UTM 12S 0479510 – 3559116 (NAD 27) thus indicating that there is still the potential of lion movement in and out of the Tucson Mountains.

The camera at site 50 at the Avra underpass under I-10 had to be removed in late 2009 as a result of construction, so data are limited at this site. Although no bobcats were photographed by camera 50, L. Haynes documented bobcat tracks in the underpass prior to camera placement. (We also photographed a domestic cat at this site.) On camera 51, there were so many photos of suspicious human activity, we removed it after a short period.

No mountain lions were documented in any of the linkage sites or the CAP Canal. However, our other focal species, the bobcat, was photographed at sites 24C, 30, and 51; at CAP cameras 1, 3, 5, and 6; and documented by tracks at site 50.

Ancillary Objectives and Benefits – In addition to the primary objectives, we realized several other products or benefits.

Felid Sign – We documented very little mountain lion sign during the course of the study. Two kills were recorded, one near camera 28 and one near camera 8C. L. Haynes observed lion tracks associated with the kill near camera 28. No other lion tracks, scrapes or scat were observed during the course of the study. Bobcat sign was ubiquitous throughout the study area.

Other Wildlife – A significant benefit to the study beyond the assessment felids was documentation of a wide diversity of wildlife throughout the study area. We collected over 12,000 photographs documenting at least 21 mammal species (plus humans), 16 bird species, and two reptile species (Tables 1 and 2). An assessment of the relative numbers of photos of medium to large or most common species revealed interesting results (Table 3). Humans were most commonly photographed (our camera checks not included), followed by mule deer, coyotes, foxes, and other wildlife. However, it must be noted that oftentimes multiple photographs were taken in single events where people milled around in front of the cameras. The cameras recorded a variety of human activities (Table 4).

Although kit foxes have been documented in or around the Tucson Mountain area, they are rare (D. Swann, pers. comm.). We were not able to closely scrutinize the 1371 fox photographs to attempt to identify kit foxes from gray foxes. However we would like to do so in a future analysis.

We obtained 227 photographs of skunks, most which are notoriously difficult to identify by species. However we took a subset of 57 photographs and had them identified by Dr. Christine Hass, an expert on skunks. She allocated them as: 7 common hog-nosed skunks, 8 Western spotted skunks, and 42 hooded skunks. None of them was a striped skunk in our sample. We will identify all of the skunk photographs in a future analysis.

Table 1. Mammal species photographed by infrared-triggered “trail” cameras located in and around the Tucson Mountains, AZ from 2008-2010

[1] Pimary Cameras were those placed within and around the mountains.
[2] Cameras placed in and around the Starr Pass Resort Development.
[3] CAP are Central Arizona Project cameras placed in designated wildlife crossings (where the canal runs underground).
[4] *Corridor cameras—CAP #1-10, Robles Pass (#30), Avra-I-10 (#50, 51), Tributary to the Santa Cruz River (#24)*
*We have yet to analyze all the fox photographs to detect the possible occurrence of kit fox.
**Although we examined a subset of 57 skunk photos and verified these three species at some primary cameras, we still plan to analyze the remaining photos and identify all potential skunk species at all sites.

Species	**Scientific Name**	**Primary Cameras[1]**	**Starr Pass[2]**	***CAP[3,4]***	***Robles Pass[4]***	***Avra-I-10 [4]***	***Santa Cruz Tributary [4]***
Mountain Lion	*Puma concolor*	yes	no	no	no	no	no
Bobcat	*Lynx rufus*	yes	yes	yes	yes	yes	yes
Northern Raccoon	*Procyon lotor*	yes	yes	no	no	no	no
Coyote	*Canis latrans*	yes	yes	yes	yes	yes	yes
Feral Cat	*Felis catus*	yes	no	no	no	yes	yes
Dog	*Canis familiaris*	yes	yes	yes	no	no	yes
Gray Fox	*Urocyon cinereoargenteus*	yes	yes	yes	yes	yes	yes
Kit Fox	*Vulpes macrotis*	*	*	*	*	*	*
Ringtail	*Bassariscus astutus*	yes	yes	no	no	no	no
Western Spotted Skunk	*Spilogale gracilis*	yes	**	**	no	no	no
Hooded Skunk	*Mephitis macroura*	yes	**	**	no	no	no
Common Hog-nosed Skunk	*Conepatus leuconotus*	yes	**	**	no	no	no
American Badger	*Taxidea taxus*	no	no	yes	no	no	no
Desert Cottontail	*Sylvilagus audubonii*	yes	yes	yes	yes	yes	yes
Black-Tailed Jackrabbit	*Lepus californicus*	yes	yes	yes	yes	no	yes
Collared Peccary (Javelina)	*Pecari tajacu*	yes	yes	yes	yes	no	yes
Mule Deer	*Odocoileus hemionus*	yes	yes	yes	yes	no	yes
Harris's Antelope Squirrel	*Ammospermophilus harrisii*	yes	yes	yes	no	no	no
Rock Squirrel	*Spermophilus variegatus*	yes	yes	no	no	no	no
Round-Tailed Ground Squirrel	*Spermophilius tereticaudus*	yes	yes	no	no	no	no
Virginia Opossum	*Didelphis virginiana var. californica*	yes	no	no	no	no	no
Mexican Long-Tongued Bat	*Choeronycteris mexicana*	yes	no	no	no	no	no

