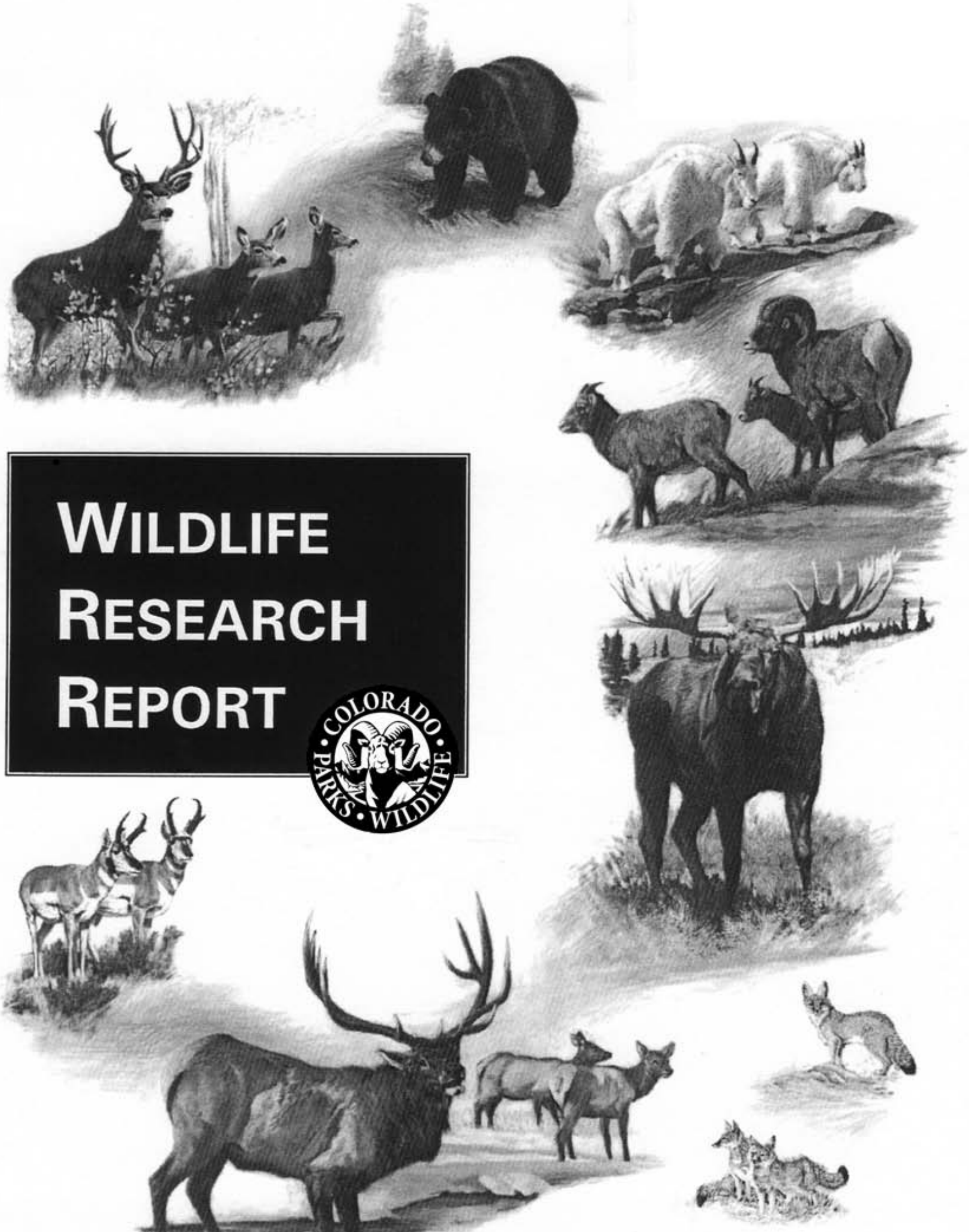
MAMMALS - JULY 2013



WILDLIFE RESEARCH REPORT

WILDLIFE RESEARCH REPORTS

JULY 2012 – JUNE 2013

MAMMALS PROGRAM

COLORADO DIVISION OF PARKS AND WILDLIFE
Research Center, 317 W. Prospect, Fort Collins, CO 80526

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Colorado Division of Parks and Wildlife
July 2012 – June 2013

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July 2012–June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0638	:	Species Conservation Planning and Coordination
Task No.:	N/A	:	Small mammal and breeding bird response to bark beetle outbreaks in Colorado
Federal Aid Project No.	N/A		

Period Covered: July 1, 2012 – June 30, 2013

Author: J. Ivan

Personnel: A. Seglund, Colorado Parks and Wildlife, R. Truex, U.S. Forest Service

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ABSTRACT

Mountain pine and spruce beetle infestations have reached epidemic levels in Colorado, impacting approximately 6.6 million acres since the initial outbreak in 1996. Though bark beetles are native to Colorado and periodic infestations are considered a natural ecological process, the geographic scale of their impact and simultaneous infestation within multiple forest systems has never been observed. This historic outbreak is having significant impacts on composition and structure of forest stands that will propagate for decades into the future. The widespread and rapid mortality of forested systems in Colorado is likely to have a dramatic, but poorly understood effect on wildlife species that depend on these habitats. This project proposed here will use occupancy estimation to determine which wildlife species (both species of conservation concern and game species) maintain a presence throughout the course of an outbreak, which species disappear once a stand is infected, and when or if extirpated species return as the stand recovers. Statewide sampling began during summer 2013 and half of the proposed 300 sites were surveyed for breeding bird and small mammal activity. Data entry is ongoing and no formal analyses have been completed to date.

WILDLIFE RESEARCH REPORT

SMALL MAMMAL AND BREEDING BIRD RESPONSE TO BARK BEETLE OUTBREAKS IN COLORADO

JACOB S. IVAN

PROJECT NARRATIVE OBJECTIVE

Assess the impact of mountain pine beetle (*Dendroctonus ponderosae*) and spruce beetle (*Dendroctonus rufipennis*) outbreaks on small mammal and breeding bird communities in Colorado.

SEGMENT OBJECTIVES

1. Complete peer-reviewed study plan and power analyses for bark beetle project.
2. Complete fieldwork for first of two years of sampling.

INTRODUCTION

Mountain pine beetle (*Dendroctonus ponderosae*) and spruce beetle (*Dendroctonus rufipennis*) infestations have reached epidemic levels in Colorado, impacting several million acres since the initial outbreak in 1996 (http://foresthealth.fs.usda.gov/portal/PestSummary/DamageSummary). Though bark beetles are native to Colorado and periodic infestations are considered a natural ecological process, the geographic scale of their impact and simultaneous infestation within multiple forest systems has never been observed (Western bark beetle strategy; http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5338089.pdf). This historic outbreak is having significant impacts on composition and structure of forest stands that will propagate for decades into the future.

The widespread and rapid mortality of forested systems in Colorado is likely to have a dramatic, but poorly understood effect on at least some wildlife species that depend on these habitats. However, most work examining the impacts of beetle infestation on wildlife originates from the Pacific Northwest (e.g., Martin et al. 2006, Norris and Martin 2008, Ritchie 2008, Drever et al. 2009, Kroll et al. 2012). Studies assessing beetle impacts in the Southern Rockies are scant (e.g., Stone 1995) and no project to date has focused on Colorado. Additionally most previous work has focused largely on the avian community. Here we propose a study to assess the impacts of beetle infestations on a suite of wildlife species inhabiting the subalpine zone in Colorado. We focus on 3 mammalian and 12 avian species of conservation concern (Table 1). Note, however, that the sampling methods proposed here will likely result in detections of many other species beyond those of conservation concern, including game species. We will attempt to make statewide inference to both lodgepole pine (*Pinus contortus*) and Engelmann spruce (*Picea engelmanni*)/subalpine fir (*Abies lasiocarpa*) systems, which are being infested primarily by mountain pine beetle and spruce beetle, respectively.

We expect wildlife response to the beetle epidemic to vary by species and forest system. For instance, in mature lodgepole pine stands, we expect red squirrels to be fairly ubiquitous in areas that have not been or have only recently been impacted, but as the infestation runs its course and cone-producing trees die, we expect occupancy to decline (Fig. 1). Conversely, in that same system, we expect occupancy of snowshoe hares to be near zero in stands that have little or no beetle impact, but occupancy should increase dramatically as the canopy is opened up and understory develops (Fig. 2).

METHODS

This project will primarily use occupancy estimation to determine which wildlife species maintain a presence throughout the course of an outbreak, which species decline or disappear once a stand is infested, and when or if extirpated species return as the stand recovers. As such, multiple surveys will be conducted at each site, and for each survey, we will record whether the species of interest is detected or not detected. This "1,0" encounter data can then be used to estimate the probability of detecting a species given that it occurs at a site (p), as well as the proportion of sites (ψ) in the population that are occupied (MacKenzie et al. 2002, MacKenzie et al. 2006). For avian species, multiple "surveys" result from binning the detections of each species during a 5-minute point count into 1 minute intervals (thus 5 "surveys"). Additionally, sampling for avian species involves conducting surveys at 16 spatial replicates within each 1-km sample unit of interest (see *Sampling Avian Species* below). Thus, multiple survey information may come from space as well as time. For mammalian species, we will bin camera data into daily or weekly intervals to transform continuous camera sampling into the multiple survey framework of occupancy estimation. Note that because both the mammalian and avian species we will sample are mobile, the metric we are estimating is more appropriately termed "probability of use" rather than "probability of occupancy" (MacKenzie et al. 2006, p. 213). That is, we will attempt to estimate the proportion of sites being used by a particular species of interest and relate that to beetle infestation. Sampling will occur statewide with sample sites stratified by system (lodgepole pine or spruce/fir). For the purposes of this project, we will assume that each selected site is closed to changes in occupancy over the course of our sampling session. Thus, we assume that each cell is either used by a species of interest or not, and this status does not change over the course of the sampling period (end of May through early July for avian species; end of May through end of August for mammalian species). Additionally, we assume that if abundance of a species changes in response to beetles, that change will be reflected in occupancy estimates. In other words, species will not appreciably change their home range size as their abundance changes, a phenomenon that could make occupancy estimation blind to the wildlife response that is actually occurring (Efford and Dawson 2012).

