THE USU COUGAR PROJECT: OPTIMIZING NONINVASIVE MONITORING FOR AN ELUSIVE LARGE CARNIVORE

by

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ABSTRACT

Cougar (*Puma concolor*) monitoring efforts are lacking throughout most of the species' range, with most data on cougar populations based on imprecise and potentially biased harvest data. Although ranked as 'Least Concern' by IUCN, the global abundance of cougars is declining primarily due to habitat loss and fragmentation. The primary barriers to efficient surveys for the species are elusiveness, wide-ranging movements, and low density. In recent years, many studies have used camera-traps in attempts to monitor cougar abundance, but results are variable and no conclusive assessment on the effectiveness of this method yet exists. Using an occupancy framework, I compared camera-trap surveys to natural sign surveys for monitoring cougars in the Bear River Range. I conducted parallel camera-trap and natural sign surveys for cougars on 5 separate 64 km^2 grid units and recorded all detections from September 2016 through April 2018. Undergraduate volunteers helped achieve a survey effort of more than 1100 camera-trap-nights and 260 km of natural sign surveys, resulting in a total area of more than 200 km^2 surveyed. Sixty occupancy models were run with different spatial levels, covariate combinations, and model types. Cougars were detected a total of 25 times in 17 locations. Camera-traps generally had a higher detection probability by 4.2%, though natural sign surveys had higher detection probabilities during winter. The two survey methods produced mutually exclusive detections at any site except in a few instances. Season had the greatest effect on natural sign detection probability, whereas survey effort had the greatest effect on camera-trap detection probability. Cougar occupancy (a measure of the proportion of home ranges occupied in an area) was estimated at 100% in the Bear River Range, with estimates at a smaller scale showing the proportion of habitat use within home ranges between 33% and 75%. Large-scale habitat preference for aspen and coniferous forest corresponded with increased proportional habitat use for survey units dominated by those habitat types. The success of both methods was a function of skill development during a pilot study, standardized survey design, and the help of volunteer citizen scientists. Primary challenges faced were feasibility of surveys and unreliable parameter estimates. Recommendations for future work address these issues, primarily via changes in study design which also better correspond with new knowledge of the target population. The analysis here suggests that overall trends in occupancy estimates provided by these monitoring efforts were robust across model type and parametrization. Using a consistent survey design and recruiting volunteer citizen scientists to meet survey effort requirements – particularly undergraduate students pursuing wildlife-related degrees – occupancy estimates could provide a meaningful alternative to harvest indices for cougar population monitoring and management. With these large-scale, long-term monitoring efforts, local data on wildlife communities may be compiled across space and time to contribute to widespread biodiversity monitoring.

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INTRODUCTION

Basic knowledge of population status and trends is essential for the proper management and conservation of wildlife. Some species, however, evade enumeration by common methods due to low density, small populations, large ranges, low detectability, avoidance of humans, and preference for remote or inaccessible habitat. Attempts to assess population status of the order Carnivora (hereafter referred to as carnivores) are hindered by the tendency of these species to exhibit several of the above traits (Long and Zielinski 2010). Many carnivore populations are at risk due to historic persecution, sensitivity to human activity, and global trends in habitat loss and fragmentation (MacKay et al. 2008). Thus, lack of baseline population data compromises proper management and conservation.

Early work on carnivore enumeration focused on mark-recapture techniques, often through trapping and radio-collaring individuals to estimate abundance and collect spatial and behavioral data (e.g., Craighead and Craighead 1965; Mech 1966; Seidensticker et al. 1973). Besides the exorbitant costs associated with such studies, the risk inherent in handling wildlife – both for the animals and humans involved – is a common challenge. To counter these concerns, advances in technology have been increasingly applied to wildlife research for the purpose of noninvasively monitoring populations. "Noninvasive" refers to study methods that do not require human handling of animals, minimizing wildlife stress and associated behavioral changes (MacKay et al. 2008).

Current research and conservation efforts emphasize noninvasive techniques for large-scale population monitoring (synthesized in Long et al. 2008; see also Zielinski and Kucera 1995; Kelly et al. 2012). Several of these methods have been optimized for various species in a range of landscapes (e.g., Karanth 1995; Zielinski et al. 2005; Long et al. 2007). Techniques employ baited track stations, genetic analysis of hair or scat samples, camera-traps, and novel statistical approaches to evaluate the population status of these elusive species. However, the formalization of species-specific noninvasive surveys is the exception rather than the rule, and further exploration and refinement of noninvasive methods is necessary for confident application to new species, new populations, and new landscapes.

Puma concolor, also known as the cougar, mountain lion, puma, or panther, is the most widely distributed terrestrial carnivore of the Western Hemisphere (McRae et al. 2005). Cougars have increasingly been limited to fragmented habitat in the western region of their historical range (Stoner et al. 2006) and their global population trend is decreasing (Neilson et al. 2005). Hunting occurs in eleven of thirteen states where the species occurs in the United Sates, yet accurate population estimates on which to base harvest quotas are virtually nonexistent. Nonetheless, the status of a given cougar population is extremely difficult to determine due to their wide-ranging nature, low density, and elusiveness. Though extensive scientific literature is available on cougar ecology and behavior (e.g., Hornocker and Negri 2010), no universal cost-efficient method has been established for confidently assessing population status despite repeated calls to explore the topic by wildlife scientists and managers (Becker et al. 2003; Cougar Management Guidelines

Working Group 2005; Toweill et al. 2008; Williams et al. 2011; UDWR and the Cougar Advisory Group 2015).

Wildlife managers throughout the United States and Canada often rely on indirect indices such as track surveys and hunt data to set harvest quotas. The uncertainty associated with these indices is a widespread concern in wildlife management that prompts investigation into better indicators of cougar population status, especially with threats of habitat fragmentation and overhunting (Choate et al. 2006). The lack of information on cougar populations is concerning given recent evidence for a high probability of local extinctions due to habitat fragmentation (Benson et al. 2016), as well as the risk associated with setting harvest limits without referencing any explicit measure of abundance (Stoner et al. 2006; Packer et al. 2009; Wolfe et al. 2015). The latter issue has been voiced by many Utahns in recent years as the state continues to raise harvest quotas for cougars despite a lack of direct population estimates (Maffly 2016). These concerns are valid, as anthropogenic influences such as hunting have been demonstrated in multiple cases to limit cougar populations in Utah and elsewhere (Stoner et al. 2006; Cooley et al. 2009). Anthropogenic effects are exacerbated when connectivity is limited between heavily hunted “sink” populations and more resilient “source” populations (Stoner et al. 2006; Wolfe et al. 2016). Investment in effective survey methods for cougars is warranted by range-wide habitat fragmentation, human harvest, and the ecological significance of this apex predator.

Many noninvasive methods for cougar monitoring have been explored with contrasting results. Smallwood and Fitzhugh (1993, 1995) developed a protocol for estimating density via identification of individual cougars by their tracks in southern California. Though effective, this method relies on a widespread substrate (e.g., dirt roads) which registers fine enough detail in the tracks for precise measurements. In other environments, such a substrate may not be available, as lightly trafficked by vehicles, or as consistently traveled by cougars. Most recently, noninvasive genetic samples have been employed to estimate cougar populations. The primary challenge with this approach is the need to collect a sample from the animal. Unique tactics have been employed, including the use of biopsy darts on treed cougars (Beausoleil et al. 2016) and hair snare cubbies baited with auditory predator calls and mule deer meat (Yeager et al. 2016). Both methods require intensive effort to collect samples and, in the case of the hair snare cubbies, expensive equipment. More realistic sample collection can be achieved using scat detection dogs. With dogs’ olfactory capabilities, a sufficient sample of scats to estimate population abundance can be collected along transects within a month (Davidson et al. 2014). Further, Alexander (2016) found scat detection dogs to be more cost-effective than camera-traps and hair snares for estimating cougar population density. The main drawback here is that few highly trained scat detection dogs are available and thus the cost of hiring detection canine services is extraordinary.

In the past few decades, the use of camera-traps in wildlife research has exploded (O’Connell et al. 2011). A scientific consensus has not yet been reached on the efficacy of monitoring cougar populations using camera-traps (Foster and Harmsen 2012). Camera-trapping involves field setup of remote-sensor cameras, automatically triggered by motion and heat, to detect and photograph wildlife. Modern remote-sensor cameras (commonly known as trail cameras) are easy to operate, low maintenance, relatively cheap, and do not disturb natural behavior of wildlife. Camera-traps have the added advantage of collecting information on all medium-to-large mammals, including important prey species and competing carnivores, within an ecological community. Camera-trapping has been effective for monitoring other wild felids such as the jaguar (*Panthera onca*, Silver et al. 2004) and ocelot (*Leopardus pardalis*, Trolle and Kéry 2003). Camera placement and grid sampling techniques were originally developed for estimating tiger (*Panthera tigris*) population density in India (Karanth 1995; Karanth and Nichols 1998). Kelly et al. (2008) adapted Karanth's and Nichol's methodology to estimate cougar density in the rainforests of South America, and many small-scale projects throughout the cougar's distribution are similarly assessing the use of camera-traps to monitor populations (various poster sessions in Becker et al. 2003 and Toweill et al. 2008). Testing the efficacy of the camera-trap system in a seasonal environments with migratory prey would contribute to the growing body of science on whether camera-trap surveys can be used to effectively monitor cougars, and if so, how.

The overarching purpose of the USU Cougar Project is to gather baseline population data on cougars in northern Utah, USA, specifically in the Bear River Range east of Logan. While doing so, the larger issue of cougar monitoring methods was evaluated, and camera-traps were tested as a monitoring tool for the species. An ancillary objective is collecting data on the local wildlife community to which cougars belong. The project began in 2015 with the help of two other USU wildlife students – Daniel Johnson and Talon Jeppson, under the guidance of Dr. Daniel MacNulty and Dr. David Stoner. From then until present, the project has grown substantially on multiple fronts, including spatial extent, methodology, student involvement, and public outreach. With the continuation of this project by future students, a large database of species activity data will accumulate for long-term monitoring of wildlife in the Bear River Range.

PART 1: NOVEMBER 2015 – SEPTEMBER 2016

OBJECTIVES

The emphasis of this pilot study was to monitor cougar activity along the wildland-urban interface (WUI) in Cache Valley. The wildland-urban interface presents a unique set of challenges to wild animals as well as opportunities for interactions between humans and wildlife. Although most other large carnivores are intolerant of human disturbance, cougars can become habituated to the nearby presence of urban areas and frequently exploit areas of human activity within their home ranges (Stoner 2011; Knopff et al. 2014). Collecting data on cougars here would improve management and inform our understanding of how humans can coexist with these and other large carnivores. The goal of this baseline survey was to answer the following questions:

1. Where are cougars located in the Bear River Range?
2. How active are cougars along the Cache Valley-Bear River WUI?
3. What spatiotemporal relationships exist between cougars and other species, particularly humans and prey species?
4. What factors influence cougar activity in the Bear River Range?

MATERIALS

Ten remote-sensor cameras of two main brands were used throughout the study: RECONYX and Moultrie. Models included three RECONYX PC85, three Moultrie M-880i, three Moultrie M-550i, and one Tasco brand camera used infrequently. The RECONYX cameras were older and less sensitive to movement, but more resilient against extreme weather conditions, more battery-efficient, and had a higher trigger speed resulting in clearer photographs. The Moultrie cameras were highly sensitive, with the advantage that failing to detect animal movement was minimized and the disadvantages of many false-triggers (photographic events due to moving vegetation or changes in lighting) which may render the camera unfunctional by either filling the memory card or losing battery power. Based on home testing the viewing range on human subjects, the models were comparable in their ability to detect large warm-bodied animals such as our focal species.

Each camera was equipped with rechargeable batteries (8 AAs for Moultrie, 6 Cs for RECONYX) and an SD card ranging from 2GB to 8GB, enabling a minimum storage capacity of ~4000 photographs and capable of photographing for months at a time. Cameras were protected from weather and theft. All cameras were locked to the camera tree via either MasterLock and cable or by Python brand lock-cables. Metal security boxes were also locked around Moultrie cameras when available. Cameras without security boxes were protected from snow by simply duct-taping a multilayer cardboard “roof” to the top before deployment. A third measure of theft security was provided by a five-digit code lock mechanism which prevents unauthorized persons from using the devices. Lastly, all cameras were labeled with project contact information in case found.

METHODS

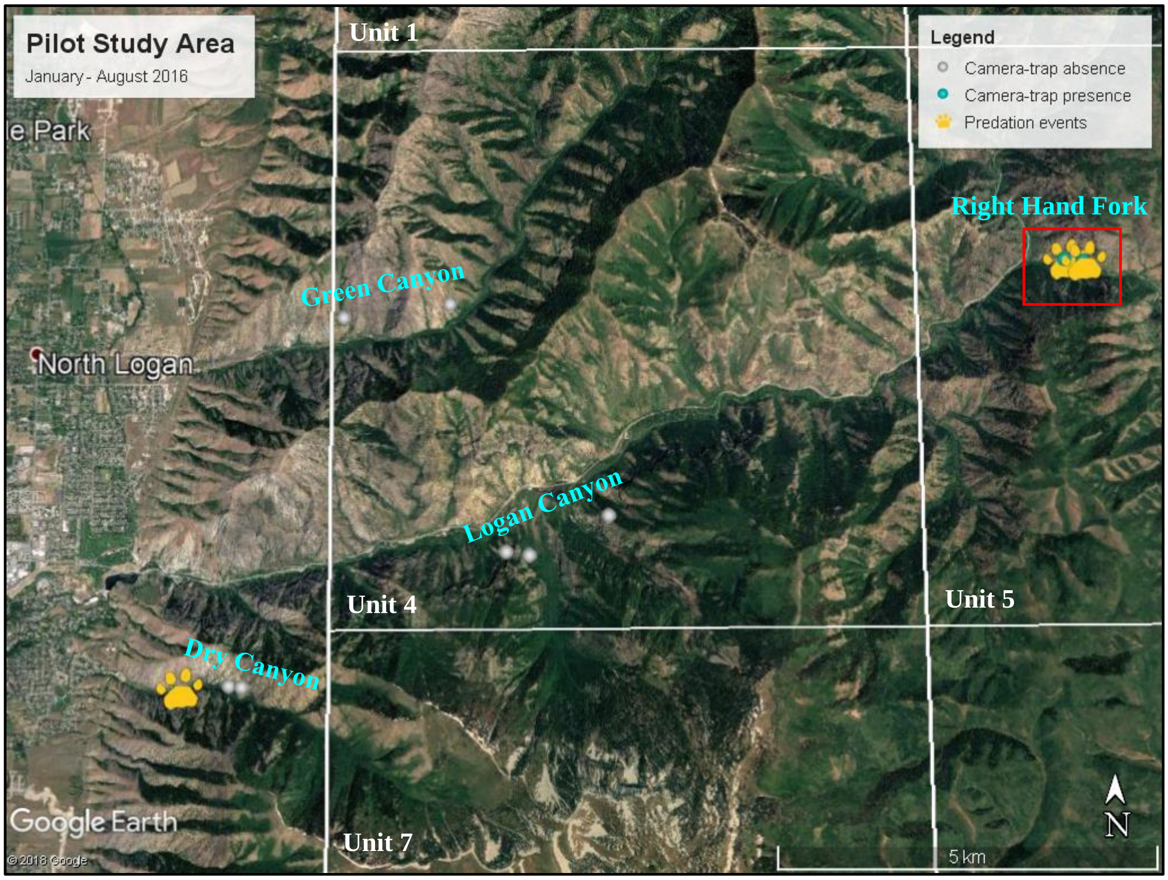
Monitoring effort included camera-trap surveys and recording natural sign of large mammals, including tracks, scats, and predation events, for comparison. Camera-traps were placed in three adjacent canyons east of Logan, UT with variable levels of human activity. From north to south, Green Canyon is moderately impacted by humans including seasonal vehicle traffic and heavy recreational use by humans, Logan Canyon is highly impacted with year-round highway traffic, and Dry Canyon is lightly used by human recreationists with no vehicle traffic. Twelve camera sites were active between 23 January 2016 and 11 September 2016 (**Figure 1**). Total monitoring effort was 685 trap-nights with an average 49 trap-nights per camera (range 7 – 140). Two cameras were originally placed in each of the canyons described above to compare cougar activity. Additional camera stations were established opportunistically when cougar presence was suspected, or when original camera stations were moved to sample a new area.

Due to a lack of cameras, one original camera station was moved after fifteen days to confirm presence of cougar in an area with heavy natural sign. Not including this camera, the other five original stations showed a longer on average and more consistent monitoring period ($\overline{\mathrm{X}} = 66 \pm 22$ days). The primary disadvantage of camera-traps is sensitivity of species detection to camera placement (e.g., Harmsen et al. 2010), so specific camera locations were biased towards maximizing potential cougar activity. Cameras were placed on heavy game trails, with a preference for locations that act as topographic "funnels" ensuring that most animals passing through the area would be detected by the camera. Nine cameras were placed on heavily traveled game trails, two on suspected cougar predation events, and one on a game trail with cougar tracks present (**Figure 1)**. Monitoring focused on areas where previous activity was confirmed or suspected based on hunting records and public sightings.

RESULTS

Overall, twelve mammal species were detected including cougar, mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), bobcat (*Lynx rufus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), striped skunk (*Mephitis mephitis*), domestic sheep (*Ovis aries*), human (*Homo sapiens*), and squirrels (*Sciurus spp.*), as well as various bird species (Class Aves). Cougars were detected at two camera sites, both placed to monitor suspected predation events in the Right-Hand Fork area in March 2016. The carcasses were located about 250 meters from one another, each about 100 meters from a seasonally open gravel road. The first was a yearling elk located on February 28 in open sagebrush-juniper (*Artemisia spp.-Juniperus spp.*) habitat. The elk was consumed about 85% by the cougar and was in good general condition upon death based on marrow appearance. The second predation event was a mature bull mule deer located on March 19 in dense bigtooth maple forest (*Acer grandidentatum*). This animal was senescing and in poor nutritional condition based respectively on dental wear and marrow appearance. At least one cougar fed on the carcass from March 19 – 23, with scavengers such as red fox and striped skunk visiting the site after. The carcass was nearly fully consumed after two weeks, with only major long bones, hide, and rumen remaining. Both carcasses belonged to preferred prey species and showed feeding patterns characteristic of cougar (Halfpenny 2000). These animals were most likely killed by a cougar, but scavenging is possible (Bauer et al. 2005). Site-specific monitoring continued through early September 2016 with no additional cougar activity recorded (**Figure 1**). No distinguishing features in photos confirm the number of animals participating in these events. However, both detections likely represent activity by an individual animal based on cougar space requirements and avoidance behavior. The only other potential cougar sign was a mule deer predation event in Dry Canyon, reported by a reputable wildlife student but not confirmed as cougar-caused by project researchers.

The initial field season served as an opportunity for project members to refine camera placement, natural sign recognition, and other field skills. The major challenges encountered throughout the process were biased camera placement, inconsistent monitoring timeframes between camera-traps, and a lack of decision protocol on when and where to move cameras. Though wildlife was detected at all camera sites, detection of the target species was only accomplished by moving cameras to sites with preexisting cougar sign. Future work focused on separating monitoring and behavioral aspects of the project and establishing specific protocols for camera placement to increase detection rates and avoid uncertainty and bias. The focus also shifted from the WUI to the Cache National Forest for two primary reasons. First, a larger area could be surveyed and therefore a larger proportion of the cougar population included in monitoring efforts. Second, high levels of cougar activity near the highway and in a highly recreated area suggest that human presence is not significantly interfering with cougar behavior in the WUI.