Table 2. Non-mammalian species recorded by infrared-triggered "trail" cameras located in and around the Tucson Mountains, AZ from 2008-2010. In addition to the bird and lizard species listed, there are other records of birds and lizards that we were unable to identify to species.

Cactus Wren	Pyrrhuloxia
Canyon Towhee	Roadrunner
Curve-Billed Thrasher	Scott's Oriole
Gambel's Quail	White-Winged Dove
Gila Woodpecker	Mockingbird
Turkey Vulture	Mexican Whip-poor-will
Mourning Dove	Clark's Spiny Lizard
Northern Flicker	Gila Monster

Table 3. Relative numbers of photographs of medium-large or most common species recorded by infrared-triggered "trail" cameras located in and around the Tucson Mountains, AZ from 2008-2010. Several other small or rarely recorded animals are not listed.

Human (not including camera checks)	2094
Mule deer	1823
Coyote	1591
Fox	1371
Cottontail rabbit	1070
Javelina	909
Jackrabbit	610
Bird (without designation)	315
Dove (mourning and white-winged)	281
Bobcat	267
Gambel's quail	254
Skunk	227
Dog	180
Squirrel	157
Roadrunner	79
Raccoon	71
Owl	44
Mountain lion	36
Ringtail	20
Whip-poor-will	20
Badger	2

Table 4. Characterization of human activity photographed by infrared-triggered "trail" cameras located in and around the Tucson Mountains, AZ from 2008-2010. Human activities were described in a wide-variety of ways. We summarized that list into the following categories.

Working	Horse-back riding
Riding ATV	Conducting telemetry
Bee extermination	Riding golf carts
Hiking	Riding trucks
Jogging	Bow hunting
Mountain biking	Buffelgrass control

We made two notable observations from this study. The first is a sighting (confirmed by Don Swann of Saguaro National Park) of *Didelphis virginiana v. californica*, a subspecies of Virginia opossum native to Sonora, Mexico (Babb et al. 2004) on 9-5-2009 at site 19. This represents a range expansion for this species. We will pursue publication of this event. The second is a new winter record of the Mexican long-tongued bat (*Choeronycteris mexicana)* in the Tucson Mountains (photo taken on December 12-4-2008 at site 15SB). Dr. Ronnie Sidner, who confirmed the species identification, indicates that this species typically migrates in the winter because it is unable to hibernate. She speculates that it must have found a warm spot to overwiinter, perhaps associated with human habitation.

It is notable that the American badger was only photographed at the CAP wildlife crossing sites, which is testament to the crossings' usefulness as linkage zones. (Biologists are becoming increasingly concerned about badgers due to habitat loss throughout their range. The species commonly occurs in flat valley bottoms, which are being filled in by human development, farms, and infrastructure.)

Volunteers – This project greatly benefited by the extraordinary efforts and contribution of a small group of committed volunteers. The monitoring of 63 camera sites and the cataloging of over 12,000 photographs by these "citizen scientists" is a testament to the value of engaging members of the public in wildlife research. Their diligence in entering and categorizing all the photos allowed us to document and analyze a wide diversity of wildlife, in addition to the project's primary focus on mountain lions and bobcats. Their professionalism, enthusiasm, and commitment was integral to this project's success!

Notes on Cameras — As noted earlier we had two cameras stolen outright and one camera was stolen and eventually recovered (12). In all cases, the camera thieves must have used bolt cutters to cut the locks or cables. Still, given the number of human photographs documented by these cameras (2094), it is remarkable that so few were stolen.

We had considerable problems with woodpeckers damaging the cameras by poking out the lenses covering the infrared emitters. Repair kits are available from the manufacturer but replacing lenses is time and labor intensive. Many of the cameras were also damaged by battery acid leakage. This may have been due to inadequate seals on the camera housing during rainy periods.