Sampling Avian Species:

Avian sampling will follow the design described by Pavlacky et al. (2012) in which the each sample unit (1-km cell) is sub-sampled by 16 point count stations separated by 250m (Fig. 3). Each sample unit will be surveyed by a pair of technicians over the course of a single morning (half-hour before sunrise to 5 hours after sunrise) during the breeding season (late May to early July). Point counts will last for 5 minutes at each of the 16 stations, and technicians will record each species seen or heard during each minute of the count. They will also measure the distance to each individual using a laser range finder to facilitate truncation of detections for analysis and for use in density estimation via distance sampling. At the conclusion of each point count at each of the 16 stations, technicians will play short recordings of both dusky grouse (*Dendragapus obscures*) and northern goshawks (*Accipiter gentilis*) in an effort to elicit a response from those 2 species of interest.

All sampling will follow established protocols (Hanni et al. 2012). That is, access to each site will be verified ahead of time to avoid trespassing, exposure to unsafe conditions, and to ensure completion of the survey in the allotted time. At each station, in addition to recording birds seen and heard, technicians will record covariates potentially important in explaining variation in detection probability including cloud cover, wind speed, and temperature. They will also record the general habitat type, along with attributes of the canopy, shrub, and ground cover layers. See "Covariates" below for further details.

Sampling Mammalian Species:

Presence-absence data on small to medium-sized mammals species can be efficiently obtained over a broad scale using snow tracking, track plates, or remotely triggered cameras (Zielinski et al. 1995, Zielinski et al. 2013). Snow tracking is highly dependent on environmental conditions, raises safety and access issues, and cannot be dove-tailed efficiently with breeding bird sampling. Track plates work well, but require frequent visits to remove tracks and replace bait. Recent advances in remotely triggered cameras coupled with the availability of large, cheap memory allow for extended camera deployments with few, if any, visits between the initial deployment and retrieval (Kucera and Barrett 2011). For these reasons, we will use cameras as the primary mechanism for sampling the small to medium-sized mammals of interest.

To maximize efficiency, avian crews will deploy a single camera in the center of each 1-km sample unit as they are conducting point counts (Fig 3). Cameras will remain deployed for at least 8 weeks, then will be retrieved during mid to late summer after avian surveys have been completed. Deployments will be altered slightly from typical game animal set-ups to account for the smaller-bodied targets. That is, cameras will be positioned slightly lower (~70cm) and closer to a lured target tree (~3m). We will use only a small amount (<5 ml) of lure (whichever of the following performs best during ongoing pilot work: commercial apple scent, rabbit lure, squirrel lure, marten lure, or peanut butter) to draw individuals in the immediate vicinity to the target tree, and thus pull them in front of the camera. Note that while the camera will be deployed in the center of each $1km^2$ sample unit, we do not assume that the camera is sampling all small mammals in that unit. We will treat the camera itself (and its zone of sensitivity) as the sample unit for the mammalian portion of the project, as is customary for occupancy estimation using this method.

***Power Analyses*:**

In an effort to test remote cameras as a means for monitoring lynx (*Lynx canadensis*), 120 were deployed in the San Juan Mountains of southwest Colorado (exclusively spruce/fir forest) from Fall to early Summer, 2010–2011 (Ivan 2011). In addition to lynx photos, that effort yielded >4,000 photos of snowshoe hares (*Lepus americanus*), >1,000 photos of red squirrels (*Tamisciurus hudsonicus*), >400 photos of American marten (*Martes americana*) as well as several thousand photos of game species such as black bears (*Ursus americanus*), moose (*Alces alces*), elk (*Cervus canadensis*), and mule deer (*Odocoileus hemionus*). We used these pilot data to estimate probability of detection and occupancy (use) for these species. Binning the continuously collected data into weekly intervals resulted in detection probabilities of 0.11, 0.14, and 0.24 for marten, squirrels, and hares, respectively ($\psi = 0.27$, 0.33, and 0.47, respectively). Given that these sets were specific to lynx and that others have had better success sampling these species during summer (R. Truex, United States Forest Service, unpublished data; K. Blecha, Colorado State University, unpublished data), these estimates are likely conservative.

To determine sample size necessary to meet our objectives, we used these pilot estimates to conduct a power analysis. Using Program MARK (White and Burnham 1999), we simulated a scenario intended to mimic the expected response of snowshoe hares to pine beetle outbreaks in the lodgepole system. That is, for each simulation we specified a true model in which $p = 0.2$, and ψ for un-impacted stands was very low (0.1) but increased linearly to ~0.5 for stands that were impacted 15 years ago. We then fit to the data generated from this true model, an estimation model with the same structure as well as a second estimation model that did not include the linear relationship. We conducted 1000 simulations in this fashion for sample sizes of $N = 50, 75, 100, \ldots, 250$ sample units. We then computed the proportion of times out of 1000 simulations in which Akaike's Information Criterion (corrected for small sample size, AIC_c, Burnham and Anderson 2002) selected the estimation model that reflected truth. We interpreted this proportion as a measure of power, the probability of correctly identifying the underlying relationship given the sample size. This exercise indicated that we need to sample 125–175 units in order to attain enough power ($1-\beta = 0.80$) to reasonably expect to identify relationships of interest (Fig. 4). We assumed that these power estimates would be conservative for avian species as more information is available for estimating parameters of interest due to the 16 spatial subsamples within each primary unit.

***Site Selection*:**

We obtained a 1-km grid covering western Colorado from the Rocky Mountain Bird Observatory (RMBO). From this we selected the population of sample units of interest based on the following criteria: Units had to occur largely on public land (i.e., we selected only those cells in which the ownership in the RMBO GIS layer was indicated as Forest Service, Bureau of Land Management, National Park Service, or State of Colorado), ≥75% of each unit had to occur above 8500' to ensure a reasonable chance of detecting hares and martens (Buttery and Gillam 1987, Armstrong et al. 2011), and ≥75% of each unit had to be covered with coniferous subalpine forest vegetation (i.e., spruce/fir, lodgepole pine, or mixed cover types as mapped using the Colorado Vegetation Classification Project dataset [CVCP, ndis.nrel.colostate.edu/coveg]). This resulted in a 15,113 sample units available for sampling.

Next, we overlaid the CVCP vegetation layer and tallied the percentage of each sampling unit covered by spruce/fir forests (CVCP values 61, 71, 81) or lodgepole forests (CVCP values 68, 77, 86). A unit was classified as spruce/fir if at least 2/3 of the vegetation cover within it was coded as spruce/fir; similarly, a unit was labeled as lodgepole pine if at least 2/3 of its land area was covered by that vegetation type. Units that could not be classified as one of these 2 vegetation types but for which the sum of the spruce/fir and lodgepole types exceeded 2/3, were classified as "mixed" forests. Because mixed forests generally occur adjacent to pure lodgepole pine stands, and because we do not have the resources to sample 3 stand types, we lumped these with lodgepole pine for the purposes of site selection. There were 7,035 units available for sampling in the spruce/fir stratum; 8,078 available in the lodgepole/mixed stratum

We selected a sample of 150 1-km^2 units from each of the 2 strata (spruce/fir, lodgepole/mixed) using the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Fig. 5, Theobald et al. 2007). This algorithm draws a random sample from the population of potential sample units, thus ensuring that the inference drawn from the sample applies back to the population. However, it also guarantees spatial balance such that selected sample units cover the full extent of the occurrence of the population in space. Importantly, the algorithm also assigns a sampling order to every unit available so that if and when units need to be discarded due to issues with access, safety, etc., new units (e.g., units 151, 152, 153, etc.) can be added on the fly to replace discarded ones without compromising the integrity of the sample.

To identify the types of relationships described in Section D above, the sample units should ideally be spread across the range of the primary covariate, "time since initial infestation." To check that this was roughly the case, we created a histogram binned by year of initial infestation. In general, the spatially balanced sample from the lodgepole/mixed stratum resulted in roughly equal representation of the available year classes. However, because the spruce beetle epidemic has not advanced to the extent of the pine beetle outbreak, stands that had not yet been infested were over-represented in our initial spatially balanced sampled from that stratum (i.e., 60% of the units selected had not yet been impacted). To even out our sampling (reduce the amount of sampling in the un-impacted category and spread the effort to other categories), we re-ran the RRQRR algorithm, this time specifying an inclusion probability of 0.2 for unimpacted units, 1.0 for all others. This resulted in a sample that was still balanced over space, but also more balanced with respect to time since initial infestation.