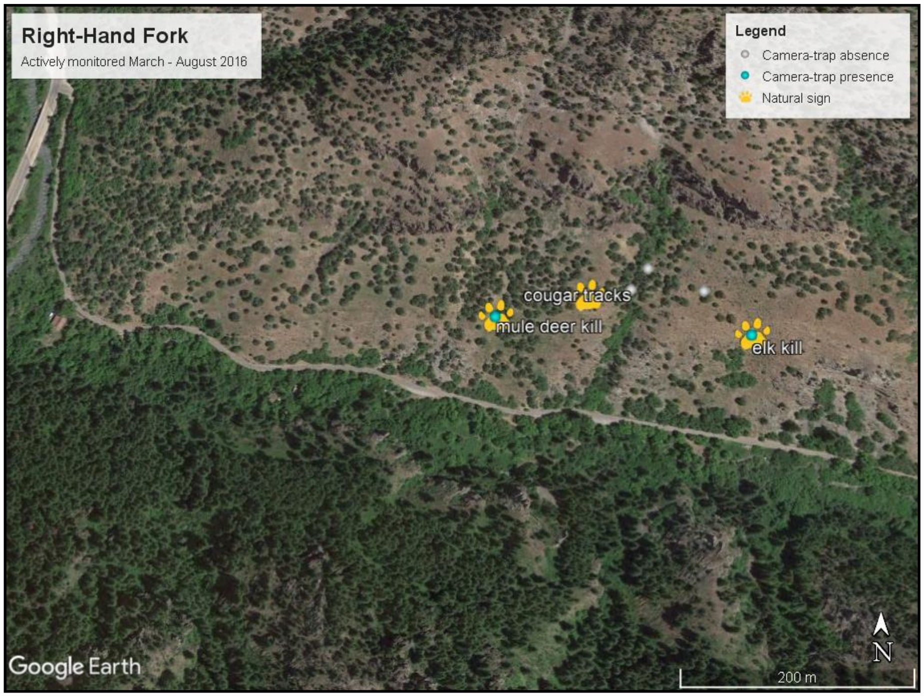


Figure 1. *Locations of camera-trap sites and predation events among the three study canyons with survey unit boundaries overlaid (top) with inset of high activity Right Hand Fork area in red (bottom).*

PART 2: SEPTEMBER 2016 – MAY 2018

OBJECTIVES

The initial survey made the difficulty of monitoring this species more apparent. As such, the primary focus of part two was to determine *how* to effectively detect cougars and test the efficacy of camera-trapping towards this purpose. Accordingly, the project objectives were modified:

1. Establish a camera array for collection of presence-absence data on wildlife species within the Bear River Range.
2. Determine whether camera-traps are an effective tool for detecting cougar presence in the Bear River Range by comparing to a traditional survey method: natural sign search.
3. Estimate habitat occupancy of cougars in the Bear River Range and describe characteristics of cougar habitat where detected.

METHODS

Study area

The study area represents 768 km^2 of the Wasatch Mountains in the Bear River Range directly east of Logan, Utah and includes Logan Canyon, the Logan River, and Blacksmith Fork River. Most of this area is on the Cache National Forest, though areas of state property (Hardware Ranch) and small private parcels are included. Elevations range from 1,300 meters (4,400 feet) at Cache Valley to just over 3,000 meters (10,000 feet) at Naomi Peak. Climate is characterized by hot, dry summers and cold, snowy winters and varies with elevation. During the study period, temperatures ranged from -26°C to 37°C (-15°F to 99°F) in the valley and -23°C to 27°C (-9°F to 81°F) in the mountains (Utah Climate Center, Franklin Basin SNOTEL and Utah State University COOP weather stations). Most water in this area is derived from snowfall, with 1.56 meters of total snowfall on Cache Valley in 2016 and 2.32 meters in 2017, with larger amounts of snow at higher elevations. Maximum snow depth from 2015 to 2018 was 0.76 meters in the valley and 2.77 meters in the mountains. More rainfall is also received at higher elevations, with 0.64 meters at Utah State University and 1.40 meters at Tony Grove during 2016.

The primary habitat type (based on SWReGAP data) is sagebrush steppe (32.1% of the study area; Lowry et al. 2005), dominated by big sagebrush (*Artemisia tridentata ssp.*) and commonly including antelope bitterbrush (*Purshia tridentata*), rubber rabbitbrush (*Ericameria nauseosa*), and snowberries (*Symphoricarpos spp.*). Sagebrush steppe is associated with lower elevations and serves as critical winter forage for local large ungulates. As elevation increases, this habitat type grades into juniper (*Juniperus scopulorum*) woodland (3.3%) which includes sagebrush (*Artemisia spp.*), curl-leaf mountain mahogany (*Cercocarpus ledifolius*), and rubber rabbitbrush as understory components. Juniper woodland is found at low to mid-elevations on dry south-facing slopes. Similarly, mountain mahogany woodland (3.3%) is mainly found along steep south-facing slopes at low to mid-elevations. Bigtooth maple (*Acer grandidentatum*) ravine woodland, often co-dominated by Gambel oak (*Quercus gambelii*) and boxelder maple (*Acer* *negundo*) dominates the canyon bottoms at these lower elevations. At low to mid-elevations, mixed conifer forest (14.3%) dominated by Douglas fir (*Pseudotsuga menziesii*) interspersed with Engelmann spruce (*Picea engelmannii*), white fir (*Abies concolor*), and Colorado blue spruce (*Picea pungens*) is the primary habitat type along north-facing slopes. Middle to high elevations consist largely of aspen (*Populus tremuloides*) forest (16.7%) and aspen-mixed conifer forest (1.6%). Small grassland patches (1.2%) with oatgrass (*Danthonia spp*.), Idaho fescue (Festuca idahoensis), muhly species (*Muhlenbergia spp*.), and bluebunch wheatgrass (*Pseudoroegneria spicate*) punctuate middle to high elevation forests. The highest elevation slopes consist primarily of dense subalpine spruce-fir (*Picea engelmannii-Abies lasiocarpa*) forest (6%) interspersed with patches of subalpine meadow (2.7%) and occasional patches of open lodgepole pine (*Pinus contorta*) forest (1.5%). Subalpine meadows support diverse forbs and wildflowers (e.g. fleabane [*Erigeron spp*.], beardtongues [*Penstemon spp*.], lupines [*Lupinus spp*.], goldenrods [*Solidago spp*.], and mule's ears [*Wyethia spp*.]) among a grassland matrix of tufted hairgrass (*Deschampsia caespitosa*) and prairie Junegrass (*Koeleria macrantha*). At wet sites (0.6%), subalpine meadows include a variety of sedges (*Carex spp.*) and American globemallow (*Sphaeralcea coccinea*) along with other forbs listed above. Exposed high elevation ridgelines support limber-bristlecone pine (*Pinus flexilis-Pinus longaeva*) woodland (0.9%). Riparian woodland (1.6%) is found at all elevations and commonly includes boxelder maple (*Acer negundo*), Rocky Mountain maple (*Acer glabrum*), gray alder (*Alnus incana*), willows (*Salix spp.*), cottonwoods (*Populus spp.*), birches (*Betula spp.*), and red-osier dogwood (*Cornus sericea*). Cliff and canyon supports little vegetation and covers 4.5% of the study area. Invasive grassland (primarily cheatgrass [*Bromus tectorum*] and crested wheatgrass [*Agropyron cristatum*]) covers 1.5% of the study area.

The Bear River Range represents a large tract of wildland with minimal human impacts. Anthropogenic land cover, including development and agriculture, accounts for less than 1.5% of the total area. The only paved roads are two highways that cross the study area and three short Forest Service roads. Thirteen of the 23 unpaved Forest Service roads close from December through March. The remaining Forest Service roads, though open through the winter, are mostly limited to snowmobiles. The primary human impact in the area is heavy recreation, though most activity is limited to designated routes such as popular hiking trails, well-established roads, and the local ski resort. As such, local wildlife is left relatively undisturbed during part of the year. Furthermore, the Bear River Range is recognized as a regional wildlife corridor by The Wildlands Network (2018), connecting the Greater Yellowstone Ecosystem to the Uinta Wilderness and southern Rocky Mountains. The large tract of habitat here provides a passageway for wide-ranging wildlife, especially ungulates, carnivores, and migratory species, to traverse an otherwise human-dominated landscape. The result is enhanced genetic connectivity between populations and potential recolonization of historic range by extirpated species. For example, gray wolves (*Canis lupus*), wolverines (*Gulo gulo*), Canadian lynx (*Lynx canadensis*), grizzly bears (*Ursus arctos*), and bighorn sheep (*Ovis canadensis*) historically occurred in Utah (Armstrong 1977). In recent decades, gray wolves, wolverines, and Canadian lynx have been recorded moving through the Bear River Range, sometimes hundreds of miles from the nearest known population (e.g., Switalski et aal. 2002; UDWR 2016). The wildlife community includes megafauna such as cougars, black bears (*Ursus americanus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), moose (*Alces alces*), beavers (*Castor canadensis*), and mountain goats (*Oreamnus americanus*). The Bear River Range was chosen as a study area because it represents prime cougar habitat (based on ungulate availability and stalking cover (D. Stoner, pers. comm., Utah State University), and the distribution and status of this cougar population is unknown.

Survey methods

A 3-by-4 grid of 8-by-8 km cells delineates the twelve sampling units used to systematically survey for cougars throughout the study area (**Figure 2**). A Utah female cougar has a home range somewhere between 60 km^2 and 100 km^2 (Stoner et al. 2006; Logan and Sweanor 2010), thus each sample unit covers an area roughly the size of an average home range for the target species as suggested in Long et al. (2008). I targeted females for two reasons: First, females represent the breeding potential of the population, and as such are the focus of management to direct population growth (Logan and Sweanor 2010). Second, detection rates for females will likely be higher than those for males for two reasons: Female cougars tend to hold smaller home ranges compared to male cougars and female home ranges tend to exhibit more overlap than males (Logan and Sweanor 2010), therefore there are typically more females in the population. Corresponding with Moruzzi et al.'s (2002) recommendation for an exhaustive inventory of species present, a minimum four-week survey period was defined for camera-trap surveys. For each survey period, one grid unit was randomly selected for active monitoring. Neither units surveyed in the previous twelve months nor units adjacent to those surveyed in the previous three months were considered in the random sample.

Precise occupancy estimates require replication such that effects of detection probability may be parsed from species occupancy (MacKenzie et al. 2006). The standard method for achieving replication is by surveying all sites multiple times within the same survey season. A survey season represents a period of demographic closure, with 3 months meeting this assumption for a large, slow-to-mature mammal like the cougar (Karanth and Nichols 1998; Kays and Slauson 2008). Due to logistical constraints, I used spatial subsampling instead (Karanth et al. 2011). Hines et al. (2010) suggest that spatial subsampling is biased due to lack of independence between spatial subsamples, but their analysis was based on transect sampling. In contrast, surveying evenly spaced subunits functions on the premise of randomly encountering an animal within a portion of their home range. This probability should be equivalent between subunits, given equal survey effort and habitat preference – both of which can be incorporated into an occupancy model as covariates. Sample units selected for monitoring were evenly divided into nine subunits via a 3-by-3 grid with 2.67-km side length. Subunits were then surveyed independently and concurrently for cougar presence using two survey methods: camera-traps and natural sign. Camera-trap surveys served as the test method, while natural sign surveys served as a baseline traditional method for comparison. Volunteers assisted with all surveys.

Camera-trap surveys consist of stationing motion- and heat-activated trail cameras at the center of each subunit at the start of the survey period, then retrieving the cameras after all nine had been concurrently active for a minimum of 30 days. Individual camera stations were installed within a 250-meter buffer around the corresponding subunit's center point (**Figure 2**). This buffer enabled flexibility in camera placement such that the probability of detecting a cougar could be maximized based on available knowledge of the species' movements and behavior (see Beier et al. 1995; Laundré and Hernández 2003; Hornocker and Negri 2010). Compared to the individual range and daily movements of these animals, 250 meters is an insignificant distance and, given the goal of detecting a cougar if present anywhere within the subunit, should not bias results. Further, flexibility of survey station placement is standard practice in noninvasive surveys for large carnivores (Kelly et al. 2012; Chandler and Clark 2014) and is arguably necessary due to the elusiveness of the target species. In effect, camera stations were generally placed along the heaviest used game trail near tree cover and rough terrain (i.e., steep with topographic cover).

An aluminum pie tin was hung directly above and in front of each camera to serve as a close-range lure. As visual predators, cougars are likely to investigate such an object, thereby encouraging animals to pass in front of the camera and increasing the likelihood of detecting an animal within eyesight of the camera station (D. Stoner, Utah State University, pers. comm.; E. Gese, Utah State University, pers. comm.). See **Figure 3** for appearance of a typical camera station setup. Small-scale habitat characteristics (e.g., dominant vegetation, slope, aspect, overstory cover, etc.) were recorded at camera stations and natural sign detection points to account for potential variation in detectability between camera stations and sample units, as suggested by Long and Zielinski (2010). Upon completion of a survey, photos were stored by camera station, surveyed dates, and species and all camera-traps were relocated to the next randomly selected sample unit.

Natural sign surveys were conducted concurrently and spatially coincident with camera-trap surveys, though opportunistically encountered sign in unmonitored units was also recorded. Natural sign surveys involved hiking trails (human or animal) throughout each sample

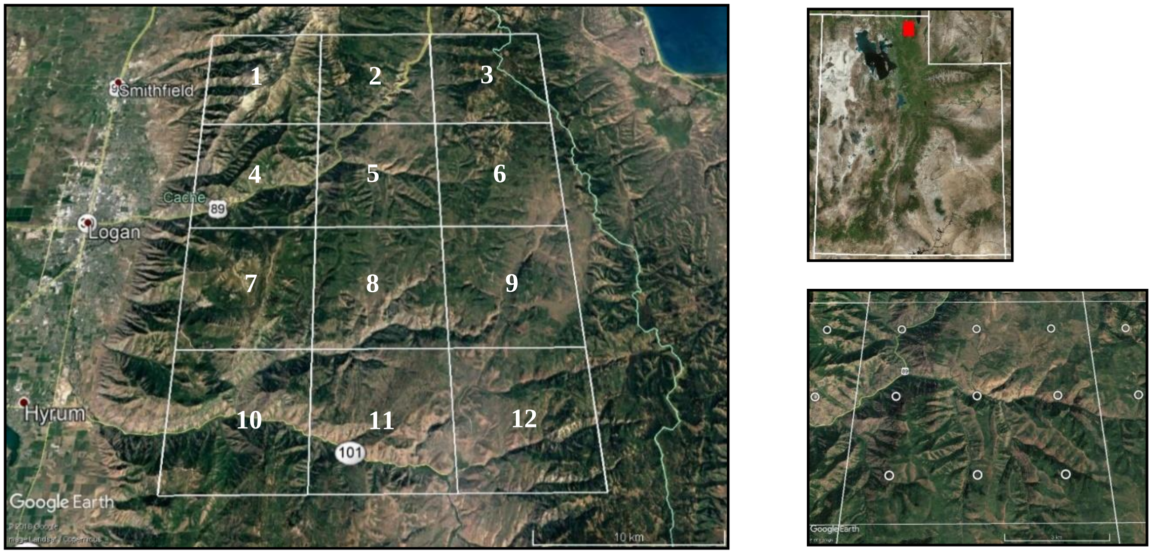


Figure 2. Numbered sampling units (left), study area extent (top right), and example of buffers camera station placement within a unit (bottom right).

Figure 3. *A typical camera station with camera and pie tin set up along a game trail. This site yielded 2 cougar detections.*

unit actively searching for cougar sign such as tracks, territorial scrapes, scats, and/or evidence of cougar predation events. Preference was given to areas recognized as traditional cougar habitat – rough terrain with vegetative and/or topographic cover and heavy mule deer and elk sign (Reith 2010) – and preferred cougar travel routes – ridges, drainages, and lightly traveled roads and trails (i.e., "the path of least resistance"; Dickson et al. 2005; Harmsen et al. 2010). To confirm identity, every track or other sign suspected to belong to cougars was GPS-marked, photographed, and measured. Other identifiable wildlife sign encountered during surveys was also noted by species and general location. Survey effort was measured by estimating the distance spent actively searching for natural sign (as in Russell et al. 2012). An extra camera was held in reserve for placement at sites that could potentially be revisited by the target species (such as carcasses, territorial scrapes, or well-used trails) to confirm recent presence and record behavior.

For camera-trap surveys, I defined a detection as a photograph or set of photographs in which the target species was identified (**Figure 4**). Sets of photos start when the animal enters the camera field of view and end when the animal exits the camera field of view. Sets of photos of cougars were not considered different detections if separated by less than one minute (based on the camera time-stamp). For natural sign, a detection represented any instance in which a track, scat, or other animal sign was confidently assigned to the target species, either in-person or via photographs taken by volunteers with location and scale attached (**Figure 4**). Smallwood and Fitzhugh (1989) was sometimes referenced for confirming identity of cougar tracks vs. canine tracks. Tracks were not counted as a natural sign detection if any ambiguity existed due to key feature discrepancies, poor track quality, or incomplete knowledge (e.g., size).

Occupancy modeling

Efficacy of survey methods was compared primarily by detection probabilities estimated from occupancy modeling. Detection probability (p or P[]) is used in an occupancy model to correct for false absences, thereby bringing the estimated occupancy value (*Psi* or ψ) closer to the true value (MacKenzie et al. 2002, 2006). Detection probability represents the likelihood of recording species presence in a survey area given true presence. Therefore, a higher detection probability estimate would indicate a better method for surveying the target species than lower detection probability estimates. Detection histories of presence-absence records for each survey method at each spatial scale (i.e., subunit [n=28] and unit [n=5]) were constructed for input into the occupancy model

Photo by Daniel Johnson

Figure 4. *Examples of a camera-trap detection (left) and three separate natural sign detections in varying substrates (right).*

analysis (see MacKenzie et al. 2006, p. 85). Presence-absence observations were pooled into one survey period to avoid problems with data sparseness caused by lack of overlapping survey periods between sample units. Occupancy modeling served three purposes: 1) comparison of survey methods, 2) explanation of differences in detection probabilities, and 3) measure cougar population status in the Bear River Range using repeatable standardized methods. To address the first two purposes, different model types and covariates were run for each spatial scale so that effects of survey method could be parsed from other factors.

Three occupancy model types were used: simple single-season occupancy (MacKenzie et al. 2002), multimethod occupancy with temporal replication (Nichols et al. 2008), and multimethod occupancy (Nichols et al. 2008) with spatial replication (Hines et al. 2010). The latter was run only at the unit resolution, since subunits in this case represented the spatial replicates, or "repeated surveys". The simple single-season model, excluding covariates, estimates occupancy and detection probability based on a single presence-absence observation for each site-survey combination. Therefore, this model type was used separately on detection histories for camera-traps, natural sign, and on detection histories which pooled observations across methods. In contrast, a site-survey record in the multimethod occupancy model includes a presence-absence observation for each survey method. This allows the multimethod model to concurrently estimate separate detection probabilities for each survey method. With multiple surveys in the data, the multimethod model also estimates θ, which is the probability that the target species is available for detection by the survey methods during each survey.