Discussion

Although we tried to identify individual mountain lions as recommended by Kelly and Camblos (2004) and Kelly et al. (2008) we were unable to distinctly identify any individual mountain lion. Kelly's studies were conducted in areas with relatively more homogeneous habitat, contiguous with other mountain lion populations, and also in more mesic or Neotropical conditions. These characteristics may have contributed to more marks or scarring on their mountain lions, enabling biologists to more easily identify individuals. Their higher densities of mountain lions may have contributed to more intraspecific strife (fighting), which results in scars, torn ears, etc. Also bot flies and external parasites are more prevalent in these areas, resulting in more scarring. In our study area the lions in the photographs were very clean, with few or no scars or marks, possibly the result of very low population density, little intraspecific strife, and few or no major external parasites.

The fact that there were more mountain lions photographed in Saguaro National Park than Tucson Mountain Park may be due to two factors: 1.Saguaro National Park is more mountainous and rugged overall, and 2. there may be less human activity in the National Park. It would be interesting to evaluate the correlation between detections of humans and mountain lions across the study area.

In a prior analysis we documented mountain lion reproduction within the Tucson Mountains when we photographed a female with a young kitten (Hackl et al. 2006). In our current study, the presence of the subadult(s) indicates either reproduction within the mountain, or immigration from surrounding populations, or both. Genetic isolation and inbreeding (i.e. mating between closely related individuals) is the greatest cause for concern for this population. Unfortunately, there is no way to determine genetic relatedness or evidence of immigration-emigration without either more intensive genetic analysis or radio telemetry or both (although photo documentation of lions in corridors would be encouraging evidence).

For mountain lions and bobcats to maintain gene flow and connectivity with surrounding populations, it is critical that biological corridors are conserved and function as linkages between core habitats in perpetuity. This is true for both species of wild cats, but mountain lions are far more sensitive to urbanization and landscape fragmentation. Mountain lions are a focal species for conservation planning due to their critical role as a top down ecosystem regulator. For an excellent review of this topic see Beier (2010). Bobcats serve a similar function, although at smaller spatial and ecological scales.

There are two major factors to consider when planning for ecological connectivity: roads and general landscape permeability. First, road kill has been documented as the highest source of mortality for both cat species in urban areas (Lyren et al. unpublished data in Riley et al. 2010, Quigley and Hornocker 2010). Mountain lions will sometimes cross roads at grade (and potentially be struck by vehicles), even when passable culverts in drainage-ways are available (Beier 1995). In Florida, where road kill is currently the highest mortality factor for the endangered "Florida panther", carefully designed under-crossings and fencing of the entire right-of-way of Interstate 75 has drastically reduced deaths (Beier 2010). In Arizona, GPS data from radio collared mountain lions indicate that interstate highways are major barriers (R. Thompson, Arizona Game and Fish Department, pers. comm.), and preliminary genetic analyses indicate subtle genetic subdivision in populations on either side of the I-10, I-17, I-19 interstate system (M. Culver, University of Arizona, pers. comm.) indicating interruption of gene flow. For bobcats, studies in California have shown that bobcats can successfully use culverts and under-crossings of major highways (Riley 2006). But secondary roads are even more problematic, because bobcats either avoid crossing them or so many are killed by vehicles that roads create a mortality sink (Lyren et al. unpublished data in Riley 2010). In several instances, telemetry data have shown that roads and highways create linear home range boundaries, which the animals do not cross (Riley 2006, Riley et al. 2010).

Secondly, it's important to consider the general permeability of the landscape, i.e. the pattern of development surrounding core habitats. Even if animals successfully cross under or over roads, the density of urbanization on either side can determine whether the landscape is permeable to their movements between core areas. For bobcats in the greater Tucson area, the landscape may be fairly permeable (other than in the city center and other highly developed areas, or when roads become significant barriers), because bobcats are commonly seen in low-density housing developments (unlike some areas in California, where bobcats significantly avoided human-associated areas {Riley et al. 2003}). Mountain lions, however, are highly sensitive to urbanization and usually avoid areas associated with humans (Beier 2010), including in the Tucson area (Nicholson 2009). However, occasionally, mountain lions may thread their way through lightly developed areas (Beier 1993, Nicholson 2009), which is integral to gene flow across fragmented landscapes (Beier 1996).