***Covariates*:**

There are numerous variables that may influence both p and ψ. Some of these are of genuine interest (e.g., how occupancy estimates vary with time since initial infestation) while others are simply nuisance variables that create noise in the modeling process (e.g., daily differences in wind speed or differences between observers). Either way, variables that have a significant impact on either parameter should be measured and included in the analysis to afford the best opportunity for discovering how species react to beetle infestations. We provide a list of potential covariates of interest (Table 2) and indicate which will be collected during sampling, after sampling, and from remotely sensed information.

***Data Analysis*:**

Data from the avian surveys will be uploaded daily and housed on a server maintained by RMBO. The RMBO database is designed to handle the type and quantity of data collected for this project and will facilitate queries necessary to prepare data for analyses. We will employ the hierarchical occupancy model described by Pavlacky et al. (2012) to analyze avian data. This model properly treats the 16 subsamples and will allow us to make inference about occupancy at the 1-km scale of interest as well as at subsampling scale (16 points). At a minimum, we will fit for each species, or guild of species, models that specify a constant, linear, quadratic, or 3rd order polynomial relationship between occupancy and time since initial infestation. We will make inference regarding which of these hypotheses best describes the response of a given species to beetle infestation using AIC_c. As described above, there is likely to be a large number of covariates that can potentially influence estimates of occupancy and/or detection probability, and an even larger number of potential combinations of these covariates. Given this reality, we will likely employ some sort of ad hoc method for limiting the size of the model set (Lebreton et al. 1992, Doherty et al. 2012). Because we will record the radial distance from the point count station to detected individuals, it may be possible to estimate density using distance sampling for at least some species (Buckland et al. 2001).

For mammalian species, all photos and associated data will be stored in a custom database previously designed by CPW for camera work. For each species and habitat type, we will fit models reflecting the same relationships between occupancy and time since initial infestation described above. However, these models will be fit using the tradition single-season occupancy formulation as described by MacKenzie et al. (2002, 2006) and implemented in Program MARK (White and Burnham 1999). As with modeling of avian response to beetle outbtreak, we will consider several covariates likely to influence detection and/or occupancy, and will use an ad hoc method to limit the number of possible models to fit.

RESULTS

As planned, we sampled 150 sites (N = 75 in each stratum) from May 28 to July 17, 2013. We were unable to secure permission to sample in wilderness using remote cameras. Therefore we excluded 74 sites selected in the original spatially balanced sample and replaced them with other sites outside of wilderness. Additionally, 7 sites from the original sample were discarded due to private property; 4 were discarded as they were deemed too difficult to access and/or sample; 4 were discarded due to wildfire activity. We hope to obtain permission to sample wilderness sites for the 2013–14 sampling season. In that case we will sample wilderness sites selected initially in addition to those sites slated for sampling in 2013–14.

At this time, all data from the avian sampling portion of the project has been entered into the RMBO database, but no analyses have been performed. Fifty-six of the 150 remote cameras have been retrieved, yielding over 61,000 photos. Two of these cameras were destroyed by the West Fork Fire, which started near Wolf Creek Pass in the middle of June. No photos could be salvaged from those 2 devices. Two more cameras suffered severe, internal water damage. These cameras operated for at least part of the sampling period and we retrieved photos taken during their active period. Camera retrieval is ongoing and is expected to be complete by September 30. Photos have not yet been archived, but a cursory look at the sample indicates that all 3 mammalian species of interest were detected. Additionally, we obtained photos of elk, deer, moose, black bears, ground squirrels (*Callospermophilus* sp.), chipmunks (*Neotamias* sp.), and several species of birds.

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Prepared by____________________________
Jake Ivan, Wildlife Researcher

Table 1. Species of conservation concern targeted for sampling within the proposed project. All species are listed as Tier 1 or Tier 2 under the Colorado Wildlife Action Plan (CWAP) and/or as sensitive species by the United States Forest Service Region 2 (USFS R2) and/or as vulnerable at the Sub-national scale by NatureServ. Note that snowshoe hares and red squirrels are not listed specifically by any of these entities (thus the gray symbols), but together they comprise nearly 100% of the diet of Canada lynx, a state and federally listed species.

Species	CWAP	USFS R2	NatureServ
Mammals			
snowshoe hare	x		
red squirrel	x		
American marten		x	
Birds			
American Three-toed Woodpecker	x	x	x
Broad-tailed Hummingbird	x		
Cassin's Finch	x		
Cordilleran Flycatcher	x		
Dusky Flycatcher	x		
Dusky Grouse	x		
Evening Grosbeak	x		
Northern Goshawk	x	x	x
Olive-sided Flycatcher	x	x	x
Red Crossbill	x		
Red-naped Sapsucker	x		
Williamson's Sapsucker	x		

Table 2. Potential covariates that may influence detection probability (p) or occupancy (ψ) or both.

p	ψ
observer[a]	habitat type[a]
wind[a]	time since initial infestation[c]
cloud cover[a]	maximum severity of infestation[c]
temperature[a]	topographic wetness index[d]
habitat type[a]	canopy cover/height/species composition/live-dead[a]
canopy cover[a]	shrub cover/height/species composition[a]
shrub cover[a]	ground cover/type[a]
slope[b]	distance to edge of infestation wave[d]
	basal area[b]
	trees/acre[b]
	saplings/acre[b]
	coarse wood[b]
	horizontal cover[b]

[a] Recorded at each of the 16 point count stations during avian surveys; habitat covariates measured via ocular estimate.

[b] Detailed common stand exam measurements taken at camera location upon retrieval of camera

[c] Obtained from USFS Aerial Detection Survey Data, 1996-2012

[d] Computed using GIS

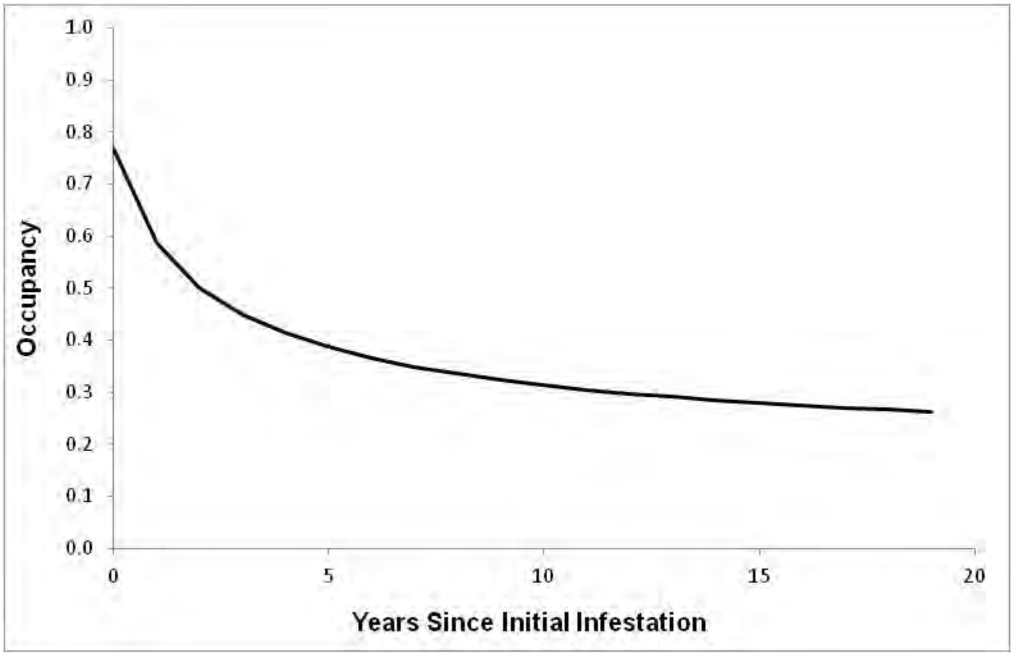

Figure 1. Hypothesized relationship between red squirrels time since initial infestation by mountain pine beetles. Occupancy should be high for mature lodgepole stands that have not yet been impacted by beetles, but should drop over time as cone production declines.

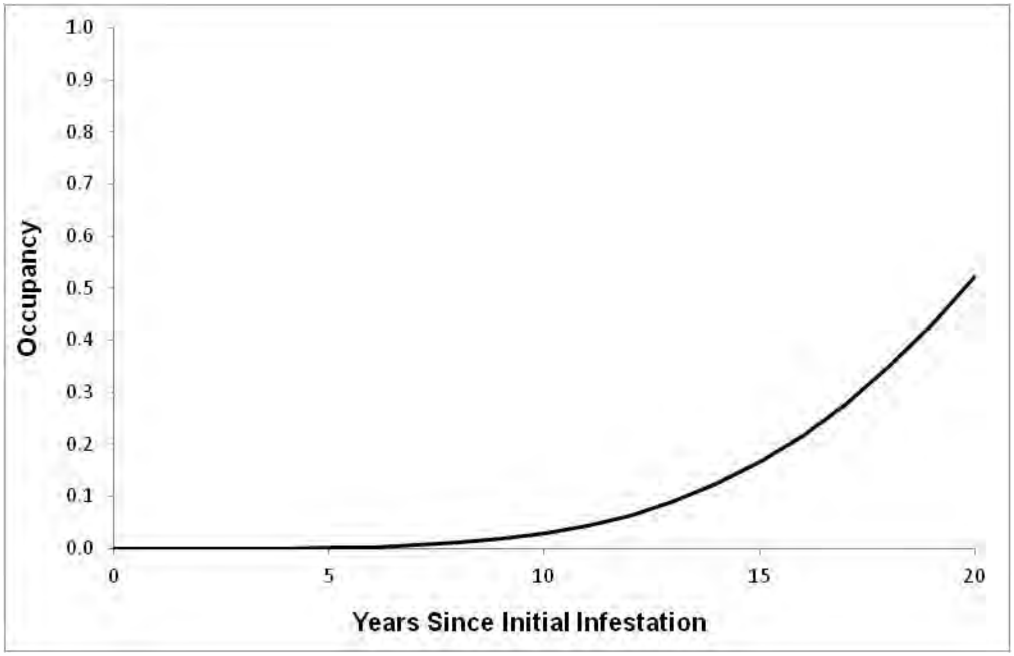

Figure 2. Hypothesized relationship between snowshoe hares and time since initial infestation by mountain pine beetle. Occupancy should be near zero for mature lodgepole stands that have not yet been impacted by beetles, but should increase over time as the understory develops.