Sampling covariates included in the occupancy analysis were season (spring [Mar-May], summer [Jun-Aug], fall [Sept-Nov], winter [Dec-Feb]) and effort (trap-nights for camera-trap surveys and distance surveyed in kilometers for natural sign surveys). If the sampling timeframe for a subunit did not fall fully into a season, the site was assigned to the season in which most sampling occurred. Each season was denoted as a binary "dummy" variable, whereas survey effort was denoted as a continuous variable. All covariates were considered sampling covariates which pertain to a sampling event (as opposed to site covariates which pertain to a locality where sampling occurred) and were included as multiplicative parameters on detection probability. In multimethod models, covariates were represented by two parameters: one multiplicative on each method-specific detection probability, P[cams] and P[tracks]. Covariate combinations included all seasons plus effort (the global model), three seasons (excluding summer) plus effort, effort, all seasons, three seasons, and none. Summer was excluded due to only three sites being sampled in that season- about half as many as other seasons– which likely prevents accurate estimates.

In addition to models run on the full study area, occupancy models were run on each unit surveyed to compare habitat use in different areas of the study area. Presence-absence was recorded within subunits during 30-day survey periods. The number of survey periods used for each unit was that which minimized AIC for a simple single-season model with no covariates. Five simple single-season models were run on each unit: using the camera-trap detection history with effort (trap-nights) as a covariate, natural sign detection history with effort (distance surveyed) as a covariate, camera-trap detection history with no covariates, natural sign detection history with no covariates, and a pooled (camera-trap + natural sign) detection history with no covariates. Multimethod models were not used on each unit because of small sample sizes, which prevent accurate estimates for the additional p and θ parameters. Season was also excluded from these models because individual units were mostly surveyed within the same season. In total, 60 occupancy models were run for the analysis using PRESENCE software version 12.7 (Hines 2006). A summary of the data used, model type, methods included, and covariate combinations for each model set can be found in **Table 1**.

Model synthesis

Model fit was assessed on the global model (i.e., the model with the most parameters; Burnham and Anderson 2002) by a chi-squared statistic and model dispersion by $\hat{c}$ (chi-squared test statistic ÷ average chi-squared test statistic based on 1000 bootstrap estimates), as recommended by MacKenzie and Bailey (2004). Any models with convergence less than two significant digits or a chi-squared p-value less than or equal to 0.10 were discarded. Model selection within each set employed corrected Akaike's Information Criterion (AICc) when $\hat{c}$ was less than 1 (indicating underdispersion), and quasi-likelihood AICc (QAICc) when $\hat{c}$ was between 1 and 4 (indicating slight overdispersion). AICc and QAICc were used as opposed to simpler uncorrected information criterion because sample sizes were small (< 40) and the number of parameters (K) relatively large (Burnham and Anderson 2002). Only results from the top models were used to estimate cougar

Table 1. *Model sets include all models run on the same data. Data is characterized by spatial resolution and extent, survey method(s), number of sites, and number of surveys included. Different covariate combinations were run on each model set.*

Set	Spatial resolution/extent	Method(s)	Sites × Surveys	Model type	Covariate combinations run
1	All subunits	CT & NS	28 × 1	Multimethod	seas + eff, 3seas + eff, seas, 3seas, eff, none
2	All subunits	CT	28 × 1	Simple	seas + eff, 3seas + eff, seas, 3seas, eff, none
3	All subunits	NS	28 × 1	Simple	seas + eff, 3seas + eff, seas, 3seas, eff, none
4	All units	CT & NS	5 × 1	Multimethod	seas + eff, 3seas + eff, seas, 3seas, eff, none
5	All units	NS	5 × 1	Simple	seas + eff, 3seas + eff, seas, 3seas, eff, none
6	Unit 9	CT, NS, P	7 × 1,2*	Simple	eff, none
7	Unit 7	CT, NS, P	3 × 2,3*	Simple	eff, none
8	Unit 5	CT, NS, P	6 × 2,3*	Simple	eff, none
9	Unit 4	CT, NS, P	6 × 2,3*	Simple	eff, none
10	Unit 3	CT, NS, P	6 × 1	Simple	eff, none
11	All units	CT, NS, P	5 × 7**	Multimethod w/ spatial replication	eff, seas, none

CT = camera-trap, NS = natural sign, seas = all seasons, 3seas = seasons except summer, eff = effort, none = no covariates

*** Number of surveys different between models due to missing observations at beginning/ending surveys. Models run with more surveys only if AIC values lower than same model with fewer surveys.**

**** "Surveys" in this case represent spatial replication, rather than a traditional repeated temporal survey at a site.**

occupancy and habitat use within the study area and compare detection probabilities between methods.

Converged models with acceptable fit were used to compare detection probabilities between survey methods. Any detection probabilities equal to 0 or 1 were excluded from the comparisons since these boundary estimates indicate a lack of convergence (Welsh et al. 2013). PRESENCE 12.7 calculates detection probability estimates for each site-survey combination based on model parameters. For each model, mean site-specific detection probabilities were calculated separately for each method and these means were used in comparisons. This value was used rather than the raw detection probability estimates because the site-specific values account for covariates with effects on *p*. The mean of the site-specific detection probabilities thus represents the average *functional detection probability* given field conditions, rather than a parameter estimate which means nothing in practice.

The primary comparison made was difference between paired estimates of camera-trap and natural sign functional detection probabilities. For multimethod models, method-specific functional detection probabilities calculated from the same multimethod model were paired. For simple single-season models, models run on the same sites with equivalent parametrization, which differ only in the survey method used, were paired. To analyze method-specific seasonal effects, functional detection probabilities were compared in season-method combinations. To investigate effects of survey effort on detection probability of each method, linear regression models were fit between site-specific detection probabilities and survey effort using estimates from each model including effort as a covariate. The slope of the regression equations represents the per-unit effect of survey effort on estimated detection probability. Trends in effects of survey effort were then summarized.

Habitat preference

Detection locations from part 1 and part 2 of the project were compared with available or unused locations in the study area to determine whether cougar detections were associated with certain habitat characteristics. Small-scale habitat preference was based on field-collected habitat data at camera stations and natural sign detection locations. Descriptions of seven habitat variables were considered: habitat type, overstory cover, aspect, topography, human access, and human activity levels. These habitat variables were divided into 36 total habitat descriptions. Habitat type descriptions included aspen forest, aspen-mixed conifer forest, bigtooth maple ravine woodland, cliffside, Douglas fir forest, Douglas fir-juniper forest, juniper woodland, mountain mahogany woodland, mountain mahogany-Douglas fir forest, riparian woodland, sagebrush steppe, and subalpine forest. See study area in methods for details on these habitat type descriptions. Overstory cover descriptions included dense (>50% overstory cover), moderate (25-50%), and open (0-25%). Aspect descriptions included north-, east-, south-, and west-facing. Topography descriptions included flat, moderate slope, rugged moderate slope, steep slope, rugged steep slope, drainage bottom, and ridge. “Rugged” in this case refers to topographic or terrain roughness, a measure of the amount of variability in slope, aspect, and overall shape of the Earth’s surface in the given area. Human access descriptions included on road, on off-highway vehicle (OHV) road, on hiking trail, near (within 200 meters of) road, near OHV road, near hiking trail, and none – meaning that all roads and trails were more than 200 meters (and in most cases farther) from the location. Human activity level descriptions included heavy (> 15 people), light (1-5 people), and none (0 people). For each habitat variable, a count of each description was taken within used (detection locations) and unused (camera stations with no cougar detections) habitat categories. A habitat preference index (HPI, see "selection ratio" in Manly et al. 2004) was then calculated by dividing the used count by the unused count for each habitat description.

A Python GIS module was also developed to compare large-scale habitat use with available habitat. Spatial covariates (i.e., habitat variables) were collected by extracting data from GIS layers including a 10-meter USGS Digital Elevation Model (DEM; Utah AGRC), the SWReGAP landcover model (Lowry et al. 2005), aspect layer (derived from DEM), and slope layer (derived from DEM). Used habitat was represented by areas within a 500-meter radius of detection coordinates and available habitat was represented by areas within 500 meters of randomly selected coordinates throughout the study area. Pixel counts for each habitat level within a spatial covariate were calculated for each buffered set of coordinates and then summed across habitat levels within used and available categories. A chi-squared test of independence was conducted to determine whether counts for habitat levels differed significantly between expected (available) and observed (use) categories.

RESULTS

Survey effort

A survey effort of one unit per month with nine camera stations in each unit proved logistically unattainable. Instead, survey periods for individual sample units ranged from 5–11 weeks and survey effort was decreased to 3–7 cameras stations per unit. Initial monitoring throughout the study area was prioritized over resampling units, compromising occupancy model estimates due to lack of temporal replication. As of February 2018, 28 subunits within five units ($\bar{X}$ = 5.6 subunits per unit, SD = 1.5) were actively surveyed by a total of 29 camera stations, resulting in a surveyed area of about 190 km^2 (**Figure 5**). A mean of 6.0 cameras per unit (SD = 1.9) were active for 1118 total trap-nights. Mean camera-trap survey effort was 224 active trap-nights (SD = 56, minimum 178) per unit and 40 trap-nights (SD = 21) per subunit. More than 260 km were covered during natural sign surveys with a mean of 55.9 (SD = 29.1) km per unit and 8.5 (SD = 7.3) km per subunit (**Figure 5**).

Detections

Cougars were detected at eleven subunits, with camera-trap detections at seven subunits and natural sign detections at six subunits. Only two subunits had detections from both methods. Camera-traps yielded twelve total detections at seven camera-trap stations, with five of these

Table 2. *Survey effort by season. Mean values are per subunit. Only detections and surveys within the study area are included.*

	Natural Sign			**Camera-Traps**			
Season	**Σ Distance Surveyed (km)**	**X̄ Distance Surveyed**	**Number Detections**	**Σ Trap-Nights**	**Σ Number Cameras**	**X̄ Trap-Nights**	**Number Detections**
Fall	130	10.0	3	347	13	27	5
Spring	32	5.3	5	319	7	53	4
Summer	21	7.1	0	178	3	59	1
Winter	73	9.1	1	274	6	46	2
Total	256	8.5	9	1118	29	40	12

detections at unit nine subunit seven, including one detection of an adult cougar with a kitten. Ten camera-traps detections (83%) occurred at stations where pie-tins were placed as visual lures. Natural sign surveys yielded nine total detections at eight locations within the study area, with two additional detections outside of the study area (**Figure 6**). Four of these natural sign detections occurred in unit five, subunit seven in the Card Canyon area. Detections by camera-trap occurred within five units and by natural sign within four units. Within actively monitored units, the mean detection rate among subunits (i.e., number of subunits with detections in unit *x* ÷ total number of subunits surveyed within unit *x*) was 26% for camera-trap surveys and 20% for natural sign surveys. Camera-traps yielded at least one detection in each unit whereas the number of detections per unit was highly skewed for natural sign surveys, ranging from zero to four. This led to a large difference in naïve occupancy between the two methods: 100% for camera-traps and 60% for natural sign surveys at the unit level. The difference in naïve occupancy was much smaller at the subunit level: 25% for camera-traps and 21% for natural sign. Considering detections pooled across methods, naïve occupancy was 100% per unit and 40% per subunit. Since subunits are smaller than an estimated home range, the latter value roughly corresponds to habitat use within a home range-sized area. Subunit naïve occupancy estimates are likely lower than true values due to recorded false-absences.

Non-target species detected by camera-traps included mule deer (81 detections), elk (34), snowshoe hare (*Lepus americanus*, 18), coyote (13), cottontail rabbits (*Sylvilagus spp*., 12), moose (6), red fox (3), striped skunk (3), northern flying squirrel (*Glaucomys sabrinus*, 3), raccoon (*Procyon lotor*, 1), mountain goat (*Oreamnus americanus*, 1), mink (*Neovison vison*, 1), long-tailed weasel (*Mustela frenata*, 1), human, domestic dog (*Canis domesticus*), cattle (*Bos taurus*), domestic sheep, squirrels, and miscellaneous bird species. Additional species detected during natural sign surveys included deer (most likely mule deer, though few whitetail deer are present in the study area), elk, moose, weasel (with both long-tailed and short-tailed [*Mustela erminea*] present in study area), coyote, red fox, bobcat, American marten (*Martes americana*), snowshoe hare, squirrels, domestic dog, domestic cat (*Felis silvestris*), North American porcupine (*Erethizon dorsatum*), cottontail rabbit, raccoon, and human.

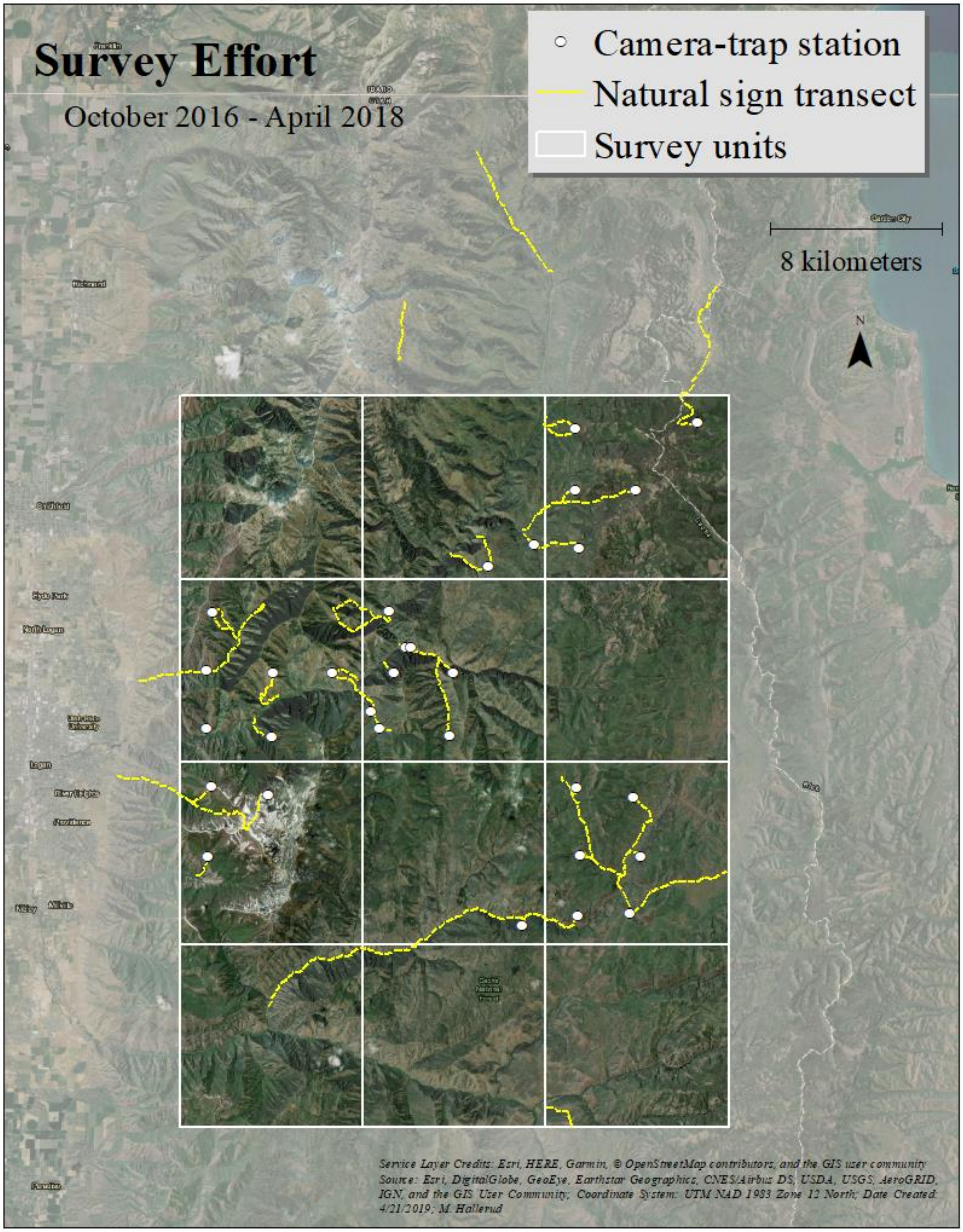


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Figure 5. *Spatial survey effort October 2016 to April 2018.*

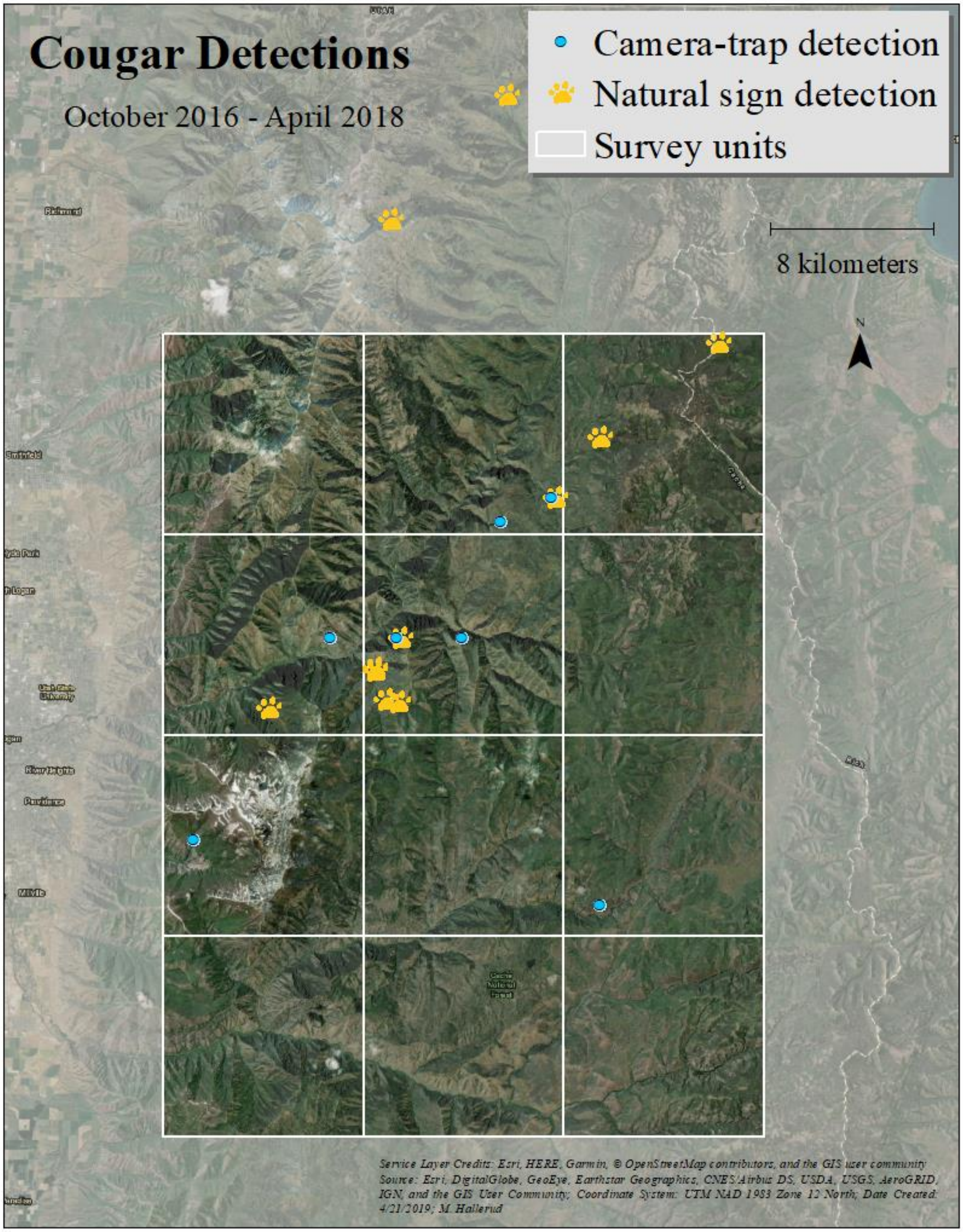

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Figure 6. *Locations of all cougar detections within the study area*