Given the above realities, maintaining landscape connectivity for both cat species between the Tucson Mountains and surrounding core habitats will be a challenge, especially with respect to mountain lions. Large, busy surface roads such as Ajo, Silverbell, Avra Valley, and Sandario Roads may be significant barriers, and/or mortality sinks, for both species, as is Interstate-10.

For mountain lions, the most likely avenue for ingress and egress is to the west of the Tucson Mountains. It is still likely that mountain lions can weave through the low density housing and the CAP Canal crossings to connect with the open desert of Avra Valley, the Tohono O' Odham Indian Reservation, and the Roskruge Mountains to the west. This area should be a high priority for conservation land use planning. To the south, it is probably still possible (although less likely) that mountain lions could make their way through the relatively low density housing to the south, particularly if linkage zones are enhanced with wildlife crossings across Ajo Road (at Robles Pass), and development is not intensified between Ajo Road and the San Xavier Indian Reservation. To the east it is conceivable that mountain lions could use the Santa Cruz River as a travel corridor. One mountain lion was discovered in a trailer park near Oracle Road and the Rillito River (J. Heffelfinger, Arizona Game and Fish Department, pers. comm.), indicating at least one individual navigated close to a major river wash in the city. To the north it is unlikely that there are pathways for mountain lions due to the intensive agriculture and increasing development north of the mountain. The planned wildlife crossing under Interstate 10 near Avra Valley Road may be the only avenue for mountain lion connectivity to the to the north/northeast, although as discussed previously, even with wildlife underpasses, interstate highways without fencing may still be problematic for mountain lions. Under current conditions, all of the potential biological linkages are compromised for mountain lions (and to some degree for bobcats). These realities have been recognized in regional planning and conservation efforts such as the Sonoran Desert Conservation Plan; and decisive action should be taken to maintain, or even enhance these areas for conservation.

Recommendations and Continued Analysis

As mentioned previously we would like to continue our assessment of skunk species, and more closely examine all the fox photographs to detect kit foxes.

We have recently become aware of a new program, which easily conducts detailed analyses (e.g. activity patterns, species associations, occupancy, etc.) of large data sets such as ours (J. Sanderson, pers. comm., Harris et al. 2010). This would entail re-opening each photograph and categorizing them into simple folders for site location, species, and number of individuals. Once this is done a freeware program called ReNamer labels each photograph so that it can easily be incorporated into the program. The expected outputs are listed in Appendix 1. We will conduct this analysis.

We highly recommend continued monitoring of camera sites that recorded mountain lions (Fig. 3). Our volunteers are still eager to monitor and maintain cameras into the future. We would also like to reestablish camera stations at those CAP sites that photographed the larger animals such as mule deer and javelina, which may eventually document lion movements in and out of the Tucson Mountains. If or when wildlife crossings are installed at Robles Pass and at the Avra Valley/I-10 site, it would be worthwhile reestablishing camera stations at those sites. However, on the east side, the Santa Cruz River is too wide, the potential corridors are too dispersed, and the probability of camera theft or vandalism is too great to practically monitor that side of the mountain with cameras.

We also recommend continued genetic analysis of scat DNA.

Although some limited information has been gained by this project (and other noninvasive techniques, i.e. scat genetics and track surveys), radio telemetry is the most direct and effective method to answer questions regarding population status and landscape connectivity. The Tucson Mountains are likely too small for the home range of an adult male mountain lion. Under normal circumstances in the Sonoran Desert (especially west of I-10), males would likely incorporate several mountain ranges in their home range. Therefore, radio-tracking males (especially with advanced GPS satellite telemetry technology currently available) could produce critically needed data with respect to movement corridors between the Tucson Mountains and surrounding mountain ranges. Radio collaring subadults, as they become independent and disperse away from their natal home range, would serve the same purpose and would be highly valuable for conservation planning—especially for this most “endangered” of sky island mountain ranges in southern Arizona. The Pima County Sonoran Desert Conservation Plan calls for conservation of corridors, or critical landscape linkages. In many instances corridors set aside for large wide-ranging species, such as the mountain lion, serves many other species as well. The only way to truly define corridors for the mountain lion, the most wide-ranging and one of the most critically important species, is through radio telemetry. However, radio collaring mountain lions in urbanized areas is politically problematic. Radio collaring, or problems with telemetered animals can be touchstones for controversy. In the meantime, the conservation and ethical value of this critically needed information is lost. We recommend initiating a community discussion with respect to the risks and benefits of telemetric research, as well establishing processes for veterinary, technical, and ethical oversight, if the collective decision is made to initiate telemetry-based research.