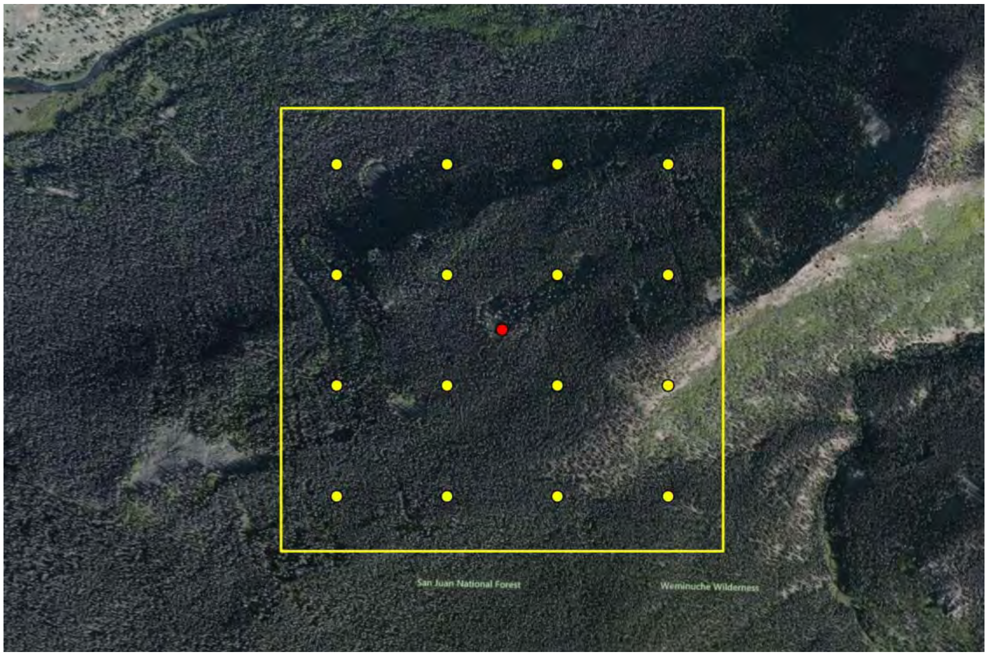

Figure 3. Example 1 km^2 sample unit with 16 equally spaced (250m) point count locations (yellow circles) inside and a remote camera deployed in the center of the unit (red circle).

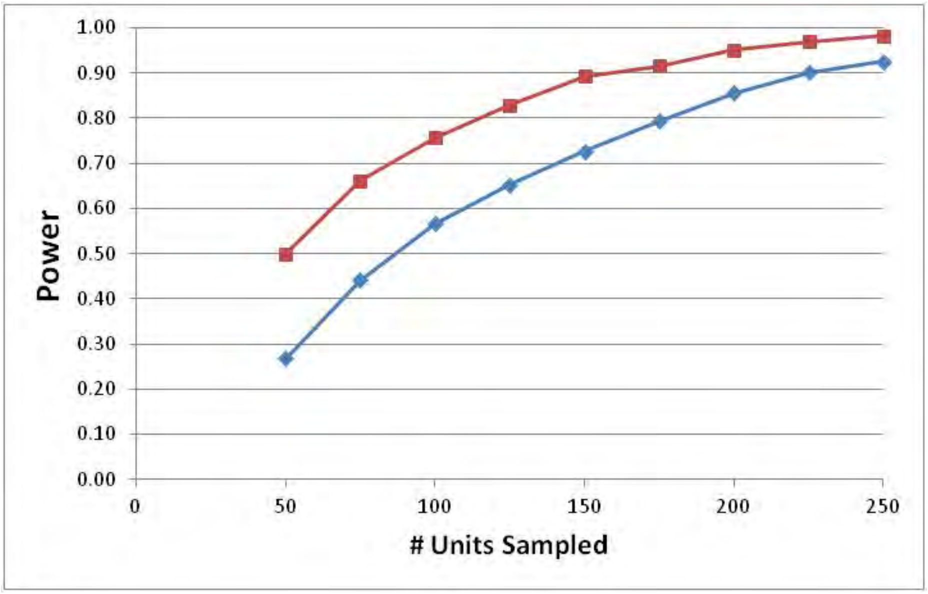

Figure 4. Power for detecting a linear relationship between occupancy and "time since initial infestation" for various sample sizes (number of 1-km units sampled). Curves are based on estimates of *p* obtained from pilot work. For all simulations ψ was specified to be 0.1 for un-impacted stands and increased linearly to 0.5 for stands impacted 15 years prior. Curves represent the proportion of 1000 simulations in which AIC$_c$ correctly identified the model with the "time since initial infestation" covariate as the better model (red squares) or the better model by at least 2 AIC$_c$ units (blue diamonds) compared to a constant model without the effect.

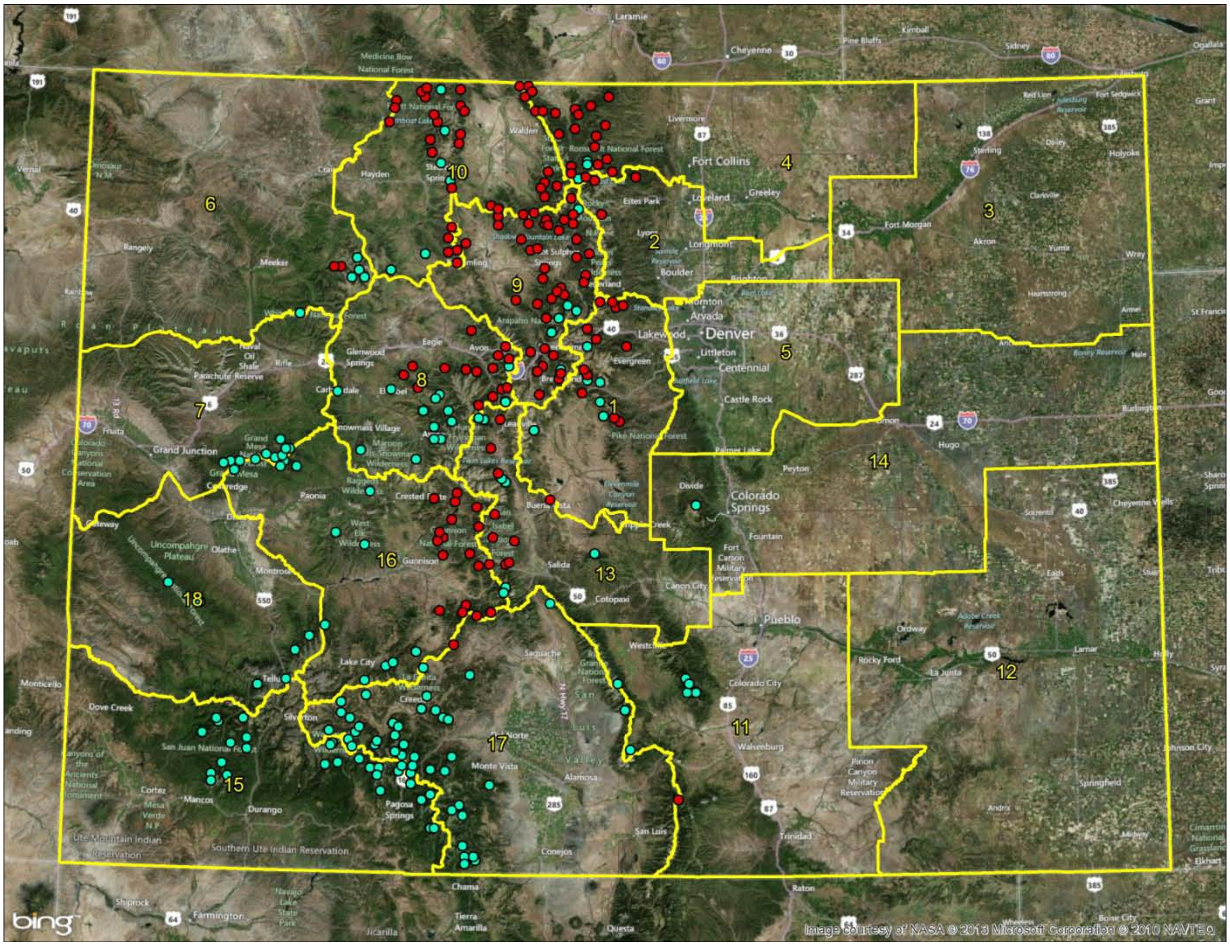

Figure 5. Initial selection of sample sites overlaid on Colorado Parks and Wildlife Area boundaries (yellow polygons). Red markers indicate the initial 150 sites selected for sampling the lodgepole pine/mixed system. Teal markers indicate the initial 150 sites selected for sampling the spruce/fir system. Selection was random and spatially balanced. Note that these sites are only the initial selection. Some will be discarded and replaced due to safety, access, and other issues during the course of sampling.