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Table 3. *Results from top occupancy models within each model set based on AICc. The next best model in a set was also included if ΔAICc < 2. Models with p-value < 0.10, model convergence < 2 significant digits, and boundary estimates (i.e., 0 or 1) were excluded. See* ***Table 1*** *for a description of the data used and covariate combinations run in each model set.*

Model Description				**Assessing Fit**			**Parameter Estimates**		
Set	**Model Type**	**Extent**	**Covariates**	**ΔAICc**	**P-value**	**$\hat{C}$**	**ψ (95% C.I.)**	**P[CT]**	**P[NS]**
1	Multimethod	Subunits	Effort	0.000	0.271	1.223	0.502 (0.275–0.728)	0.563**	0.510**
	Multimethod	Subunits	-	1.210	0.738	<0.001	0.750 (0.056–0.993)	0.333	0.286
2	Simple (CT)	Subunits	Effort	0.000	0.780	-0.139	0.333 (0.119–0.648)	0.769**	-
3	Simple (NS)	Subunits	Effort	0.000	0.662	<0.001	0.552 (0.052–0.965)	-	0.389**
	Simple (NS)	Subunits	-	0.150	0.677	-1.217	0.463 (0.000–1.000)	-	0.463
4	Multimethod	Units	None	0.000***	0.496	0.933	1.000 (0.000–1.000)*	1.000*	0.600
5	Simple (NS)	Units	4 Seasons	0.000	0.999	2.070	1.000 (0.000–1.000)*	-	0.600**
6	Simple (CT)	Unit 9	Effort	0.000	0.653	0.312	0.143 (0.018–0.581)	1.000*	-
7	Simple (P)	Unit 7	-	0.000***	0.647	0.745	1.000 (-Inf – Inf)*	0.167	-
8	Simple (NS)	Unit 5	Effort	0.000***	0.209	1.470	0.707 (0.027–0.995)	-	0.325**
	Simple (NS)	Unit 5	-	0.928***	0.3297	1.253	1.000 (0.000–1.000)*	-	0.182
9	Simple (CT)	Unit 4	Effort	0.000***	0.266	1.346	0.391 (0.014–0.966)	0.234**	-
	Simple (CT)	Unit 4	-	0.943***	0.524	1.220	1.000 (0.000–1.000)*	0.067	-
10	Simple (CT)	Unit 3	Effort	0.000	0.370	<0.001	0.500 (0.168–0.832)	1.000*	-
	Simple (P)	Unit 3	-	0.000	0.5794	<0.001	0.707 (0.000–1.000)	0.7071	-
11	Multimethod with spatial replication	Units	-	0.000	0.982	<0.001	1.000 (0.000–1.000)* θ = 0.750 (0.056–0.99)	0.333	0.286

CT = camera-trapping, NS = natural sign, P = pooled

*** Boundary estimate.**

**** Mean of site estimates.**

***** ΔQAICc.**

Model synthesis

Of the 60 occupancy models run, three were discarded for p-values > 0.10, three for model convergence to less than 2.0 significant digits, and six for meaningless estimates. Of the remaining 48 models, the top model(s) (based on ΔAICc or ΔQAICc) from each model set are listed in

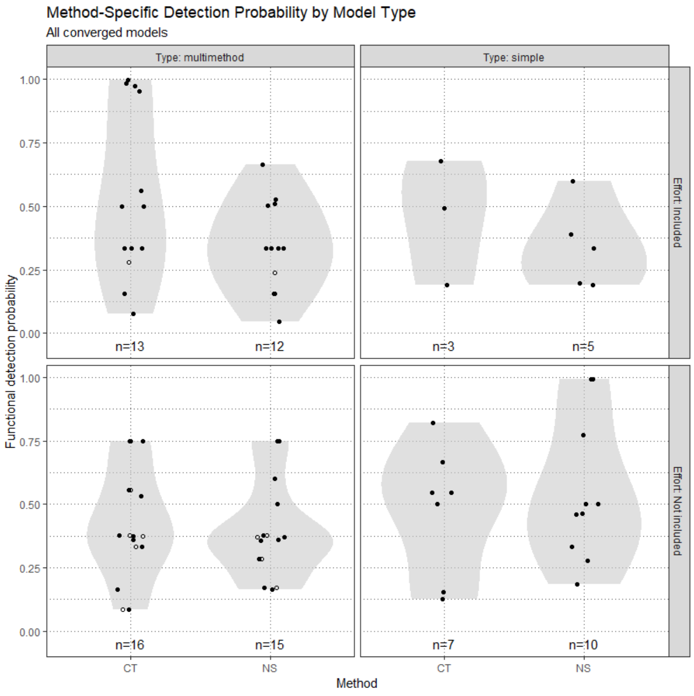

Figure 7. *Each point represents the functional detection probability from a single model. Models are grouped by survey method (bottom axes [CT = camera-trap and NS = natural sign]), model type (labels on top [white dots represent multimethod with spatial replication]), and whether effort was included as a covariate (labels on right). The light gray area represents the estimated probability distribution of the functional detection probabilities within each group.*

Table 3. Frequently encountered issues in the occupancy analysis included lack of power for parsing occupancy and detection probability estimates, extremely low ĉ indicating underdispersion, boundary estimates of ψ and *p*, instability of model estimates as seen by comparing parameter estimates with bootstrapped (n = 1000) estimates, and inconsistent results among parametrizations run on the same data. To demonstrate the pervasiveness of these issues, ~46% of the models had ĉ < 0.05. Only ~27% had a ĉ value between 1.0 and 2.0, the values generally deemed acceptable without correction. In addition, 16 models (~33%) included in the analysis had boundary estimates for occupancy (ψ) and 9 models (~19%) had boundary estimates for detection probability. Boundary estimates were more common for occupancy models run on the subunits within a single unit than for models run on the full study area. Large ranges in functional detection probability (the mean of site-specific detection probabilities by survey method for each model) across all model groups indicate consistent unreliability of detection probability estimates (**Figure 7**) and suggests that variability in estimates cannot be accounted for by bias introduced from model type or from including a continuous covariate, effort.

For these reasons, I compared overall trends in model results rather than parameter estimates from individual models. Of the 30 available model pairs, differences in functional detection probabilities between methods could be calculated for 18. Of these pairs, camera-trap detection probability was greater for 14, natural sign greater for 2, and 2 were equal between methods. At the subunit level (including differences from multimethod, simple single-season, and multimethod with spatial replication models), camera-trap functional detection probability was greater for 10 of the 11 pairs. Differences between functional detection probabilities were consistent among these pairs, with a mean of 0.042 and range from 0.037 to 0.053. At the unit level, camera-trap functional detection probability was greater for three of the five pairs and equal for the other two pairs. The mean difference at the unit level was greater for camera-traps by 0.184. The remaining two pairs were from models of unit four and gave conflicting results which are likely a reflection of sparse data. At both spatial scales, model pairs favoring natural sign or neither method included seasons as covariates.

Comparing functional detection probabilities by season, spring and winter were generally higher and fall lowest, with summer generally having values between those groups. Significantly lower detection probabilities for fall may be accounted for by lower mean camera-trap survey effort per subunit, though mean natural sign survey effort was higher (**Table 2**). Camera-trap functional detection probability was noticeably greater during spring and summer and natural sign greater during fall and winter, though there was a high degree of overlap between camera-trap and natural sign functional detection probabilities during fall and winter especially (**Figure 8**).

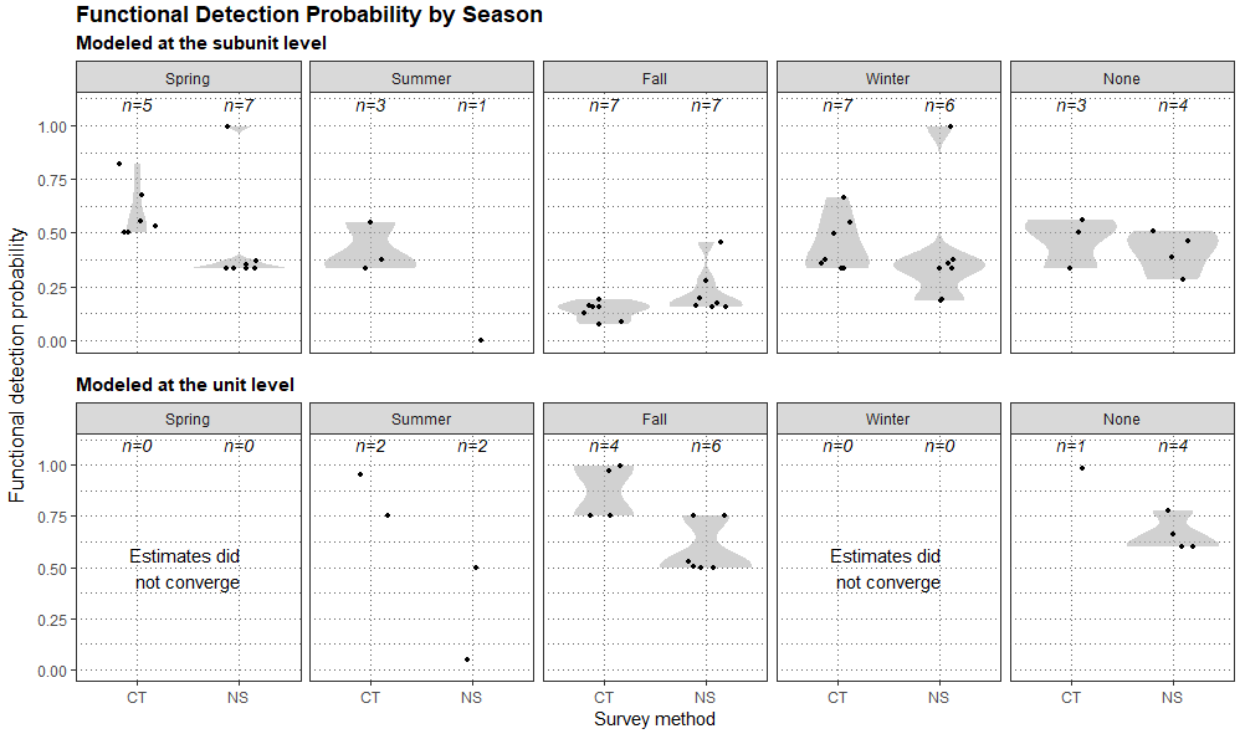

Figure 8. *Each point represents the functional detection probability from a single model. The light gray area represents the estimated probability distribution of the functional detection probabilities within each group of models. Models are grouped by season, spatial resolution, and survey method (CT = camera-trap, NS = natural sign).*

Functional detection probabilities were nearly equivalent across methods when season was not considered in the occupancy model.

Regression models of estimated detection probability against survey effort were only considered for occupancy models at the subunit scale to avoid overfitting data in models with a smaller sample size. Six regression equations were calculated for each method (**Table 4**). The range of slopes for natural sign equations was -0.0173 to 0.00158, indicating uncertainty in the direction of the relationship between survey effort and estimated detection probability. Mean slope was 0.00810 – detection probability is expected to decrease about 0.8% for each additional kilometer surveyed. R-squared values for the natural sign regression equations ranged from 0.039 to 1.0, suggesting a high degree of variability in the strength of the relationship between survey effort and detection probability. R-squared values were high (~0.99) when effort was the only covariate included in the occupancy model but very low (0.0039 to 0.11) when season was also included as a covariate on detection probability. Further, slope coefficients for natural sign survey effort were only significant ($p < 0.10$) when season was not included in the regression model. Both factors suggest that season has a much larger and more significant effect on detection probability than survey effort.

Slope values ranged from 0.00154 to 0.0161 for camera-trap regression equations, indicating a highly significant and consistently positive relationship between survey effort and estimated detection probability across models at the subunit level. The mean slope was 0.00813 – that is, on average, increasing survey effort by one trap-night increases estimated detection

Table 4. *Regression model results for site-specific detection probability vs. survey effort with data from 6 occupancy models per survey method.*

Occupancy Model	**Natural Sign**					**Camera-Traps**				
	Slope	**P-value**	**Intercept**	**P-value**	**Adj. R^2**	**Slope**	**P-value**	**Intercept**	**P-value**	**Adj. R^2**
M + e w/ SR	-0.0105	<0.001	0.305	<0.001	0.99	0.00867	<0.001	-0.0676	<0.001	0.97
M + s + e	-0.0105	0.15	0.278	<0.001	0.045	0.00792	<0.001	-0.0661	0.14	0.72
M + e	0.00158	<0.001	0.500	<0.001	1	0.00154	<0.001	0.501	<0.001	0.99
M + s + e	-0.0100	0.1	0.302	<0.001	0.075	0.00962	<0.001	-0.082	0.002	0.93
S + s + e	-0.00189	0.77	0.240	<0.001	-0.039	0.0161	<0.001	-0.093	0.42	0.60
S + e	-0.0173	<0.001	0.497	<0.001	0.99	0.00491	<0.001	0.573	<0.001	0.94

M = multimethod

S = simple single-season

SR = spatial replication

+ s = seasons included

+ e = effort included

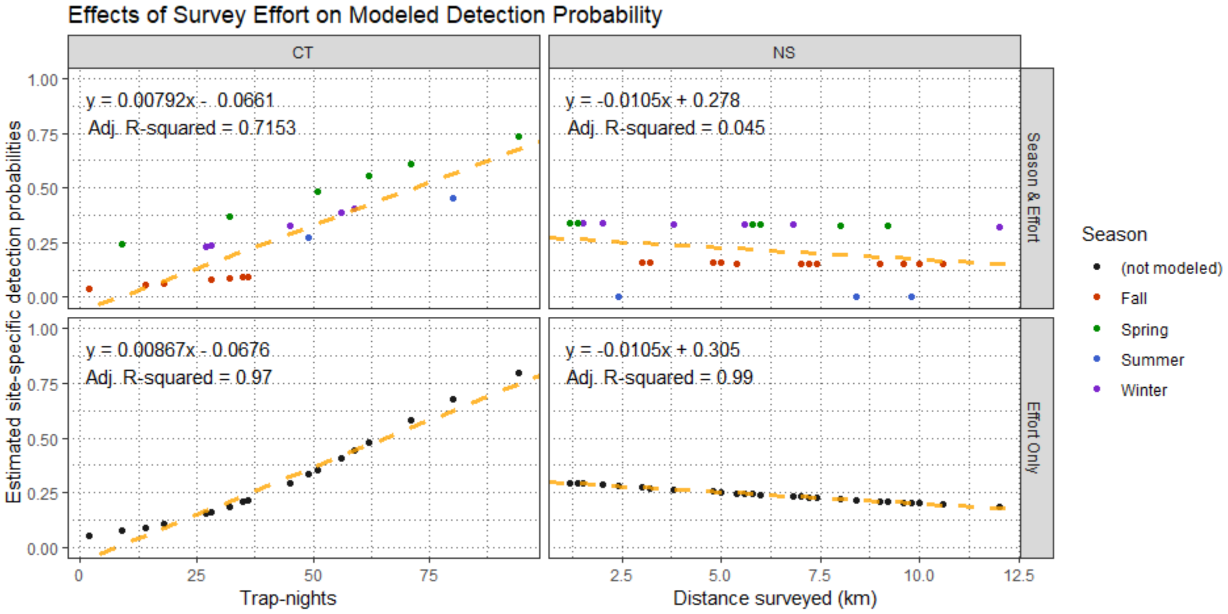

Figure 9. *Estimated site-specific detection probabilities vs. survey effort (trap-nights for camera-traps and distance surveyed for natural sign), with regression lines in yellow. Upper plots are derived from a multimethod occupancy model run at the subunit level with season and effort as covariates on detection probability. Lower plots are derived from a simple single-season model run on the subunit data for each method with effort as the only covariate with detection probability.*

probability by about 0.8%. The magnitude of these slope values is comparable to those of natural sign, however the number of trap-nights are an order of magnitude larger than distance surveyed in practice and thus survey effort accounts for a much greater amount of variation in camera-trap detection probability (**Figure 9**). Further, camera-trap survey effort coefficients were all highly significant ($p < 0.0001$) and adjusted R-squared values for the camera-trap regression equations were high (i.e., > 0.60), indicating a significant and strong relationship between survey effort and detection probability even when other covariates on detection probability (i.e., seasons) were included in occupancy models. Examples of regression models for each survey method are shown in **Figure 9**.

Habitat preference

Small-scale habitat preference calculations included 16 locations in the used category and 19 locations in the unused category. Counts and HPI (habitat preference index) values are shown in **Table 5**. An HPI value greater than 1 suggests preference, whereas a value less than 1 suggests avoidance (Manly et al. 2004). The highest small-scale preference values were associated with riparian woodland, subalpine forest, Douglas fir-juniper forest, sagebrush steppe, OHV road nearby, and roads. Cougars were detected during every sampling instance of these habitat types. Moderate small-scale preference values were associated with (listed from highest to lowest HPI): drainage bottoms, steep slopes, juniper woodland, bigtooth maple ravine woodland, hiking trails, flat slopes with no aspect, and south-facing aspects. Moderate avoidance values were associated with (from lowest to highest HPI): west-facing aspects, Douglas fir forest, north-facing aspects, east-facing aspects, dense cover, and hiking trails nearby.

Each habitat category included only one or two sampling instances, therefore the above preference levels are likely overestimated due to low sample sizes. For example, the two available samples on roads resulted from natural sign detections on roads. If other roads were sampled, cougars would likely not be detected in a significant portion of the sample. The lowest preference values were associated with mahogany-Douglas fir forest, aspen forest, cliffside, OHV roads, rugged moderate slopes, and ridges. Cougars were never detected when sampling these habitats; however, these values might be underestimated due to small samples sizes as well.

For large-scale habitat preference, chi-squared tests for all four habitat variables were highly significant ($p < 0.01$), indicating that some level of habitat preference is present since cougars are not using habitat in proportion to its availability on the landscape. To determine which habitat types contributed to this result, t-tests were run to compare use-versus-availability within each level of the habitat variables. All p-values, HPI values, and pixel counts for each habitat level within used and available categories are shown in **Table 5**. Preference is supported with significantly greater use than availability of a given habitat level, whereas avoidance is supported with significantly lesser use than availability (Johnson 1980). There was very strong support ($p < 0.01$) for avoidance of east aspects (HPI = 0.35) and preference of coniferous forest cover (HPI = 3.37). This means that, relative to its availability on the landscape, cougars use east aspects 35% as much as they are available, and coniferous forests 337% as much as available. Strong avoidance of grassland cover (HPI = 0.03) was also supported ($p < 0.05$). Some support ($p < 0.10$) exists for avoidance of cliff and rock landcover (HPI = 0.15) and 15 to 30° slopes (HPI = 0.71).