Telemetric studies of bobcats can also provide valuable, locally specific information. We would like to see radio telemetry studies with respect to potential wildlife crossings of Silverbell and Sandario Roads, Robles pass, and the Avra–I-10 underpass. Bobcats, due to their sensitivity to roads, are valuable as a focal species for wildlife/transportation planning, may serve as an umbrella species for many other species of wildlife, and may possibly yield useful information for their larger cousins, the mountain lion.

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Appendix 1. A list of outputs from a new program, which easily analyzes large datasets from infrared-triggered “trail” cameras.

(1) A list of sites and species used in the data analysis.
(2) File information such as the number of images in the input file, the number used in the analysis, the number of warning, and the number of rejected images that contained errors. Images with warnings and errors are sent to *Warning.txt* and *Error.txt*, respectively, for examination and possible correction.
(3) Camera Trap days. The first year, month, and day and last year, month, and day of the study, and the total number of days in the study are given.
(4) For each species, the date, time, site, and the number of days since the study began for the first image was recorded.
(5) Species accumulation curve. This is the number of days since the study began and the number and first record of a species. If several species were first recorded on the same day, these are listed together.
(6) For each trail camera location, the start and stop date, number of days in operation, and date of first and last image are listed.
(7) Trail camera effort is given. For each location, the number of days for each year is listed by month. Results by month and by location are totaled.
(8) For each location, the start date, date of first image and species recorded are listed.
(9) The maximum, minimum, and average distance between locations is given. For each parameter the location name is provided as well.
(10) Activity patterns. For each species the hour, number, and proportion of images recorded from all locations is given. A one-hour filter is used which means that only one record is used per species per location per hour (one species/location/hr).
(11) Species’ pairs activity comparisons are given in a matrix. The activity patterns of all species pairs are compared. Those that are most similar have lower values.
(12) The species pair whose activity patterns are most similar are listed.
(13) A chi-squared comparison of species pairs activity patterns is given. Those pairs that are significantly different at 5% are highlighted.
(14) Lunar activity patterns are given for each species. For +/- five days around new and full moons, each species activity pattern is listed by number and frequency. The r^2 difference is given. The species showing the greatest difference in activity between new and full moons is given.
(15) Species abundance. For all locations, the number of images, total abundance (since groups of individuals are recorded), average number of individuals, and relative abundance are listed. The total number of images is also given. A one day filter is used (one record per species (or group of species if more than one individual is present in the image) per location per day is used.
(16) The number of records recorded for each location and each species are given in matrix form. Location totals and species totals are given. A one day filter is used.
(17) For each year and for each location the total number of images recorded is given by month. A one day filter is used. Only active locations are included for each year. The total number of images, total number of active days, detection rate, and optionally monthly temperature, rainfall, and humidity are given per month.
(18) Detection rate. For each year and for each species the total number of images recorded is given by month. A one day filter is used. The total number of images, total number of active days, detection rate, and optionally monthly temperature, rainfall, and humidity are given per month. For each year the total number of images for each species is given.
(19) For each year and for each species, the number of records by location and month is given. The total number of records, total number of camera trap days (effort), and detection rate are also given. The total number of records for each location for the year is given. Optionally monthly temperature, rainfall, and humidity are given per month. For each year the total number of images for each species is given. A one day filer is used.
(20) Species detection rates. For each year and for each location, the total number of operational days, total number of records, detection rate, and for each species the total number of records is given. A detection rate summary for all years follows. A one day filter is used.
(21) Occupancy estimation. For each species, the fraction of locations where a record was obtained for a species (naïve occupancy proportion) during the study is given.

(22) For each year, and for each species, an occupancy matrix is given. Rows in the occupancy matrix represent locations, and columns camera trap occasions (a defined number of days). A “1” represents a record was obtained for the species at the location; a “0” is used when no record was obtained, and a “-“ is used when the location was not active. The matrix can be copied and pasted into program PRESENCE for occupancy estimation. The number of days during which a species might be recorded, the so-called *camera trap occasion*, was defined to be 10 days. Note that any number of days could be used and the number of days could be species dependent.

(23) Using optionally provided UTM co-ordinates, the area covered in km^2 and mi^2 by the Trail cameras is calculated. The area is bounded by a convex hull defined by the outer-most locations surrounding the study area. A list of exterior locations used to calculate the area is given. If a location co-ordinate is not known, the default value of 0 in the input file is used, and it is omitted from the area calculation.

(24) Total elapsed computer execution time is given and a normal termination notification concludes the analysis program.

The output from the analysis program is a text file listing. Text information can be input into a spreadsheet program such as Excel using the copy and “paste special’ commands.