Colorado Parks and Wildlife
July 2012–June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	N/A	:	Statewide Monitoring of Canada Lynx in Colorado: Evaluation of options
Federal Aid Project No.	N/A		

Period Covered: July 1, 2012 – June 30, 2013

Author: J. Ivan

Personnel: M. Ellis, Alaska Department of Fish and Game, M. Schwartz, U.S. Forest Service Rocky Mountain Research Station

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ABSTRACT

In an effort to restore a viable population of Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006. In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success, and that the population of Canada lynx in the state was apparently viable and self-sustaining. Here we evaluate options for monitoring the long-term success of the reintroduction effort using noninvasive techniques to assess species status and distribution. Ideally, this could be accomplished by estimating abundance of lynx in the state on a recurring basis. However, abundance estimation can be difficult for rare, wide-ranging carnivores because such efforts typically require multiple encounters with a number of individuals. Occupancy estimation may be a useful alternative as sampling under this framework requires only detection or non-detection information at the species level rather than multiple encounters with individuals. Models are fit to the detection data, collected over multiple visits to sampling units, to estimate the proportion of sample units used by the focal species within a study area. The monitoring objective may be to simply track this proportion (ψ) through time. However, ψ and abundance are clearly related; when abundance is zero, ψ is zero, and when the landscape is saturated with animals, $\psi = 1.0$. Thus, an alternative objective may be to use estimated ψ as a surrogate for abundance, and thus track abundance through time using occupancy estimation. We used a series of simulations based on pilot data to assess the effort required to detect declines (or increases) of interest in abundance and ψ of lynx in Colorado using occupancy estimation. We found that small changes could not be detected even with an enormous amount of effort. Even 50% declines or increases in abundance or ψ would require substantial effort and coordination to implement on a statewide basis. Tracking abundance through time using occupancy required relatively more effort than simply tracking a similar decline in ψ itself. Given these results, perhaps a scaled down approach is most practical. That is, CPW could implement a rigorous occupancy estimation program to track abundance, but only in a portion of the state. Elsewhere, rudimentary presence/absence surveys (i.e., surveys

conducted without repeat visits, and probably on a rotating basis so any given mountain range is only visited every ~5 years) could be conducted to ascertain the distribution of lynx among the major mountain ranges and this distribution would tracked through time as a secondary measure of population performance.

WILDLIFE RESEARCH REPORT

STATEWIDE MONITORING OF CANADA LYNX IN COLORADO: EVALUATION OF OPTIONS

JACOB S. IVAN

PROJECT NARRATIVE OBJECTIVE

Use simulation to assess occupancy estimation as a means of monitoring Canada lynx in Colorado.

SEGMENT OBJECTIVES

1. Complete simulations to assess the effort required to track various declines (or increases) in *abundance* of lynx using occupancy estimation.
2. Complete simulations to assess the effort required to track various declines (or increases) in *occupancy* of lynx using occupancy estimation.

INTRODUCTION

The Canada lynx (*Lynx canadensis*) occurs throughout the boreal forests of northern North America. While Canada and Alaska support healthy populations of the species, the lynx is currently listed as threatened under the Endangered Species Act (ESA) of 1973, as amended (16 U. S. C. 1531 et. seq.; U.S. Fish and Wildlife Service 2000) in the conterminous United States. Colorado represents the southern-most historical distribution of lynx, where the species occupied the higher elevation, montane forests in the state (U.S. Fish and Wildlife Service 2000). However, lynx were extirpated, or reduced to a few animals, in Colorado by the late 1970's, (U.S. Fish and Wildlife Service 2000) most likely due to multiple human-associated factors including predator control efforts such as poisoning and trapping (Meaney 2002). Given the isolation of and distance from Colorado to the nearest northern populations of lynx, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) considered reintroduction as the best option to reestablish the species in the state. Therefore, a reintroduction effort was begun in 1997, and 218 lynx were released into Colorado from 1999 – 2006 (Devineau et al. 2010). The goal of the Colorado lynx reintroduction program was to establish a self-sustaining population of lynx. Progress toward this goal was tracked via evaluation of criteria related to lynx survival, fidelity, and recruitment. Recently, CPW determined that the criteria had been met and an apparently viable Canada lynx population currently exists in Colorado (Shenk and Kahn 2010).

In order to track the persistence of this new population and thus determine the long-term success of the reintroduction, a minimally-invasive, statewide monitoring program is required. Ideally, this could be accomplished by estimating abundance of lynx in the state on a recurring basis. However, abundance estimation using traditional mark-recapture methods is difficult for rare, wide-ranging carnivores because such it typically requires multiple encounters with a number of individuals (Lukacs 2013). New advances in spatially explicit capture-recapture (Efford et al. 2009, Royle et al. 2009), use of multiple data sources (Sollmann et al. 2013a), and implementation of mark-resight approaches (Sollmann et al. 2013b) make the problem more tractable as these approaches generally require less intensive capture efforts than traditional mark-recapture. However, they still require some of this work, which can be both difficult and invasive.

Alternatively, occupancy estimation may be a useful approach for monitoring lynx (MacKenzie et al. 2006). Such an approach requires several visits to a set of sampling units, but the data collected for each visit is simply detection or non-detection of the focal species (MacKenzie et al. 2003). There is no need for marking or tallying individuals. The detection information is used to estimate the proportion (ψ) of sample units used by the focal species (i.e., "occupancy") which can then be monitored through time. The advantage in such an approach is that no individual identification is necessary and the information gathered during sampling is generally easier to obtain, especially for rare carnivores. The disadvantage is that information obtained about the population of interest is less resolute (i.e., knowing the proportion of the landscape used by a species is less informative than knowing the number of individuals within it).

Finally, monitoring might be accomplished by simply documenting distribution of lynx in the state. Under this approach, the metric of interest to be tracked through time would be the number of mountain ranges (of the 6–8 main ranges) with evidence of use by lynx. Currently lynx are known to be present in the San Juan, Sawatch, and Elk Mountains where the reintroduction and/or associated research occurred. Expansion into other ranges over the long-term could be considered evidence of a successful reintroduction; recession into only 1 range, or none would indicate failure. Monitoring distribution is the least costly approach considered here, but also the least informative and least rigorous.

We assume that estimation of abundance is not a viable option due to cost, although this assumption should be formally tested, especially as new statistical techniques arise. We further assume that documenting distribution is the least costly option and is thus logistically feasible. However, there is no power analysis or other statistical considerations associated with this option. Thus, from here forward, we focus on using simulation to assess the feasibility of using occupancy for monitoring lynx in Colorado.

Under an occupancy framework, the monitoring objective may be to declare ψ as the metric of interest and simply track it through time as a means of monitoring the lynx population in a coarse sense. However, ψ is clearly related to abundance; when abundance is zero, $\psi = 0$, and when the landscape is saturated with animals, $\psi = 1$. Thus, an alternative objective may be to use estimated ψ as a surrogate for abundance, and thus attempt to track abundance through time using occupancy estimation. This may be a preferable approach because abundance is ultimately the quantity of interest. The utility of this idea relies on the strength of the relationship between ψ and abundance, which is partially dependent on sampling effort and partially dependent on the characteristics of the system under study. That is, if home range size and territorial tendencies of the focal species result in an average of 1 individual per sample unit, then ψ can be expected to mirror abundance quite well. However, if the interaction of these characteristics leads to multiple individuals using a sample unit (on average), then ψ and abundance will be relatively decoupled. Abundance could decline fairly significantly before precipitating any change in ψ.

We conducted a series of simulations to assess the effort required for using occupancy estimation to detect declines (or increases) of interest in abundance or ψ of lynx in Colorado. Our simulations were calibrated to reflect estimates of ψ and detection probability (p) collected from pilot work in the state. We compare the various alternatives available for monitoring lynx in Colorado and discuss trade-offs associated with each.

METHODS

Pilot Work

CPW initiated work to evaluate methods for detecting lynx during winter 2009–2010 (Shenk 2009, Ivan and Shenk 2010). Similar to Squires et al. (2012), the pilot study area was divided into 75-km^2 sample units (roughly the size of a female home range) and 3 methods of detecting lynx were tested in 6 sample units where lynx were known to occur: snow tracking surveys, remote camera surveillance, and hair snags. The daily probability of detecting a lynx given their presence in the unit was 0.70, 0.09, and 0.00 for snow tracking, remote cameras, and hair snares, respectively (Ivan 2011). During winter 2010–2011, pilot work was expanded to include 30 wilderness sample units surveyed via remote camera and 30 accessible units surveyed via snow-tracking. The status of lynx (present or not) in these randomly selected units was unknown. We fit single-season occupancy models to data from each stratum and found $\psi = 0.33$ and $p = 0.40$ for wilderness units (Ivan 2012; camera data were collapsed by month into 5 occasions, $p = 0.40$ for each occasion), and $\psi = 0.65$ and $p = 0.37–0.43$ for accessible units (Ivan 2011; based on 3 occasions of snow-tracking surveys). Thus, overall, $\psi \approx 0.50$ and $p \approx 0.40$ for the pilot study area.