Preference for aspen-mixed conifer forest, juniper woodland, steep slopes (45-60°), flat topography (0-15°), and south-facing slopes is consistent at both scales based on HPI. Avoided habitats shared across scales include aspen forest, cliff and rock, moderate slopes (15-30°), and east-facing aspects.

Table 5. *Small-scale and large-scale habitat analysis results, including counts for used, unused, and available habitat and habitat preference index (HPI) values for habitat types at each scale, plus p-values for t-tests comparing used and available habitat counts from the large-scale analysis. HPI > 1 suggests preference, whereas HPI < 1 suggests avoidance (Manly et al. 2004).*

Small-Scale Habitat

Habitat Description	Unused	Used	Available	HPI
Riparian	0	1	1	2.19*
Subalpine forest	0	2	2	2.19*
Douglas fir-juniper	0	2	2	2.19*
Sagebrush steppe	0	1	1	2.19*
Juniper	1	2	3	1.46
Bigtooth maple	1	2	3	1.46
Mountain mahogany	1	1	2	1.09
Aspen-mixed conifer	2	2	4	1.09
Douglas fir	9	3	12	0.55
Mahogany-Douglas fir	1	0	1	0.00
Aspen	3	0	3	0.00
Cliffside	1	0	1	0.00
OHV road within 150 m	0	1	1	2.19*
Road	0	2	2	2.19*
Hiking trail	2	4	6	1.46
Road within 150 m	2	2	4	1.09
None in >=200 m	11	6	17	0.77
Hiking trail within 150 m	2	1	3	0.73
OHV	2	0	2	0.00
Open cover	2	3	5	1.31
Moderate cover	7	8	15	1.17
Dense cover	10	5	15	0.73
Drainage bottom	1	3	4	1.64
Steep slope	1	3	4	1.64
Rugged steep slope	1	1	2	1.09
Flat	3	3	6	1.09
Moderate slope	10	6	16	0.82
Rugged moderate slope	1	0	1	0.00
Ridge	2	0	2	0.00
None/Unidentifiable	4	7	11	1.39
South-facing	3	5	8	1.37
East-facing	2	1	3	0.73
North-facing	6	2	8	0.55
West-facing	4	1	5	0.44
Heavy human activity	2	2	4	1.09
No human activity	8	7	15	1.02
Light human activity	7	4	11	0.80

Large-Scale Habitat

Habitat Level	Used	Available	P-value	HPI
Aspen-mixed conifer	30	1	0.13	30.00
Coniferous forest	1635	485	***<0.01***	3.37
Pinyon-juniper	509	169	0.16	3.01
Wet meadow	2	1	0.33	2.00
Developed	1	1	1.00	1.00
Agriculture	1	1	1.00	1.00
Mountain mahogany	149	160	0.93	0.93
Sagebrush steppe	1206	1396	0.65	0.86
Maple woodland	301	564	0.34	0.53
Aspen	296	660	0.32	0.45
Riparian	58	128	0.24	0.45
Cliff and rock	104	685	*0.09*	0.15
Grassland	1	37	***0.04***	0.03
Slope 45 - 60°	1775	926	0.28	1.92
Slope 0 - 15°	14160	11370	0.64	1.25
Slope 30 - 45°	17870	15190	0.55	1.18
Slope 15 - 30°	15170	21260	*0.075*	0.71
Slope 60 - 90°	138	363	0.43	0.38
North-facing	14340	9222	0.17	1.55
West-facing	16720	12870	0.41	1.30
South-facing	12690	12010	0.88	1.06
East-facing	5323	15020	***<0.01***	0.35
Elevation < 2000 m	28140	14011	0.12	2.01
2000 - 2500 m	15680	23610	0.35	0.66
Elevation > 2500 m	5300	11500	0.33	0.46
Elevation < 2000 m	28140	14011	0.12	2.01
2000 - 2500 m	15680	23610	0.35	0.66
Elevation > 2500 m	5300	11500	0.33	0.46

*** No “unused” habitat of this type observed so HPI is likely overestimated.**

DISCUSSION

Survey method comparison

Overall, camera-traps were slightly more effective at detecting cougars than natural sign surveys. At all stages of analysis, this difference amounted to about a 4-5% higher detection probability for a given site. The slightly higher overall detection probabilities for camera-trap surveys can be attributed primarily to significantly higher detection probabilities in spring and summer. The overriding effect of season on natural sign detection probability emphasizes this mechanism, with estimates nearly following a step pattern by season with winter and spring grouped together having the highest detection probabilities (**Figure 8**). The reasoning behind this is logical: tracks are nearly undetectable throughout summer and early fall, whereas snow cover in late fall, throughout winter, and through much of spring in the mountains makes tracks obvious to even inexperienced observers. Lack of seasonality makes camera-traps a more consistent survey method across space and time, though not necessarily always the most effective method. Detection probabilities could be further standardized by maintaining consistent survey effort since trap-nights had a direct positive correlation with camera-trap detection probability.

Considering both camera-traps and natural sign surveys, cougars were available for detection at a subunit for 75% of surveys (based on the top multimethod model). With the current survey design, however, measures of cougar photographic rates indicate that, if present, a cougar would likely be detected by camera-traps during the effective survey period for a unit. Camera-traps recorded 1.1 cougar detections per 100 trap-nights, with 3.6 detections per 100 trap-nights when cougars were confirmed to be present in the subunit. This suggests that any camera-trap would likely detect a cougar within 100 days (given presence), and camera stations placed where cougars frequent would have a 77% likelihood of detecting a cougar within 40 days. Latency to detection (i.e., time from camera deployment to cougar detection) was 20 days on average (SD = 18.9, range 5 – 51), indicating that most cougars are detected within 20 days of camera station placement. Latency between detections at camera stations where cougars were detected more than once were slightly longer at 11, 35, and 28 days ($\bar{X} \approx 25$ days). These latency to/between detection estimates correspond with known cougar behaviors such as preference for certain trails or paths across the landscape and repeated use of areas within a home range (Seidensticker et al. 1973). Given our average of 40 trap-nights active per camera station and our minimum of three cameras in a surveyed unit, our resulting minimum survey effort of 120 camera-trap nights would likely of yield at least one cougar detection. If a cougar was not detected within this timeframe, it may not frequent the particular camera location even if present in the immediate area.

More importantly perhaps, the analysis highlights the complementary relationship between the two survey methods. Survey methods recorded spatially unique detections in all but two instances. In both instances where camera-trap detections overlapped with natural sign detections, camera station placement was guided by natural sign observations. In some instances, camera stations were placed on observed cougar tracks with no resulting detections even when a cougar was known to have moved through the area by new natural sign observations. Thus, from an occupancy or spatial distribution standpoint, no additional data was collected by placing a camera

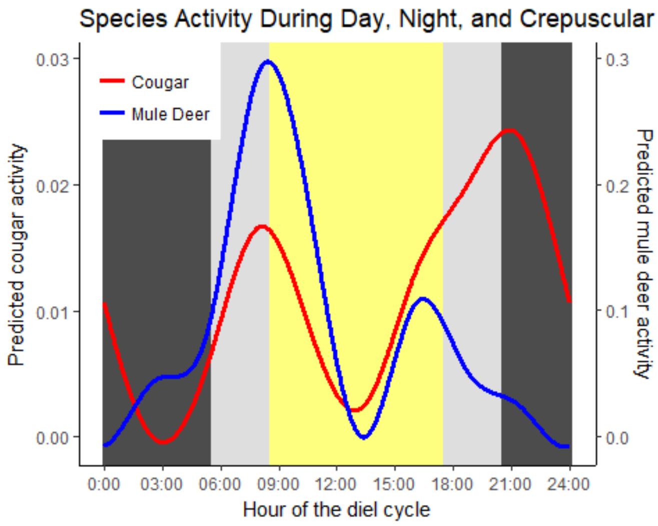

Figure 10. *Modeled cougar and mule deer diel activity based on temporal camera-trap data. Dark gray symbolizes nighttime hours, light gray crepuscular (dawn/dusk) hours, and yellow daytime hours. Note corresponding peaks and troughs between both species.*

in these locations. Likewise, camera-trap surveys are advantageous compared to natural sign surveys because they do not rely on substrate quality for data collection and therefore can yield detections when tracking would be practically impossible. The mutually supportive effect of these methods is most likely due to complementary spatiotemporal scales: camera-traps collect data at a very small spatial scale (i.e., the camera site) but longer temporal scales (e.g., often more than 30 days in this study), whereas natural sign surveys collect data at a larger spatial scale (e.g., multiple kilometer transects) but a shorter temporal scale (realistically, a few days due to degradation of track quality).

The methods also provide different supporting data. Camera-traps, for example, are capable of recording *when* exactly animals are moving via photo time-stamps, while tracks show *how* animals move across the landscape. Camera-traps in most instances give a more complete view of the wildlife community in a specific location, though some species were detected more often or only via natural sign surveys (e.g., weasels, marten). Combining high-resolution temporal data from cameras between species may inform complex issues such as trophic interactions (e.g., **Figure 10**). Camera-traps also provide specific information such as weather conditions, sunlight, snow levels, animal body condition, and age of animals (**Figure 11**, **Figure 13**). Often, natural sign observations initially detect a location used by cougars. Camera-trap placement at this location then enables collection of behavioral data detailing how and when this site is used – whether that be a human trail or a carcass – and how these behaviors compare to other species' use of that resource. Lastly, some evidence was collected on the effectiveness of hanging pie tins as a short-distance visual lure (**Figure 11**).

Population and wildlife community status

Assuming that unit size accurately represents a cougar home range, occupancy estimates of 1.00 indicate that cougars are "at capacity" within the Bear River Range. However, true occupancy is likely somewhat lower than the estimated 100% due to four factors. First, demographic closure was not achieved because data collection occurred over a period of more than three months, therefore any given unit could have been unoccupied during a portion of the study due to mortality, dispersal, migration between seasonal home ranges (Pierce et al. 1999), etc., without this absence

Figure 11. *Set of photos displaying a cougar's behavioral response to the pie tin (just beyond lower right corner of photo frame), suggesting effectiveness of the hanging pie tin as a short-distance visual lure.*

being recorded.

Second, unit size may not directly reflect home range size of cougars in the study area. High densities of prey populations in northern Utah likely lead to higher densities of cougars in the Bear River Range (Stoner et al. 2018), implying that each 64 km^2 unit may cover multiple home ranges- especially since females tend to overlap in their movements. This would lead to an overestimate of occupancy. For example, if each unit covered the size of two female home ranges but only one of these was occupied, the unit would be considered 100% occupied given a detection rather than the true occupancy level 50%.

Third, proximity of the units surveyed increases the likelihood of individual movement between units. Detections at two adjacent units, therefore, could be the cause of inter-unit movement of a single animal- a very likely possibility given the long-lived and highly mobile nature of the target species. In fact, the possibility exists (though highly unlikely) that all recorded activity in the study area was derived from a single wide-ranging individual due to the high level of uncertainty in identifying individual cougars in photographs (Alexander and Gese 2018).

Fourth, detection of dispersing animals is likely given the study area's functioning as a wildlife corridor connecting large tracts of cougar habitat. Dispersing animals should not be included in occupancy because they are traveling through the area rather than occupying it as a resident animal, yet these animals cannot be excluded from the data because dispersing individuals are impossible to differentiate from resident animals without being able to track the animal's long-distance movements. Detections of dispersing animals therefore represent false presences in the data. Regardless, I have strong evidence, including documentation of reproduction, that the species is doing well and that the Bear River Range provides highly suitable habitat.

Altogether, these factors combine to make the above estimates more indicative of proportional habitat use than true occupancy, with the unit and subunit levels representing different spatial scales from which to examine habitat use in the study area. In reality, true occupancy likely lies between the subunit estimates of 0.333 to 0.750, but further data collection and modeling would be necessary to confirm these suspicions. Occupancy estimates for individual units were interpreted as proportional habitat use that accounts for detectability of the target species. Units five and three appeared to have the highest proportion of habitat use, with 71% and 50% (or 71%, depending on the model) of their habitat being used respectively. Unit four had the next highest proportion of habitat use (39%), while unit nine had the lowest (14%). Proportional habitat use for unit seven could not be estimated because of lack of convergence in the occupancy parameter estimate due to few presence/absence observations. These estimates are comparable to occupancy calculated in other wildland areas in the Mountain West (~0.95 on Colorado's Front Range and ~0.60 on the Western Slope, Lewis et al. 2015).

Dominant habitat types in units five and three, based on SWReGAP landcover, were aspen and coniferous forest. In unit nine, dominant habitat was aspen and sagebrush steppe, while in unit 4 dominant habitat types were coniferous forest and maple woodland. The order of preference of these units is supported by the large-scale habitat analysis which had very high HPI values for aspen-mixed conifer forest (30.0), high HPI for coniferous forests (3.37), low HPI for sagebrush steppe (0.86, and very low HPI for maple woodland (0.53). General trends in the habitat analysis such as preference for coniferous forest and rugged topography and avoidance of grassland and open areas correspond with existing literature (e.g., Rieth 2010). However, the illogical and contradictory nature of results across spatial scales indicates the lack of power and utility of this habitat analysis due to insufficient amounts of data. The small-scale preferences and avoidances particularly appear to be artifacts of a small sample for each habitat description, and the results are so sensitive to these small samples that a change of one detection in many of the habitat descriptions could alter the direction of preference. For example, the strong "preference" shown for roads is due to two natural sign detections on roads.

This brings forth another problem: the habitat preference results may be confounded with differing detection probabilities in different habitats. A better approach may include only camera station descriptions because habitat data is collected for both used and unused habitat in an unbiased manner, given that habitat characteristics are recorded at the start of the survey before results are known. An alternative approach would be to test for variation in detection probabilities among habitat types by including habitat type as a covariate in occupancy models.

In total, camera-traps documented 17 mammal species plus an unidentified number of squirrel species, and an unidentified number of bird species. Natural sign surveys identified 13 mammal species, not including weasels and deer which were unidentifiable to species (2 local species of each), and squirrels of an unidentifiable number of species. Notable species detections included: A mountain goat detected by a camera-trap, a species of such low abundance in the Bear River Range that a translocation of individuals from elsewhere is being considered by the Utah Division of Wildlife Resources (UDWR). A bobcat and a marten, both elusive carnivores that are difficult to monitor and both detected by natural sign. Moose, which are an important game species in Utah and as such well-monitored. A domestic cat detected by natural sign about 6 km from the edge of Cache Valley in the Wasatch-Uinta-Cache National Forest, an indication of feral cat expansion into wildlands. High amounts of ungulate activity were detected by camera-traps and natural sign surveys throughout all parts of the study area, indicating widespread prey availability.

Lastly, one key species was *not* detected throughout the duration of the study: the American black bear (*Ursus americanus*). Black bears are not typically an elusive species: they follow game trails and leave large, distinct tracks, scats, and long-lasting scrapes on trees. The lack of detections of this species anywhere in the Bear River Range despite heavy survey effort and existence of good habitat indicates that at most, very few bears live in the areas surveyed. This is concerning given current management which allows hunting on the Cache unit despite the UDWR's objectives to increase black bear occupancy and densities in suitable habitat (UDWR 2011).

Recommendations for future work

To support long-term cougar population monitoring via occupancy measures, adjustments to the existing survey framework are necessary. The primary challenges faced were feasibility of collecting sufficient data and few detections of the target species, both common in large-scale carnivore studies. Camera stations each took about half a field day to install, and it generally took 2-3 weekends to have all cameras operational in a unit, with an additional 2-3 weekends to then retrieve all cameras after four weeks of concurrent monitoring. This increased survey periods for each unit from an expected 5 weeks to 8-10 weeks, thereby increasing the potential for detecting a cougar but decreasing the number of units sampled substantially. I addressed this during the study by reducing the number of subunits sampled to about five per unit instead of nine, but achieving this coverage was still difficult and the longer temporal sampling periods did not assist modeling. A more efficient approach would be to resize units to 6-by-6 kilometers with nine 2-by-2-kilometer subunits, setting camera stations at the center and midpoint of each edge for a total of 5 camera stations per unit and adding a 2-kilometer buffer between units (**Figure 12**). To further increase spatial coverage, removal and double sampling designs may also be considered (Chapter 6.5, MacKenzie et al. 2006), with a removal sampling design shown to be the most efficient (MacKenzie and Royle 2005).

As a result of closer clustering among camera stations, one unit surveyed per month would be feasible. This would easily allow for at least nine units (75% of the study area) to be surveyed each year and for habitat use/occupancy estimates to be compared annually. Based on Guillera-Arroita and Lahoz-Monfort (2012), surveying twelve units would result in a 96% probability of detecting a 50% change in occupancy between sampling years and a 61% chance of detecting a 25% change, given 80% power and a significance level of 0.10. For nine units, the probability of detecting a 50% change is 90% and a 25% change 51%. For six units, these probabilities are 77% and 39%, respectively. All power analyses assume that each unit is surveyed via the given survey design with 5 spatial replicates (i.e., subunits surveyed) and both survey methods per unit per season, and that detection probability is 62% based on a combination of natural sign and camera-trap detection probabilities (0.286+0.333) from the top multimethod model with spatial replication.

With feasibility of surveys increased, another option may be expanding the study area northward or westward into the Wellsville Range since the full area need not be surveyed every year. Besides increasing the feasibility of fieldwork and units surveyed, this approach yields additional benefits: 36 km^2 units would better represent a female home range size for this area, independence between units would increase, survey consistency would increase, and data resolution would increase due to the tighter camera-trap resolution. This new survey design also corresponds with MacKenzie and Royle's (2005) recommendations that a smaller area should be surveyed more intensively for common (i.e., widespread) species, as I have shown the cougar to be in this area. In sum, more of the study area could be surveyed more often and more effectively.