Assessment of using occupancy estimation to track changes in ψ

To assess the effort required to detect declines or increases of interest in ψ using an occupancy estimation framework, we conducted a series of analyses using the simulation function in Program MARK (White and Burnham 1999). Within the "robust design occupancy" data type (i.e., multi-season occupancy, MacKenzie et al. 2006), we set up a simulation model in which $\psi = 0.5$ for year 1 and $p = 0.4$, thus matching estimates derived from pilot work. We then specified linear declines in ψ to 0.45 (10% decline), 0.40 (20% decline), or 0.25 (50% decline) over a 10-year period. We also specified an increase in ψ to 0.75 (50% increase) over a 10-year period. We generated data from each simulation model for 2, 3, 4, or 5 occasions and $N = 25$, 50, 75, 100, 125, and 150 units sampled. We also considered that sampling may occur annually or only in alternate years. Thus, there were 192 possible combinations of parameters specifying the simulation model (4 levels of change in ψ, 4 levels of occasions, 6 levels of sample size, 2 levels specifying the survey interval), and we generated 1000 simulated datasets for each of the 192 combinations.

To each of the 192,000 data sets, we fit 2 estimation models. The first fixed ψ to be constant across the 10 years represented in each data set. The second specified a linear trend in estimated ψ. The true, data-generating model always included a trend of some type. Thus we defined "power" as the proportion of simulations in which Akaike's Information Criterion (adjusted for small sample size; AICc) selected the correct (second) model by at least 2 AICc units (Burnham and Anderson 2002). In general, given sparse data (such as that generated from only a few occasions and/or for a small number of sample units) AICc will select the constant model as the one that fits the data best because there is not enough information to support anything but the simplest model. As the data become richer (i.e., more occasions and/or larger sample size), AICc will begin to pick the correct model more often. We adopted the conventional benchmark of 0.8 as a cutoff for adequately identifying declines or increases of interest. That is, combinations of sample size and occasions that resulted in power = 0.80 were deemed adequate to confidently detect declines or increases under consideration.

Assessment of using occupancy estimation to track changes in abundance

To assess the effort required to detect declines or increases in abundance using an occupancy estimation framework, we conducted a series of analysis using the R (R Development Team 2013) package SPACE (Ellis et al. 2013). Specifically, we provided the package with spatially referenced data representing predicted lynx habitat in Colorado (Ivan et al. 2011). The package then randomly assigned home range centers for 125 males and 125 females on this landscape. Home range centers were only allowed to occur in cells that had reasonable probability of being lynx habitat. To mimic territoriality, males were not allowed to have a home range center within 6 km of another male; females could not be assigned a home range center within 5 km of another female. Males and females could be any distance from each other. Once home range centers were assigned for all 250 lynx, each individual was temporarily assigned a bivariate normal utilization distribution (i.e., the probability of occurrence for each individual was highest at its home range center and dissipated equally in all directions) appropriately sized for each sex. This simplistic utilization distribution was then weighted by the underlying map of predicted lynx habitat to produce an irregular, realistic utilization distribution that was unique to each individual. Thus, following this first step, a realistic number of virtual lynx were distributed across the state and assigned reasonable utilization distributions that governed their movement across the landscape. We then specified declines (50%, 20%, 10%), and increases (50%) in abundance over a decade by randomly removing or adding the appropriate number of individuals at each of 10 time steps.

Next, simulated landscapes were overlaid with a sampling grid consisting of 75-km^2 sample units. This was done for each of the 10 time steps. Based on utilization distributions assigned to each individual, SPACE computed the probability of at least 1 animal being present in each unit during each time step (i.e., sampling occasion). It then applied the detection probability specified for the simulation to generate detection/non-detection data for each unit. We generated data sets for a variable number of occasions and sample sizes similar to that described above. As before, each simulated dataset was fitted with 2 competing models, one in which the estimated ψ was fixed to be constant throughout the 10-year period, and second in which it followed a linear trend. We again defined power as the proportion of simulations in which AICc selected the correct model. We also considered the impact of sampling every other year by removing data from even years. On average, estimates of ψ and p for the first year of each simulation were 0.50 and 0.34 respectively, which is close to the values observed from the pilot work. Thus, the model was well calibrated to the field.

Sampling Details

For each of the monitoring metrics, ψ and abundance, we identified the most plausible scenario that could be implemented in the field by CPW personnel, and further detailed the effort required to complete a survey by selecting a mock sample. To accomplish this, we first defined the population of sample units of interest by overlaying a grid of 75-km^2 cells on the predicted lynx habitat layer for Colorado (Ivan et al. 2011). We identified cells as potential sample units if at least 50% of the lynx habitat pixels within them had probability values ≥0.60 (See Ivan et al. 2011 for detailed discussion of these probability values). This resulted in a population of 475 cells from which to draw a sample (Fig. 3). Next, we used the R (R Development Team 2013) package 'spsurvey' (Kincaid 2013) to enumerate each sample unit in a spatially balanced random fashion such that a valid sample of any size could be selected by simply ordering the cells by their randomly assigned number and selecting the 1st N cells. For each scenario of interest, we selected an appropriate sample, then summarized the effort required to complete the sample by CPW Area. We assumed 6 person-days would be required to sample each non-wilderness unit and 10 person-days would be required to sample each wilderness unit. These estimates were based on pilot work and assume that for snow-tracking surveys (non-wilderness units), personnel would work in pairs and complete 3 visits per sample unit. For wilderness units, we assumed personnel would work in pairs over 2.5 days to set 4 cameras in each selected unit, then work another 2.5 days per unit to retrieve the cameras after sampling. These represent minimum estimates of cost as any survey effort would also require personnel time to maintain snowmobiles and cameras, enter data, and complete analyses and reports.

RESULTS

Regardless of whether the objective was to use occupancy estimation to detect declines in ψ or abundance, power was low (≤ 0.40) for all but the most drastic changes in the lynx population, even with significant survey effort (e.g., $N = 125–150$; Fig. 1, 2). Fifty percent declines or increases in ψ over a decade could be adequately detected (power = 0.80) with 3 visits to each of 75 sample units if sampling occurred on an annual basis (Fig. 1). Reducing sampling effort to every other year did not impart dramatic changes to the sample size needed to maintain power. In contrast, annual surveys comprising 3 visits to 125 sample units were required to adequately detect 50% declines or increases in abundance over the same time span (Fig. 2). Also, in the case of abundance, reducing survey effort to every other year required ~250 units in order to maintain power.

Power curves in the panels representing results for 20% and 10% declines in abundance (Fig. 2) were relatively high at very small sample sizes, then declined with increasing sample size before increasing again at large sample sizes. These counterintuitive results are likely artifacts of fitting models to sparse data. When data are sparse, parameters may not be estimated well and the model may return values at a boundary (i.e., ψ will be estimated as either 0 or 1). If the estimates of ψ near the beginning and/or end of the time series are returned as 0 or 1, then a trend may be detected. In an actual analysis with a single data set, such a phenomenon is easy to diagnose and alternatives are available to tweak the model and prevent this from happening. However, when thousands of datasets and model fits are involved, such tweaking is impossible. Thus, these high initial values and subsequent declines should be ignored. Power to detect trends across this range of sample sizes is likely very low.

The most plausible scenarios for monitoring either ψ or abundance were those aimed at detecting a 50% change in either metric. Selection of an actual sample revealed that in both cases, the number of person-hours involved to carry out the sampling was substantial (Fig. 4, 5). For example, the scenario intended to provide an 80% chance of detecting a 50% decline in abundance over 10 years would require making 3 visits to each of 125 sample units on an annual basis. Assuming 2 Biologists, 2 District Wildlife Managers and 2 USFS Biologists were willing the carry out the work in each area, monitoring lynx under this scheme would require on average about 10 days worth of work per person per Area (Fig. 4; on average 64 person-days would be required per area; 64 person-days/6 people ≈10 days). Some Areas would require nearly 3 times that effort (Fig. 4; maximum estimated effort was 184 person-days; 184 person-days/6 people ≈ 30 days of work per person). The scenario intended to provide an 80% chance of detecting a 50% decline in ψ over 10 years was projected to require an average of 38 person-hours to complete per Area, or ~6 days per person if the same set of biologists and managers participated. Again, effort in some Areas would be nearly 3 times higher.

DISCUSSION

We rigorously tested the power to detect various changes in population status of Canada lynx in Colorado using occupancy estimation. Small changes (10% or 20% declines) could not be detected with any reasonable amount of effort. Detection of large changes (50% declines or increases in either abundance or ψ) may be possible but would require considerable investment and coordination among management entities. This was especially true for the scenarios aimed at detecting changes in abundance, which is the more preferable approach as it would be most informative. Detecting large changes in ψ over a 10-year period required just more than half of the effort required to detect the same change in abundance, thus making it more feasible. However, this level of effort would still be costly and the information gained would be of low resolution. That is, by the time ψ declines by 50%, a significant number of individuals would be lost from the landscape, and it may be too late for any action to counter the decline. Monitoring distribution rather than abundance or occupancy would likely be the most affordable option but it is also least informative and least rigorous. In fact, it was not evaluated in this report because it is completely absent of any statistical underpinnings. Furthermore, the distribution approach provides little opportunity to learn why changes are happening. The multi-season occupancy models employed here to track abundance or ψ include extinction and colonization parameters (which we have largely ignored for the purposes of simulation). Modeling these parameters may provide an opportunity to associate changes on the landscape (e.g., bark beetle outbreaks, wildfire, timber harvest) with changes in ψ, thus providing an opportunity to learn why changes are occurring.

Clearly trade-offs exist between containing costs and implementing a program that is meaningful, rigorous, and provides opportunities for continued learning. Perhaps the most practical way forward is a hybrid approach in which CPW implements a rigorous occupancy estimation program to track abundance, but only in a portion of the state, while simultaneously implementing the relatively less rigorous distributional approach statewide. Such an approach would provide detailed information about a (hopefully) representative subpopulation of lynx, but would be easier to implement as it would take less effort it would only be implemented in a portion of the state. Additionally, CPW would still obtain useful information regarding the statewide distribution of animals. If CPW were to adopt such a strategy, we suggest that the rigorous portion of the effort focus on the San Juan Range in the southwest as it provides the bulk of the lynx habitat and has long been considered a core stronghold for the species. Thus, it could be considered a "sentinel" area such that increases in the lynx population there probably bode well for the rest of the state, and declines there probably bode poorly.

ACKNOWLEDGMENTS

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Jake Ivan, Wildlife Researcher

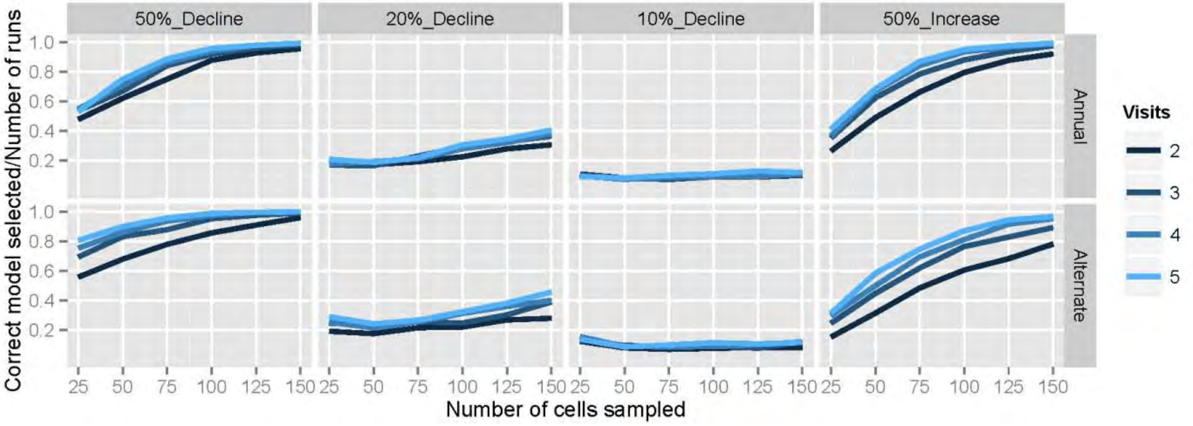


Figure 1. Power to detect various changes in the proportion (ψ) of sample sites used by lynx in Colorado using occupancy estimation. Changes were assumed to occur over a 10-year period. Power is shown for scenarios in which sample units were sampled annually (top panels) and when sampling occurred only in alternate years (bottom panels). "Visits" corresponds to the number of times selected units would be searched to collect detection/non-detection data. Visits could represent days for units surveyed via snow tracking, or they may represent blocks of time into which continuously collected camera data could be binned (e.g., 1 visit = 1 month of camera sampling).

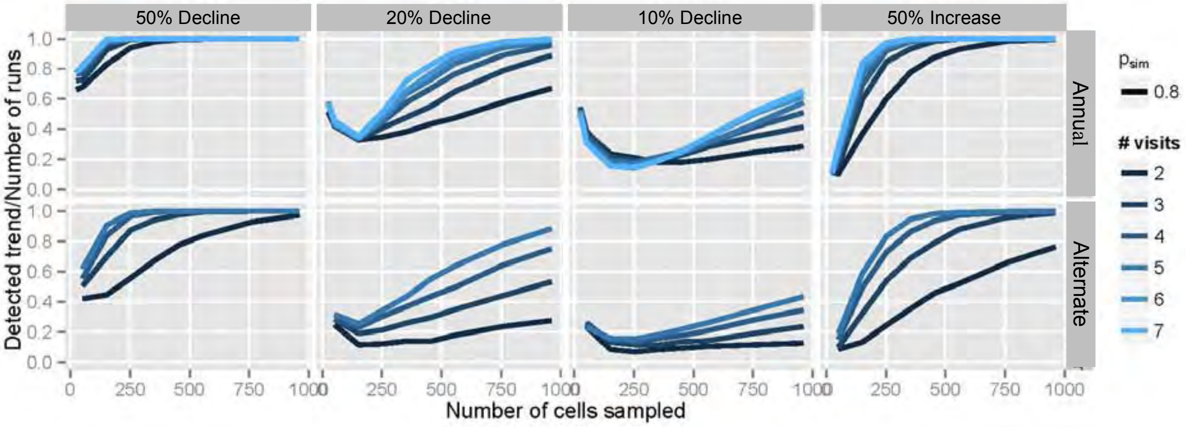


Figure 2. Power to detect various changes in abundance of lynx in Colorado using occupancy estimation. Changes were assumed to occur over a 10-year period. Power is shown for scenarios in which cells are sampled annually (top panels) and when sampling occurs only in alternate years (lower panels). "Visits" corresponds to the number of times selected units would be searched to collect detection/non-detection data. Visits could represent days for units surveyed via snow tracking, or they may represent blocks of time into which continuously collected camera data could be binned (e.g., 1 visit = 1 month of camera sampling).

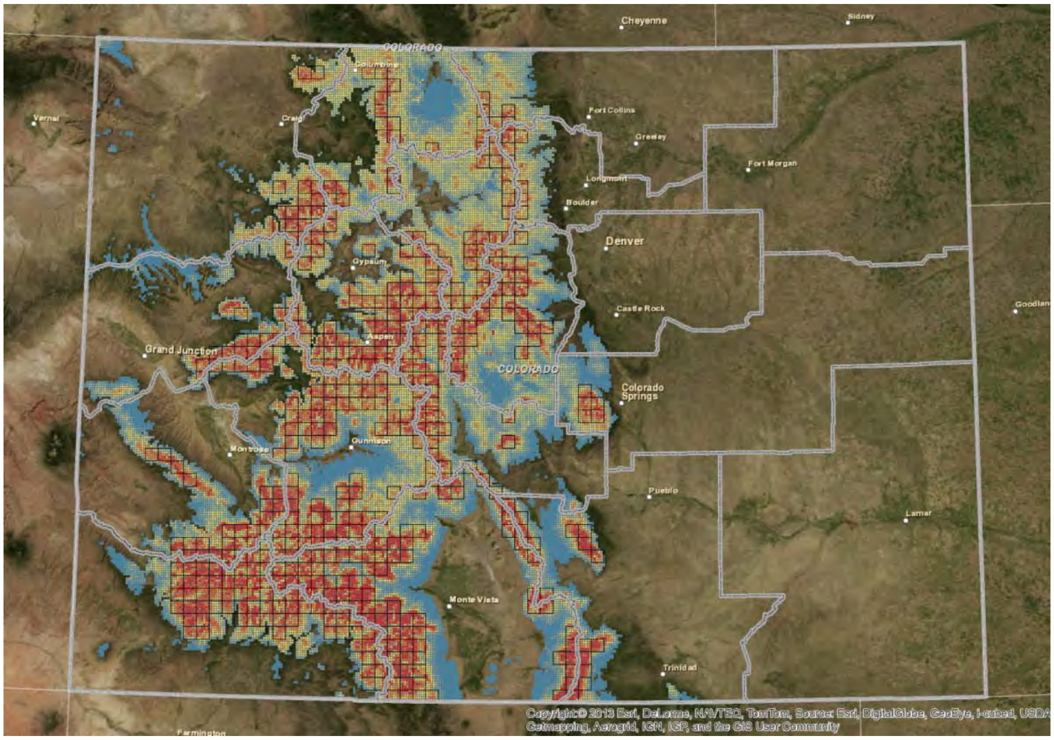
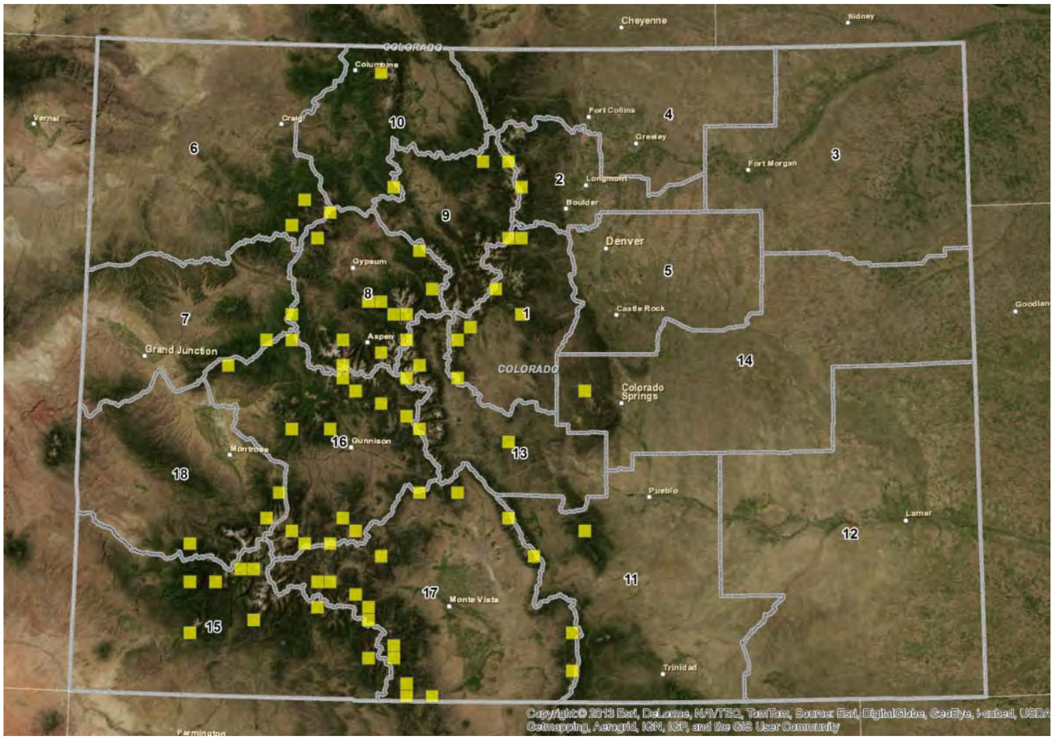