Another major complication was the data structure. The lack of multiple surveys at individual units prevented detection probability and occupancy estimates from being parsed, while the lack of concurrent surveys prevented occupancy from being estimated within a period of demographic closure. A multimethod occupancy model with spatial replication would address the first problem by using the detection histories for each subunit and method as a separate survey, though this would not allow for reliable subunit-level occupancy estimates. For the second problem, decreasing the manpower required to survey each unit may enable multiple units to be surveyed concurrently, but the structure of surveys could also be improved. One major improvement necessary is standardizing survey effort between units, particularly for natural sign

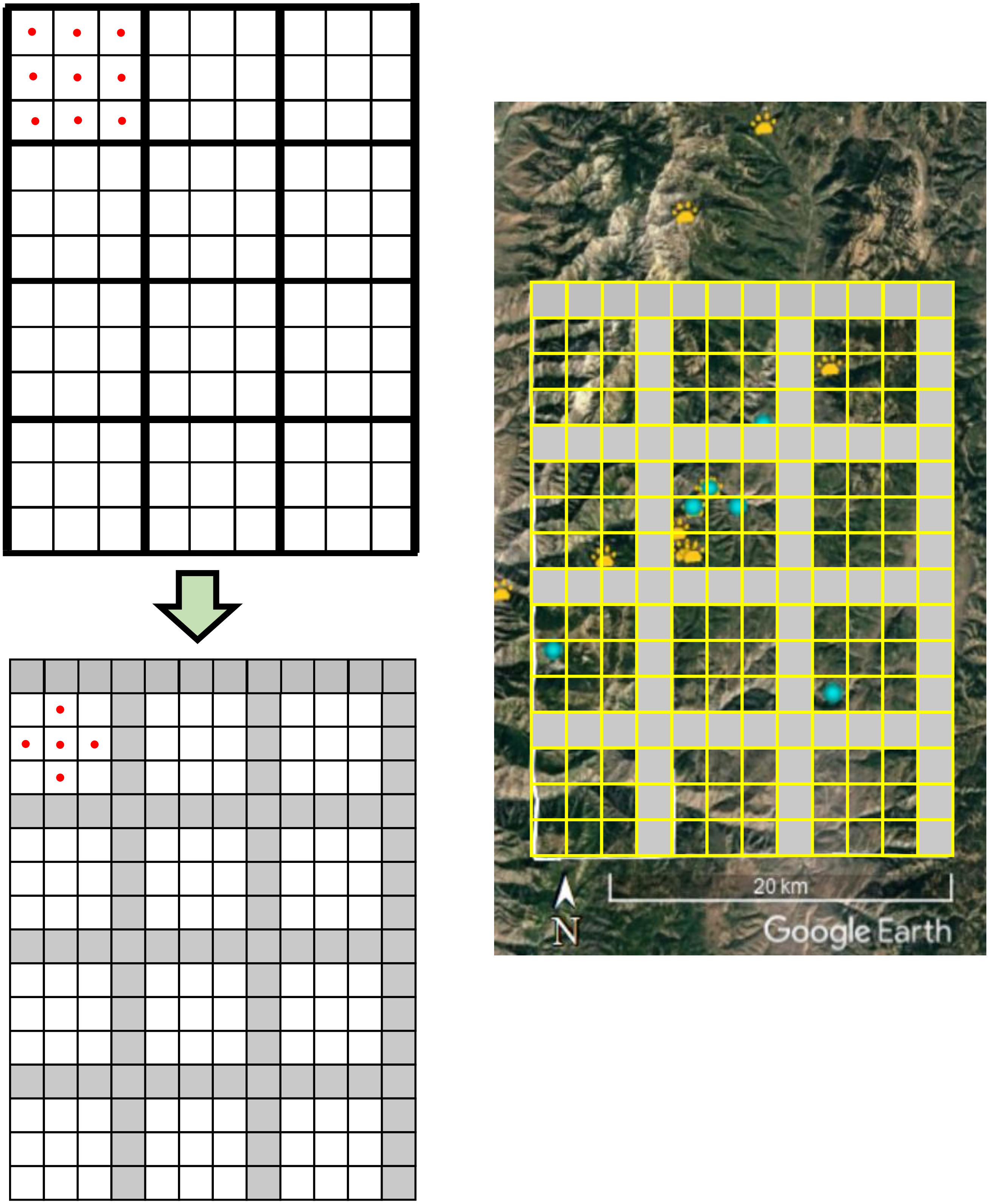

Figure 12. *Original sampling design with 8-by-8 km units (top left) compared to proposed sampling design with 6-by-6 km units (bottom left), with units in both designs divided into nine subunits. Red points represent camera-trap locations. The proposed sampling design is overlaid on the study area and previous detections at right.*

surveys. The linear relationship between camera-trap detection probability and trap-nights enables survey effort to be accounted for, but the decreasing relationship between natural sign detection probability and distance surveyed prevents such accounting. This negative relationship is likely an artifact of inconsistent survey effort, a tendency to stop surveying once sign is found, and including distances in survey effort which are not *actively* searched for sign. Easy changes can be made by continuing surveys beyond detection of cougar sign, starting to record surveyed distances only when sign is being actively searched for, and setting a minimum survey effort for both survey methods. With new data collected following this stricter protocol, a more accurate model of the relationship between distance surveyed and natural sign detection probability can be built, enabling survey effort to be accounted for later. With more reliable detection probability and related coefficient (e.g., season, effort) estimates, occupancy model power can be directed towards estimating new parameters, such as habitat variables and interspecific interactions (see Chapters 4, 8 in MacKenzie et al. 2006).

Lastly, the capabilities of this monitoring framework could be greatly improved with identification of individual cougars. By identifying individual animals, either via track measurements or visual features in photographs, "capture" histories for individual cougars could be mapped out over space and time, providing the data for analyses such as spatially explicit capture-recapture which would enable estimates of population size, survival, and recruitment (Gardner et al. 2010). Though studies have claimed to photographically identify individual South American cougars by natural characteristics (Kelly et al. 2008), Alexander and Gese (2018) found that observers could not confidently identify individual Yellowstone cougars via natural features. Observations from this project tend to agree with the latter's findings, however they did suggest that changes in field methods may increase observer confidence in identification. Starting in fall 2017, I began including PVC poles marked at one-decimeter intervals in the camera viewshed (**Figure 13**) to improve identification of individuals and classification by sex and/or age. Though I have since received too few detections to determine whether this method is effective, Alexander and Gese (2018) used a similar method without success. Regardless, innovation in this regard may advance future cougar camera-trap monitoring.

Figure 13. *Cougar next to improvised measuring pole marked at decimeters.*

Implications

I evaluated the effectiveness of camera-traps compared to natural sign surveys using the Bear River Range as a case study. Both camera-traps and natural sign surveys were shown to be effective for monitoring cougars, with the methods combined yielding almost twice as many detections as either single method. Each method produced enough detections for occupancy model convergence. While camera-traps are frequently employed for monitoring large cats and other elusive species, I did not find them to be substantially more effective than natural sign surveys in this case. The survey design used here was more standardized than many other camera-trap monitoring efforts for elusive species (see Kelly 2008) and likely contributed to our success with both methods. Small changes in survey design recommended above would further improve consistency and spatial coverage, thereby also improving precision of estimates from occupancy models. Part 1 of the project made these changes possible, and I would encourage similar pilot studies and dynamic study designs based on available knowledge of the target species in the given study area.

Despite wide variability in occupancy parameter estimates, comparison of results within individual models and trends in results were surprisingly robust to changes in parametrization and model type used. For example, the range of differences between paired camera-trap and natural sign detection probabilities was a mere 0.016 – even though camera-trap and natural sign estimates had ranges of 0.7 and 0.42, respectively. The consistency of compared results – if not the results themselves – indicate that changes in occupancy over time could be a useful metric of cougar population status, *as long as the same model and parametrizations are used.* For this purpose, I recommend using a multimethod model with spatial replication as it best corresponds with the method of data collection. Occupancy and detection frequency are more indicative of population processes than current indices based on harvest, yet not prohibitively expensive to measure as compared to density or abundance estimates for cougars.

The labor-intensiveness of both survey methods may discourage use by wildlife managers who are charged with monitoring all species in a large area. Time commitment for fieldwork for this three-year study was about two weekends every month, weather cooperating. This is not including the time needed to sort photos, manage data, and conduct the analyses. However, the total cost of this project was equipment (~$3000 total), with a handful of volunteer undergraduate students from the USU wildlife program providing the survey effort necessary to estimate cougar activity in an about ~200km^2 area. Trained citizen scientists have proven indispensable in other ecological studies, with their efforts enabling studies which would otherwise not be feasible (Dickinson et al. 2012). The major challenges would be training volunteers in natural sign identification, camera placement, coordinating efforts, and maintaining safety of all volunteers. I have accomplished these tasks by hosting training sessions for new volunteers each semester, pairing new volunteers with experienced project members in the field, and using a Facebook platform to keep interested volunteers informed. Other effects of citizen science are public education and providing means for citizens to reconnect with the natural world.

Employing grid-based spatially replicated surveys, citizen scientists for fieldwork, and camera-trapping and natural sign survey methods, managers could effectively standardize cougar monitoring across a large area. By using occupancy as a population metric, other sources of detection data (e.g., sightings) could be easily incorporated to improve knowledge of the population. Though these methods were developed for cougars, members of the felid family have similar behavior and these methods could easily be applied to other species of higher conservation concern, with small changes. Further, camera-traps would collect important information on other wildlife species in remote areas which would otherwise go undetected. Perhaps the greatest benefit of such a monitoring program would be a long-term database of cougar wildlife activity over space and time. Not only would this provide benefits to local managers and the public, but by collaborating with programs such as eMammal (McShea et al. 2016), these programs could contribute to a global camera-trap network for biodiversity monitoring (Steenweg et al. 2017).

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APPENDIX

FIELD METHOD PROTOCOLS

Camera-Trapping

PRIOR TO FIELDWORK

1. Randomly determine next unit to survey:
    a. Criteria: 1) unit is not adjacent to (i.e., does not share a side with) the past two units surveyed
       2) unit was not surveyed in the past 12 months
    b. Code in R: sample(1:12, 1)
2. Scout camera sites and determine plan of attack, noting:
    a. Ability to SAFELY and EFFICIENTLY access sites
    b. Access points for nearby roads and trails
    c. Approximate hiking distances/time requirements for each site (will change with the seasons)
    d. Effort (volunteers + time) needed to set up all sites in unit

    Note: This is most easily done via Google Earth
3. Check functionality of all cameras.
4. Recharge all batteries to 100%.
5. Recharge walkie-talkies
6. Download data and FORMAT all memory cards:
    a. Right-click on SD card folder, click “Format…” > “OK” (this ensures that photographs numbering will start at 1 again)
7. Prepare each camera:
    a. Add batteries
    b. Add clear SD card
    c. Check settings, date, and time
    d. Re-label “USU Cougar Project” and lead researcher’s contact info with Sharpie
8. Enter necessary coordinates into GPS.
9. Re-mark PVC pipe measurements as necessary.
10. Pack bag: first aid kit, GPS, compass, map, camera, SD card, batteries, security box for camera, Python/lock cable, lock, Python keys, pie tin, PVC measuring pole, data sheets, pens/pencils, ruler/calipers, personal gear (water, layers, food, phone/camera), walkie-talkies

SETTING UP A CAMERA SITE

1. Navigate to buffer area of camera site (within 250 meters of camera site coordinates)
2. Record wildlife sign throughout the process
    a. Cougar sign should be GPS-marked and investigated using the relevant data sheets- take pictures to record observations and verify later
    b. Prey species should be qualitatively noted- “heavy” vs. “moderate” vs “light” sign of deer, elk, snowshoe hare, etc.

   c. Other carnivore sign (i.e., coyote, skunk, raccoon, black bear, marten, etc.) should *always* be identified and noted
3. Split up and scout buffer area, searching for location to maximize cougar detection probability:
   a. Funnel points
   b. Topographic saddles
   c. Ridges
   d. Streams
   e. Heavily traveled game trails (no vegetation, furrowed into the ground, fresh sign) or intersections of game trails
   f. Human trails/roads (if not heavily used)
   g. Sites with cougar sign present (tracks, prey caches, scrapes, etc.)
   h. *Remember to consider how a site may change with seasonal progression- snowfall, rising streams, etc.)*
4. Once a general area is chosen, determine a camera tree:
   a. 3-8 meters from area you want to capture
   b. Large enough to prevent shaking in wind, small enough to fit cable lock
   c. Preferably shaded without too much loose vegetation that will cause false-triggers
   d. Preferably with camera facing north if not heavily shaded (to avoid sunrise and sunset directly overloading the camera's sensors)
   e. If snowfall is expected after camera placement, the camera should be high enough on the tree to avoid burial
5. Prepare camera site:
   a. Remove low-lying vegetation that may false-trigger the camera
   b. Hang pie tin
      i. In front of camera, so that any animal checking it out must pass in front of camera
      ii. High enough to be out of range of camera
      iii. Should be able to reflect light and attract animals from a distance
   c. Plant PVC measuring pole along trail in obvious view of camera
6. Record camera site characteristics
   a. ***GPS MARK CAMERA SITE-*** averaging the location is recommended
   b. Record date, time, vegetation characteristics, and wildlife sign encountered in buffer on the provided datasheet (see below)
7. Set camera up, with a helper "playing cougar" while on "Walktest" (Reconyx) or "Aim" (Moultrie) to perfect viewshed
   a. About waist-height tends to be best on level ground, adjust accordingly for slope
   b. Use pinecones, branches behind camera to angle upwards or downwards as necessary
   c. Should be able to detect animals from fox-size (ankle-height) to elk-size (chest-height) and have a range of at least 3 horizontal meters along the trail
   d. Face north if possible, to avoid blinding of camera at sunrise and sunset
8. Check settings and start camera:

    a. Moultrie: 3 photos per trigger, lowest downtime, **check date and time**
    b. Reconyx: 5 photos per trigger, lowest downtime, **check date and time**
9. Take test photo with unit-site numbers on piece of paper (e.g., 5-7 for camera site 5 in unit 7)
10. Lock camera (be careful not to disturb setup in process)

PLANNING
Camera setup is time-consuming. Generally, the maximum number that can be feasibly deployed by one crew on any given day is two camera sites. Ideally, cameras should be concurrently deployed for *at least* four weeks. If conditions don't allow, deploy the four corners and the center of the unit for at least four weeks, and other subunits as time and safe conditions allow.

Natural Sign Surveys

The effectiveness of natural sign surveys increases with distance covered. At bare minimum, natural sign should be recorded each time a camera site is installed and each time a camera site is pulled. Additional natural sign surveys should be conducted as time allows. To maximize the distance traversed, I recommend returning to your starting point by a different route (separated by at least ~300 meters) traveled on the way out. Winter and early spring, when there is snow on the ground, are the best time for natural sign surveys for cougars. Surveys should focus on detecting cougar presence in current sampling units but may also be used to confirm persistence of cougars in areas where previously detected despite lack of camera monitoring. Extra cameras may be carried during track surveys to confirm cougar presence and/or investigate cougar behavior.

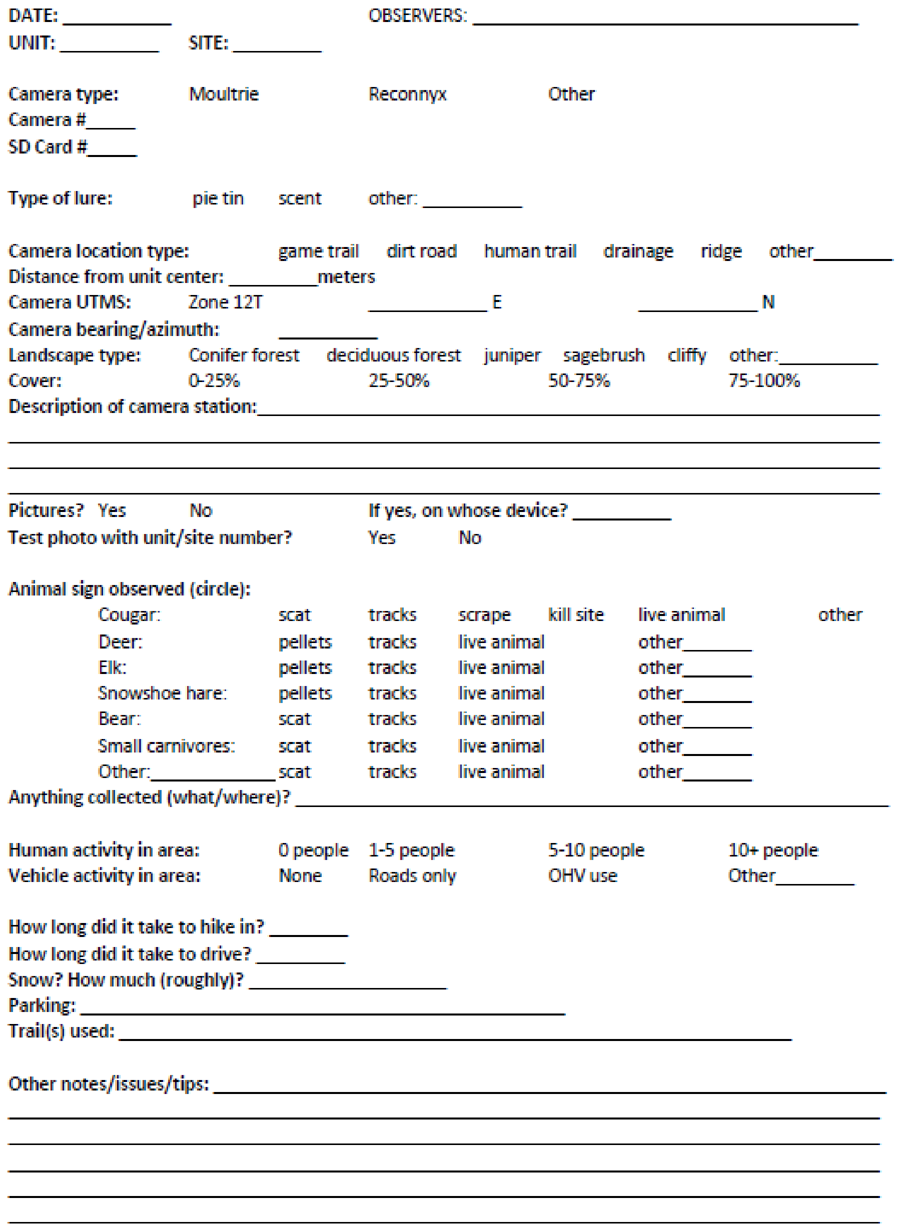
1. Observe snow, mud, and any other areas where a track could register while hiking. Pay particular attention to potential prey species (mule deer, elk, snowshoe hare, moose, etc.) and competitors/scavengers (coyotes, foxes, skunk, mustelids, bears, etc.)
2. Record survey effort:
    a. Total distance covered (unless same route is taken both directions, then only record one-way travel distance)
    b. Number and initials of observers
3. Note any species sign encountered (tracks, pellets, scrapes, browsing activity, carcasses, live animals, etc.):
    a. Identify species
    b. Age of sign (fresh vs. old)
    c. Amount:
        i. Relative if a common species (e.g., heavy mule deer or elk sign)
        ii. Number of animals if less common (e.g., one marten)
    d. Any cougar sign encountered should be GPS-marked, measured, and investigated using the relevant datasheet (track or predation event)
    e. Any cougar sign or other rare species should be photographed for verification
        i. include scale: calipers and rulers are best, but sunglasses, pocket knife, coin, or anything else of known dimensions is equally effective; scale devices should be laid down next to the track to ensure no distortion of size

Note: Tracking experience is CRITICAL to accurate identification of natural sign. Volunteers should be trained prior to conducting natural sign surveys, a field guide and measuring device (e.g., calipers, ruler, measuring tape) should always be carried, and photographs of any potential cougar sign should be encouraged.

DATA MANAGEMENT PROTOCOLS

Field Data Sheets

1. Camera setup data sheet:



DATE: ___________ OBSERVERS: ____
UNIT: __________ SITE: _________

Camera type: Moultrie Reconnyx Other
Camera #_____
SD Card #_____

Type of lure: pie tin scent other: __________

Camera location type: game trail dirt road human trail drainage ridge other________
Distance from unit center: _________meters
Camera UTMS: Zone 12T ____________ E ____________ N
Camera bearing/azimuth: __________
Landscape type: Conifer forest deciduous forest juniper sagebrush cliffy other:__________
Cover: 0-25% 25-50% 50-75% 75-100%
Description of camera station:____
____
____
____

Pictures? Yes No If yes, on whose device? __________
Test photo with unit/site number? Yes No

Animal sign observed (circle):

Cougar:	scat	tracks	scrape	kill site	live animal	other
Deer:	pellets	tracks	live animal		other_______	
Elk:	pellets	tracks	live animal		other_______	
Snowshoe hare:	pellets	tracks	live animal		other_______	
Bear:	scat	tracks	live animal		other_______	
Small carnivores:	scat	tracks	live animal		other_______	
Other:_____________	scat	tracks	live animal		other_______	

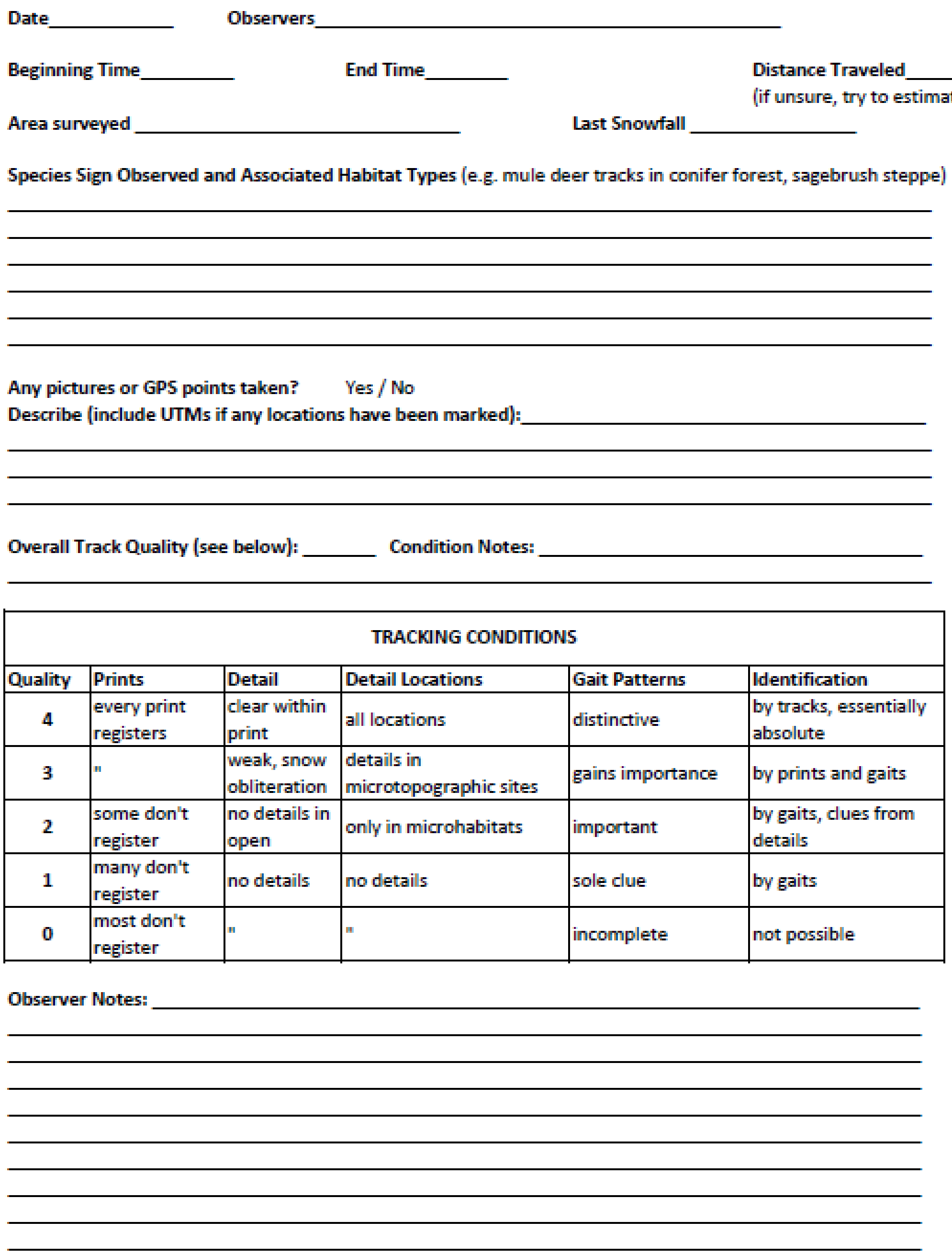
Anything collected (what/where)? ____

Human activity in area: 0 people 1-5 people 5-10 people 10+ people
Vehicle activity in area: None Roads only OHV use Other________

How long did it take to hike in? ________
How long did it take to drive? _________
Snow? How much (roughly)? ____________________
Parking: ____
Trail(s) used: ____

Other notes/issues/tips: ____
____
____
____
____
____

2. Natural sign survey data sheet:



Date____________ **Observers**____________________________________

Beginning Time_________ **End Time**________ **Distance Traveled**__________
(if unsure, try to estimate)

Area surveyed _______________________________ **Last Snowfall** ________________

Species Sign Observed and Associated Habitat Types (e.g. mule deer tracks in conifer forest, sagebrush steppe)

Any pictures or GPS points taken? Yes / No

Describe (include UTMs if any locations have been marked):_______________________________________

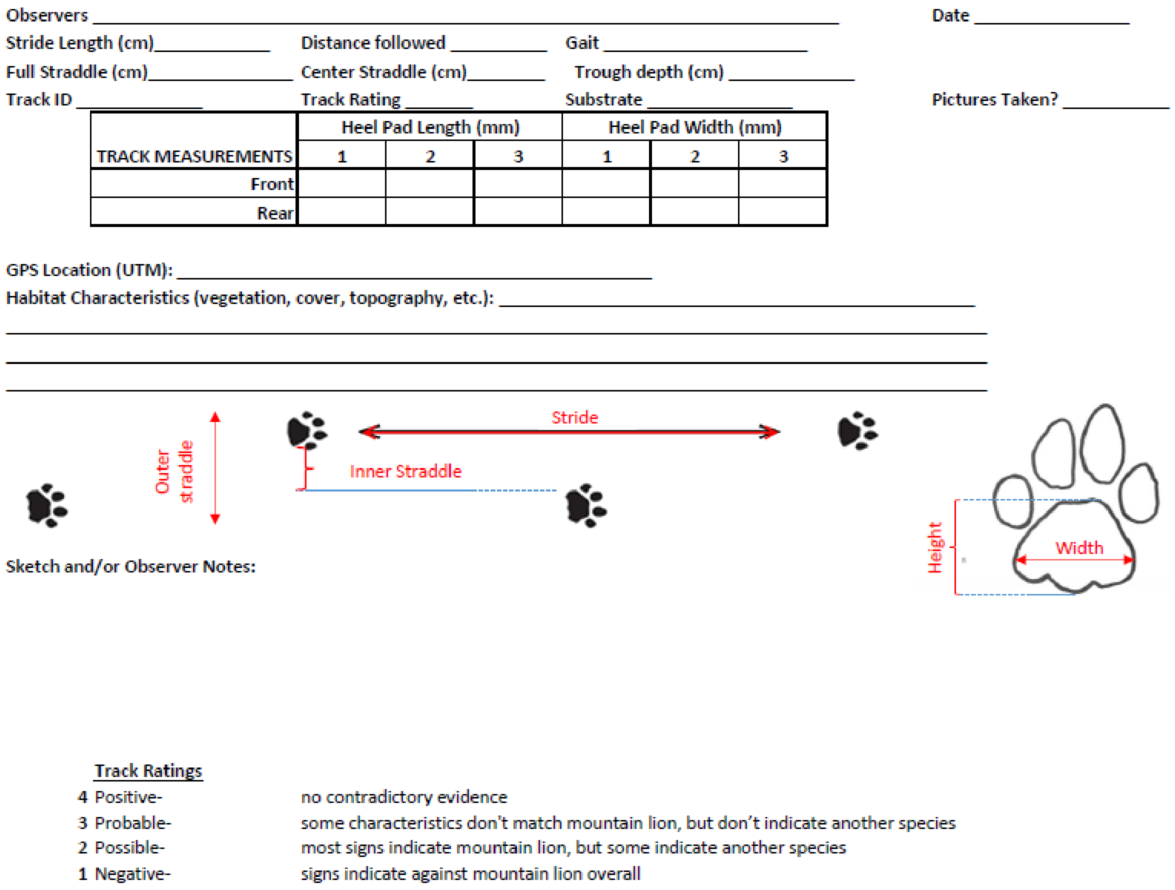
Overall Track Quality (see below): _______ **Condition Notes:** ______________________________________

TRACKING CONDITIONS

Quality	Prints	Detail	Detail Locations	Gait Patterns	Identification
4	every print registers	clear within print	all locations	distinctive	by tracks, essentially absolute
3	"	weak, snow obliteration	details in microtopographic sites	gains importance	by prints and gaits
2	some don't register	no details in open	only in microhabitats	important	by gaits, clues from details
1	many don't register	no details	no details	sole clue	by gaits
0	most don't register	"	"	incomplete	not possible

Observer Notes: ____

3. Suspected cougar tracks data sheet:



Observers ______________________________ Date ______________
Stride Length (cm)__________ Distance followed _________ Gait __________________
Full Straddle (cm)_____________ Center Straddle (cm)_______ Trough depth (cm) ___________
Track ID ___________ Track Rating ______ Substrate _____________ Pictures Taken? _________

TRACK MEASUREMENTS	Heel Pad Length (mm)			Heel Pad Width (mm)		
	1	2	3	1	2	3
Front						
Rear						

GPS Location (UTM): ____
Habitat Characteristics (vegetation, cover, topography, etc.): ____

Sketch and/or Observer Notes:

Track Ratings

4 Positive-	no contradictory evidence
3 Probable-	some characteristics don't match mountain lion, but don't indicate another species
2 Possible-	most signs indicate mountain lion, but some indicate another species
1 Negative-	signs indicate against mountain lion overall

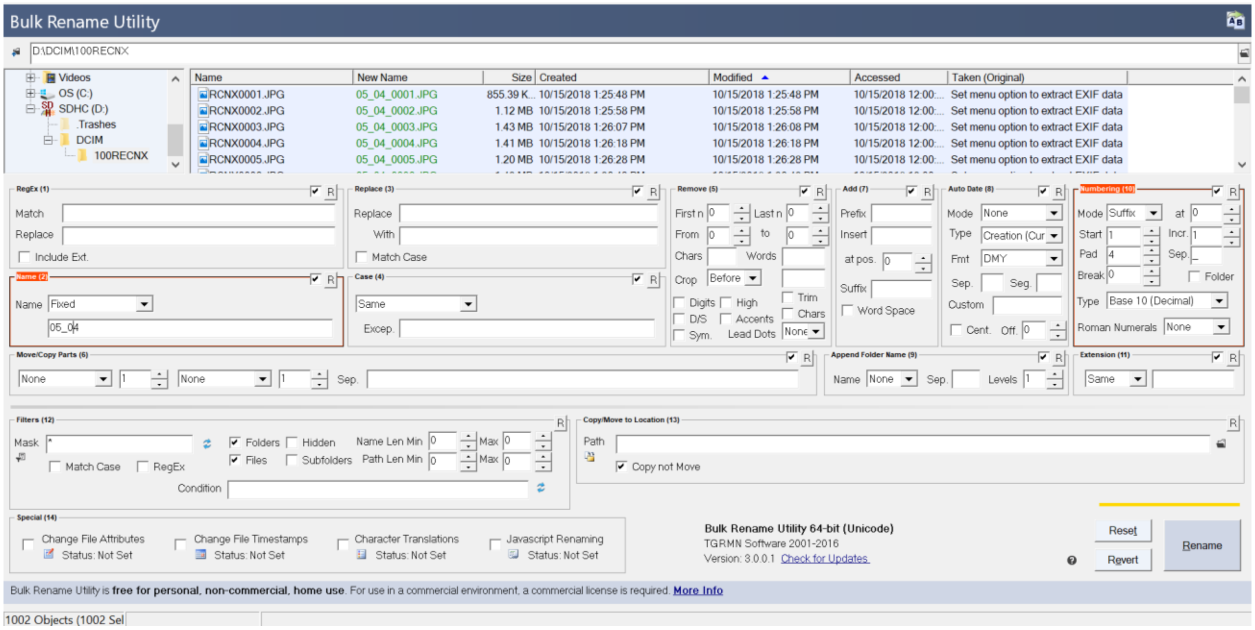
4. Immediately upon returning from the field, take photos of all data sheets and enter data into spreadsheet on:
    a. Camera installs: Location coordinates, date/time of set up, observers present during setup, site description, and species sign encountered while hiking to/from camera site.
    b. Natural sign surveys: Transect distance, quality of tracks, date, observers present during survey, date/time of survey, and species sign encountered. If cougar sign encountered, enter coordinates and track measurements.
    c. Camera pulls: Date/time camera was pulled, observers present, and species sign encountered while hiking to/from camera site.
5. Shortly after returning from the field, enter all data on data sheet into data form in Access database (Access will automatically convert these to table form).

Photographs

Thank you to Dr. Jody Tucker for sharing her photo management protocols with me!

1. Relabel all photos with the base name unit_subunit (e.g., if the camera station was unit 5 subunit 4, then the base name would be 05_04) and photo number in chronological order. This can be easily accomplished with the Bulk Rename Utility found at https://www.bulkrenameutility.co.uk/Download.php

a. Before renaming, check that photos are sorted by the Date Created. If they are in the order numbered by the camera, then they should be in order.
b. Open the Bulk Rename Utility, navigate to the folder holding the photos in the top left panel, select/highlight all photos (Ctrl + A) in the top panel, and fill out as below (Note sections with orange boxes) by changing the following:
    i. Name (2) > Name > "Fixed"
    ii. Name (2)> Type the base name (e.g., "05_04") in the second box
    iii. Numbering (10) > Mode > "Suffix"
    iv. Numbering (10) > Pad > "4"
    v. Numbering (10) > Sep. > "_"



D:\DCIM\100RECNX

Name	New Name	Size	Created	Modified	Accessed	Taken (Original)
RCNX0001.JPG	05_04_0001.JPG	855.39 K...	10/15/2018 1:25:48 PM	10/15/2018 1:25:48 PM	10/15/2018 12:00:...	Set menu option to extract EXIF data
RCNX0002.JPG	05_04_0002.JPG	1.12 MB	10/15/2018 1:25:58 PM	10/15/2018 1:25:58 PM	10/15/2018 12:00:...	Set menu option to extract EXIF data
RCNX0003.JPG	05_04_0003.JPG	1.43 MB	10/15/2018 1:26:07 PM	10/15/2018 1:26:08 PM	10/15/2018 12:00:...	Set menu option to extract EXIF data
RCNX0004.JPG	05_04_0004.JPG	1.41 MB	10/15/2018 1:26:18 PM	10/15/2018 1:26:18 PM	10/15/2018 12:00:...	Set menu option to extract EXIF data
RCNX0005.JPG	05_04_0005.JPG	1.20 MB	10/15/2018 1:26:28 PM	10/15/2018 1:26:28 PM	10/15/2018 12:00:...	Set menu option to extract EXIF data

Name (2): Name Fixed; 05_04

Case (4): Same

Auto Date (8): Mode None; Type Creation (Cur; Fmt DMY

Numbering (10): Mode Suffix; at 0; Start 1; Incr. 1; Pad 4; Sep. _; Break 0; Type Base 10 (Decimal); Roman Numerals None

Append Folder Name (9): Name None; Levels 1

Extension (11): Same

Filters (12): Mask *; ☑ Folders; ☑ Files

Copy/Move to Location (13): ☑ Copy not Move

Special (14): Change File Attributes Status: Not Set; Change File Timestamps Status: Not Set; Character Translations Status: Not Set; Javascript Renaming Status: Not Set

Bulk Rename Utility 64-bit (Unicode)
TGRMN Software 2001-2016
Version: 3.0.0.1 Check for Updates

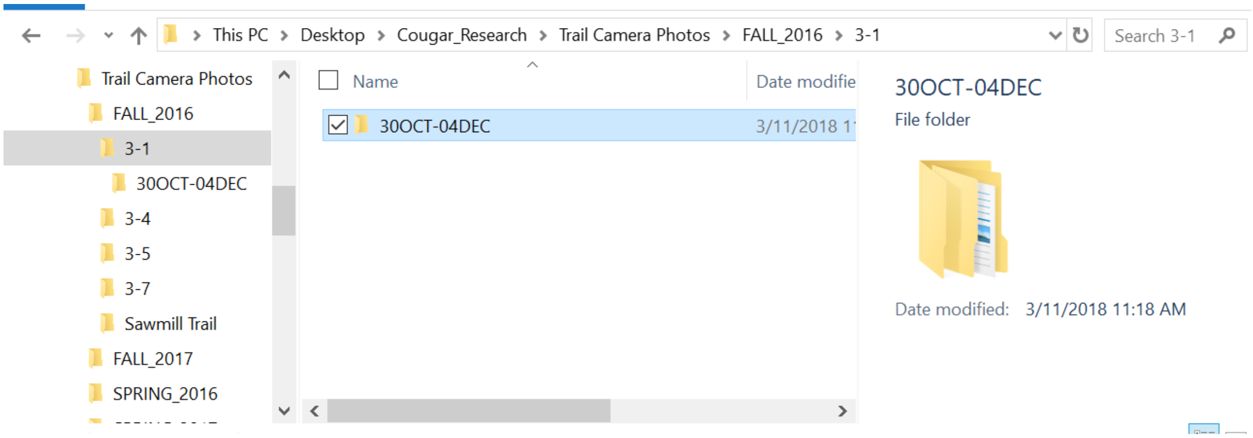
Bulk Rename Utility is **free for personal, non-commercial, home use**. For use in a commercial environment, a commercial license is required. More Info

1002 Objects (1002 Sel

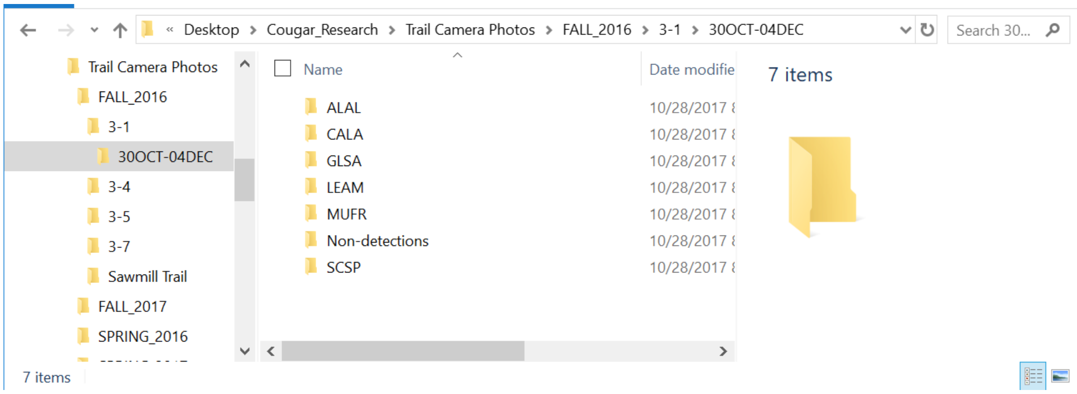
c. Double check that the "New Name" at top, in green, matches the desired name.
d. Click "Rename"
e. Navigate to the photos and double check that the tool worked.

Note: The Bulk Rename Utility can be used to adjust improperly set date/timestamps on photos.

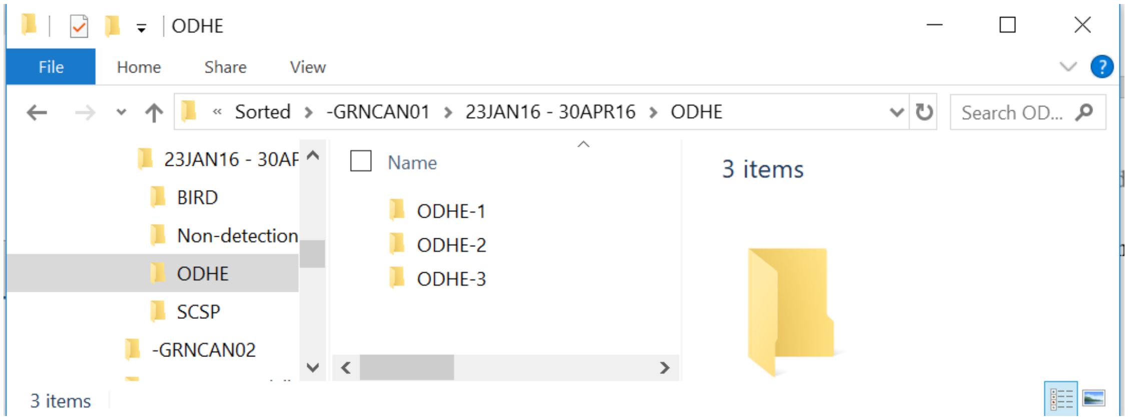
2. Create the folder structure Season > Site > DatesSurveyed for each site/survey combination.
    a. Start to end date should be included; if not recorded, check timestamps.
    b. Dates should be standardized, in this case the two-digit date + first three letters in month (e.g., October 30 to December 4 = 30OCT-04DEC)



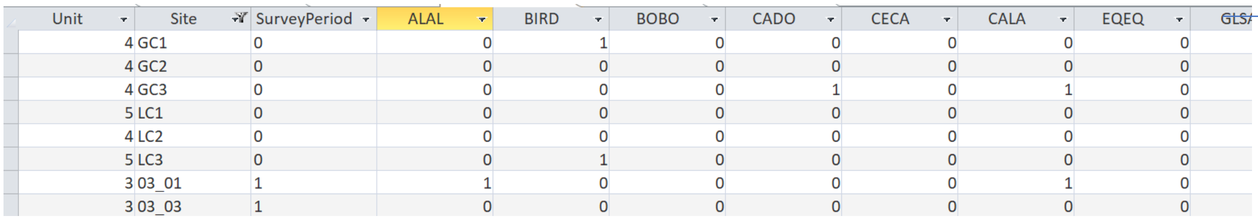
3. Sort by species into new folders within the dates folder
    a. Name each folder containing all photos of a species using the four-letter abbreviation (first two letters genus + first two letters species, all caps) to standardize species names
        i. Common abbreviations: cougar = PUCO, mule deer = ODHE, human = HOSA, CALA = coyote, ALAL = moose, CECA = elk, LEAM = snowshoe hare, SYSP = cottontail species …
        ii. Unless identified further, squirrels = SCSP for *Sciurus spp.*
        iii. Unless identified further, birds = BIRD
        iv. If animal unidentifiable, folder name = UNK
        v. If any abbreviations happen to be repeated (which has not yet happened), add a numeric suffix to distinguish the two (e.g., ALAL1 and ALAL2)
    b. All photos of project personnel and false triggers should be kept in a folder named "Non-detections"



    c. For photos including more than one animal, sort within the species folder by number of animals:



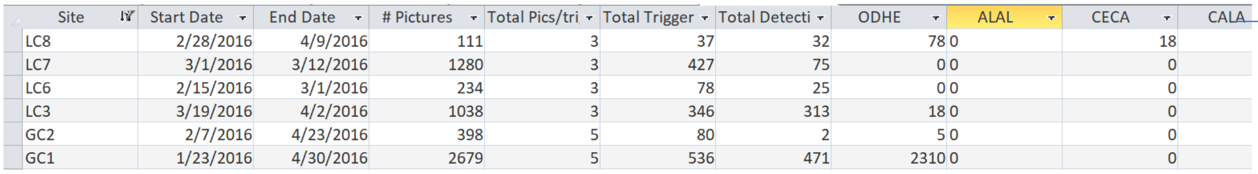
4. Enter data in Access database after sorting photos:
    a. For every survey period-camera site combination enter binary presence (1) and absence (0) records for each species (using the 4-letter species codes). (Note: dates cameras were active can be used in place of survey periods)



Unit	Site	SurveyPeriod	ALAL	BIRD	BOBO	CADO	CECA	CALA	EQEQ	GLS
4	GC1	0	0	1	0	0	0	0	0	
4	GC2	0	0	0	0	0	0	0	0	
4	GC3	0	0	0	0	1	0	1	0	
5	LC1	0	0	0	0	0	0	0	0	
4	LC2	0	0	0	0	0	0	0	0	
5	LC3	0	0	1	0	0	0	0	0	
3	03_01	1	1	0	0	0	0	1	0	
3	03_03	1	0	0	0	0	0	0	0	

more species codes

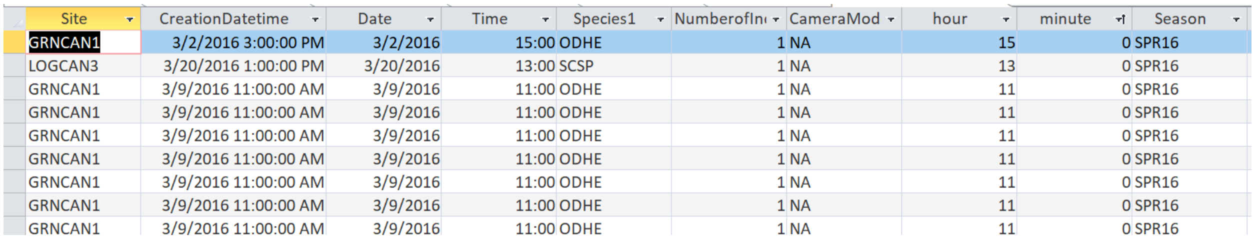
    b. Number of detections per species per site:



Site	Start Date	End Date	# Pictures	Total Pics/tri	Total Trigger	Total Detecti	ODHE	ALAL	CECA	CALA
LC8	2/28/2016	4/9/2016	111	3	37	32	78	0	18	
LC7	3/1/2016	3/12/2016	1280	3	427	75	0	0	0	
LC6	2/15/2016	3/1/2016	234	3	78	25	0	0	0	
LC3	3/19/2016	4/2/2016	1038	3	346	313	18	0	0	
GC2	2/7/2016	4/23/2016	398	5	80	2	5	0	0	
GC1	1/23/2016	4/30/2016	2679	5	536	471	2310	0	0	

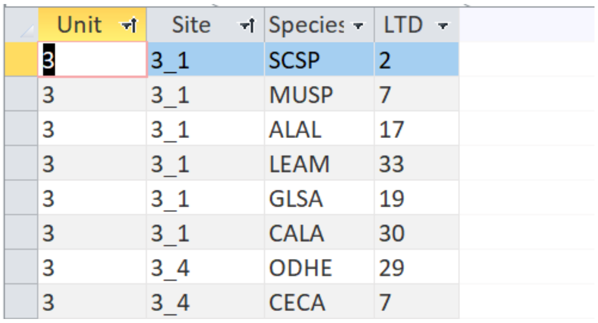
more species codes

    c. Species, date, and time per photo. Use Daminion software to export the creation date/time and species tags for each camera site folder as a CSV. Then, open this CSV and add the site name, camera model, and season abbreviation to all records. Next extract the date by copying the creation date/time and changing the format to date, time by copying the creation date/time and changing the format to time, hour using the =HOUR(time) function, and minute using the =MINUTE(time) function. The CSV can then be converted into a .xlsx file and merged into existing table in Access either by copying and pasting all records or importing the new Excel file.



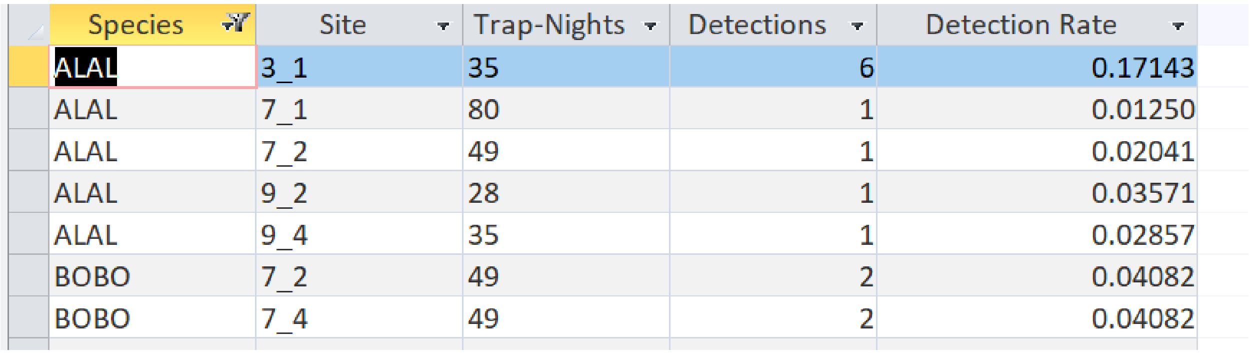
Site	CreationDatetime	Date	Time	Species1	NumberofIn	CameraMod	hour	minute	Season
GRNCAN1	3/2/2016 3:00:00 PM	3/2/2016	15:00	ODHE	1	NA	15	0	SPR16
LOGCAN3	3/20/2016 1:00:00 PM	3/20/2016	13:00	SCSP	1	NA	13	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16
GRNCAN1	3/9/2016 11:00:00 AM	3/9/2016	11:00	ODHE	1	NA	11	0	SPR16

   d. Latency-to-detection per species, or the number of days between initial camera setup and when a species was first detected:



Unit	Site	Species	LTD
3	3_1	SCSP	2
3	3_1	MUSP	7
3	3_1	ALAL	17
3	3_1	LEAM	33
3	3_1	GLSA	19
3	3_1	CALA	30
3	3_4	ODHE	29
3	3_4	CECA	7

   e. Detection rates per species, or the number of detections divided by the total number of trap-nights for every site:



Species	Site	Trap-Nights	Detections	Detection Rate
ALAL	3_1	35	6	0.17143
ALAL	7_1	80	1	0.01250
ALAL	7_2	49	1	0.02041
ALAL	9_2	28	1	0.03571
ALAL	9_4	35	1	0.02857
BOBO	7_2	49	2	0.04082
BOBO	7_4	49	2	0.04082

5. Record results over time for long-term monitoring:
   a. Changes in total species detected (biodiversity)
   b. Changes in species detection rates
   c. Changes in species-specific occupancy (see Hines 2006 for running models in PRESENCE software)
6. Other potential analyses:
   a. Interspecific interactions using PRESENCE 2-species models
   b. Modeling temporal detection rates by running a generalized additive model for each species of interest using data from the table created in 2C. (R is the most adaptive software for these purposes)
   c. Behavioral analyses by classifying photographs into behavioral groups

PERSONAL REFLECTION

When I asked Dr. Dan MacNulty about undergraduate research as a young wildlife student interested in carnivore ecology and learning field skills, he answered with a single question: What is going on with cougars in Cache Valley? That seemingly simple question launched me into an untraditional learning experience (even for a wildlife student). After a short period of literature review, I soon realized that nobody had a clue what was going on with cougar populations throughout the West, let alone what was going on with cougars in Utah or Cache Valley specifically. Coming from the Chicago suburbs, I was shocked that a large apex predator like a cougar could remain just about completely ignored by wildlife officials and the general public. So, I sought to remedy this hole in our knowledge.

With Dan's help and more literature review, I began to formulate a plan for tracking down this elusive carnivore. We decided to use cameras because they are relatively inexpensive, easy to use, noninvasive, easy to obtain permissions for, and capture photos of all wildlife passing by – thereby guaranteeing collection of some form of data on the local wildlife community, even if no cougar photos were captured. I met with Dr. David Stoner, an expert on cougars in Utah, and he agreed to help – though he was skeptical on our success studying such elusive critters using such an unselective tool as a camera. It quickly became apparent that the scale of this project was much too large for me to manage alone, especially without a personal vehicle, and I soon recruited two other wildlife students to the project – Daniel Johnson and Talon Jeppson.

The beginning of the project was a huge learning curve. Our cameras were all within 400 meters (about a quarter mile) from a road or major trail (though it often felt farther), the camera setups were imperfect, we stared at domestic dog tracks with uncertainty, and the project design enabled a high degree of subjectivity. Nevertheless, we captured tons of photos of local wildlife and were lucky enough to record cougars feeding on two separate prey items. After learning more about cougars and camera studies, we took a huge step the next year. The study area was expanded to about 12 times its previous extent, track surveys were added to our toolbox, an URCO grant doubled the number of cameras we could put on the landscape, and our methodology for camera placement was standardized to reduce subjectivity. Three more students were recruited to help run the project – Rylee Jensen, Jennifer Gardner, and Dalton Newbold – and I began to host volunteer trainings to help provide the manpower necessary to implement these changes. An email and Facebook group were started to coordinate this workforce, and before I knew it I became the impromptu leader of a massive undertaking.

I wanted to get some field experience, and boy did this project provide just that. Placing cameras went from quick morning events to intensive all-day excursions into the mountains. I personally covered more than 200 kilometers (~125 miles) through the mountains just east of Logan on foot, mostly off-trail with camera equipment on my back, in areas where I would otherwise have no reason to travel. At first, I relied heavily on a handheld GPS for any sense of direction. By the time I graduated, I was able to navigate by topography and the landscape, taking a different route back from a camera site and ending up nearly on top of my truck. I became comfortable enough in the backcountry to have friends drop me miles up Logan Canyon to retrieve a camera with my bike for the return to town. Some of my hardest hikes I intentionally did alone, as I knew my own limits and capabilities and did not want to put untested volunteers in a potentially dangerous situation.

That being said, once I had the proper training and equipment to maintain volunteer safety, I very much enjoyed taking volunteers out with me whenever possible, giving them some hands-on wildlife experience, sharing knowledge, and discussing the project which helped me see different viewpoints. Volunteers were critical to the project, but early on I learned that high levels of interest in large carnivores among wildlife students does not necessarily equate to high levels of interest in spending your weekend hiking past the point of exhaustion without any guarantee of seeing any animal larger than a squirrel. Even other project leaders slowly fell off, coming with for fieldwork occasionally but otherwise unable to make consistent time commitments due to other obligations. Regardless, a handful of volunteers stepped up and became instrumental to the project. Eri Ethington maintained cameras for a full summer while I was working out-of-state, while Natalie D'Souza and Tim Cromwell have committed to maintaining cameras on the landscape in some form once I graduate. Over the years, I had the pleasure of taking more than 30 students into the field and even after graduating I continue to advise Natalie, Tim, and Debbie Clark on related projects.

Besides networking with other wildlife students, I had the opportunity to present the project in many other settings. Beginning in spring 2015, I created and presented posters to professionals at conferences, to students across campus at university events, and to the public at Science Unwrapped. Between presentations and volunteer training, I became very comfortable speaking in public, a skill I desperately lacked in my earlier years of college. My public presentation experience culminated with USU Ignite in 2017, an event I never would have pictured myself being capable of accomplishing before college. Perhaps more difficult was my first professional oral presentation at the Utah Chapter of The Wildlife Society's annual conference, where I spoke about the status of cougar monitoring in front of wildlife researchers and managers from across the state.

I also learned a great deal about the research process through this project, particularly because it enabled me to see research through from start to finish. The freedom to develop my own project as I went along was concurrently gratifying and maddening, especially considering a project that must be built from the ground up. The basics of the project seem fairly simple – set up trail cameras and look through the photos for the target species – but the logistics are much more complicated. To begin with, the scale of operation necessary to say anything meaningful about the species is large, and accessing preferred habitat is not an easy task – let alone actually detecting them there. Next comes the problem of sorting through, extracting useful data from, and storing nearly 25,000 photos. Then comes keeping track of site-specific data such as location, observers, site description, dates cameras were active, camera used, animal sign present in immediate area, species detected on cameras, and time of species detections. Developing effective data sheets for in the field and an organized database in the lab (i.e., at home) is how I accomplished these tasks. Last came the daunting task of data analysis on the sparse detection data of a quintessentially elusive species – a task I quite honestly did not get the chance to do until after I graduated given the time needed just to implement data collection while at USU.

The modeling portion of this thesis is where my statistics minor came into play. Instead of just following the software instructions and hitting 'go', I could look deeper into how exactly the occupancy model works. This enabled me to manipulate the model in new ways and use it to make comparisons that would be statistically unsound using other methods. In utilizing every facet of the results, I was able to compare models and test their validity in a much more complete and calculating manner than simply comparing AIC values. This was the first time I truly put what I had learned in many hours of statistics classes to test on a real ecological question. Given my interests in elusive species such as cougars and noninvasive methods such as camera-traps and natural sign, this will surely not be my last time attempting to pull useful information out of sparse data. My thesis gave me an early opportunity to run these types of analyses which most wait until graduate school to attempt.

From start to finish, this project has undoubtedly been the defining characteristic of my undergraduate career, consuming most of my spare time and some of my sleep time for three straight years. My thesis project has given me exposure to implementing a large-scale, citizen science-based wildlife monitoring program and provided me with technical and personal skills that would be impossible to learn secondhand. The project gave me an opportunity to network with some wonderful fellow undergraduates and learn the value and necessity of collaboration. Through this thesis process, my interests in large-scale biodiversity monitoring and landscape-level conservation have been solidified and my career will surely be influenced positively by this experience for years to come.

AUTHOR BIOGRAPHY

Margaret Hallerud is a Wildlife Ecology and Management major with minors in GIS and Statistics graduating with a Bachelor of Science in May 2018. She will officially graduate with departmental Honors in May 2019.

A first-generation student, Margaret is originally from Lombard, Illinois and came to Utah State University to pursue an education in wildlife conservation. Besides setting up cameras in Logan Canyon throughout the duration of her undergraduate career, Margaret was also a leader in the USU Chapter of The Wildlife Society and participated competitively on the USU Cross Country and Track teams. During her summers, Margaret expanded her wildlife research experience by participating in field projects including wetland restoration on the Great Salt Lake, noninvasive monitoring of small carnivores in the Sierra Nevada, and population monitoring of black bears in the Great Smoky Mountains. Upon graduation, Margaret continued this pattern by spending 6 months working with the Mexican Wolf Recovery Program's Interagency Field Team.

By graduation, Margaret had been nominated the Quinney College of Natural Resources Senior of the Year of 2018, USU Undergraduate Researcher of the Year of 2017, and had presented at USU Ignite as well as multiple state and international meetings of The Wildlife Society. Margaret plans to take two gap years to continue her wildlife education through on-the-ground conservation/restoration work before pursuing a graduate degree focused on large-scale conservation ecology.