Figure 3. Predicted lynx habitat (red pixels = good, blue pixels = poor) in Colorado overlaid with 75-km^2 sample units (black squares, $N = 475$) from which to select a sample for monitoring declines or increases of interest in ψ or abundance. Only units where at least half of the lynx habitat pixels within them had probability values ≥0.60 were included in the population to sample from. See Ivan et al. (2011) for details regarding construction of the predicted lynx habitat map and interpretation of pixels that comprise it.



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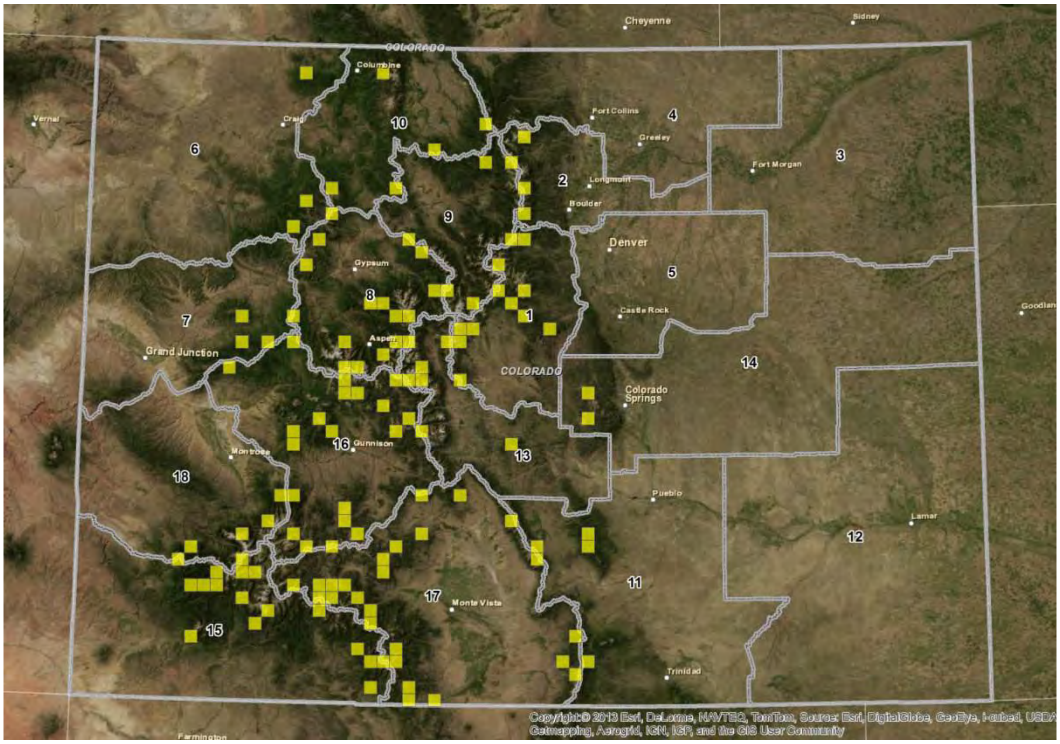
Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Region	**Area**	**#Sample Units**	**Effort (person-days)**
Northeast	1	6	44
	2	1	10
Northwest	6	2	16
	7	1	6
	8	13	102
	9	3	18
	10	2	12
Southeast	11	1	6
	13	4	28
	14	1	6
Southwest	15	8	52
	16	12	76
	17	18	128
	18	3	22
Total		**75**	**526**

Figure 4. Map and tabular summary of a spatially balanced random sample of $N = 75$ cells selected for monitoring a 50% decline or increase in ψ over a 10-year period in Colorado, USA using a combination of snow-track surveys and remote camera surveys. Estimated effort accounts for the differential time required to sample wilderness (cameras) and non-wilderness (snow-tracking) units.



Region	**Area**	**#Sample Units**	**Effort (person-days)**
Northeast	1	11	82
	2	3	26
Northwest	6	3	22
	7	3	18
	8	17	134
	9	5	30
	10	5	34
Southeast	11	4	24
	13	6	44
	14	2	12
Southwest	15	17	122
	16	19	130
	17	26	184
	18	4	28
Total		**125**	**890**

Figure 5. Map and tabular summary of a spatially balanced random sample of $N = 125$ cells selected for monitoring a 50% decline or increase in abundance of lynx over a 10-year period in Colorado, USA using a combination of snow-track surveys and remote camera surveys. Estimated effort accounts for the differential time required to sample wilderness (cameras) and non-wilderness (snow-tracking) units.

Colorado Parks and Wildlife
July 1, 2012 – June 30, 2013

WILDLIFE RESEARCH REPORT

State of Colorado : Parks and Wildlife
Cost Center 3430 : Mammals Research
Work Package 3001 : Deer Conservation
Task No. 6 : Population Performance of Piceance Basin Mule Deer in Response to Natural Gas Resource Extraction and Mitigation Efforts to Address Human Activity and Habitat Degradation
Federal Aid Project: W-185-R :

Period Covered: July 1, 2012 – June 30, 2013

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All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the authors. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

We propose to experimentally evaluate winter range habitat treatments and human-activity management alternatives intended to enhance mule deer (*Odocoileus hemionus*) populations exposed to energy-development activities. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas in Colorado. The data presented here represent the first 5 pretreatment years of a long-term study addressing habitat improvements and evaluation of energy development practices intended to improve mule deer fitness in areas exposed to extensive energy development. We monitored 4 winter range study areas representing varying levels of development to serve as treatment (North Magnolia, South Magnolia) and control (North Ridge, Ryan Gulch) sites and recorded habitat use and movement patterns using GPS collars (≥5 location attempts/day), estimated overwinter fawn and annual adult female survival, estimated early and late winter body condition of adult females using ultrasonography, and estimated abundance using helicopter mark-resight surveys. During this research segment, we targeted 280 fawns (60–80/study area) and 170 does (30–70/study area) in early December

2012 for VHF and GPS radiocollar attachment, respectively, and 140 does in March 2013 (30–40/study area) for late winter body condition assessment. Winter range habitat improvements resulting in 604 acres of mechanically treated pinion-juniper/mountain shrub habitats in each of the 2 treatment areas were completed April 2013. Post-treatment monitoring will continue for 4–6 years to provide sufficient time to measure how deer respond to these changes. Based on data collected during the pretreatment phase: (1) annual adult survival was consistent among areas averaging 80-84% annually, but overwinter fawn survival was more variable ranging from 48% to 85% within study areas, with annual and study area differences primarily due to annual weather conditions and in some cases density dependent influences; (2) migratory mule deer selected increased cover and increased their rate of travel through developed areas, but did not avoid development structures and avoided negative influences through behavioral shifts in timing and rate of migration; (3) mule deer body condition early and late winter was generally consistent within areas, with higher variability among study areas early winter, which likely relate to seasonal moisture within areas and relative forage capacity among areas; (4) mule deer densities appeared to increase in 3 of 4 areas, with a recent decline in North Ridge, but the most recent North Ridge density was comparable to the first 2 years of the study. Detailed habitat use analyses are still pending for the pretreatment period. We will continue to collect population and habitat use data across all study sites to evaluate the effectiveness of habitat improvements on winter range. This approach will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less or non-impacted areas. In collaboration with Colorado State University, we are also evaluating deer behavioral responses to varying levels of development activity in the Ryan Gulch study area and neonate survival in relation to energy development from all study areas. This will allow us to assess the effectiveness of certain Best Management Practices (BMPs) for reducing disturbance to deer and include neonatal data to other demographic parameters for evaluation of mule deer/energy development interactions. The study is slated to run through at least 2017, but extending the study through 2019 is preferable to adequately measure mule deer population responses to landscape level manipulations.

WILDLIFE RESEARCH REPORT

POPULATION PERFORMANCE OF PICEANCE BASIN MULE DEER IN RESPONSE TO NATURAL GAS RESOURCE EXTRACTION AND MITIGATION EFFORTS TO ADDRESS HUMAN ACTIVITY AND HABITAT DEGRADATION

CHARLES R. ANDERSON, JR

PROJECT NARRITIVE OBJECTIVES

1. To determine experimentally whether enhancing mule deer habitat conditions on winter range elicits behavioral responses, improves body condition, increases fawn survival, or ultimately, population density on mule deer winter ranges exposed to extensive energy development.

2. To determine experimentally to what extent modification of energy development practices enhance habitat selection, body condition, fawn survival, and winter range mule deer densities.

SEGMENT OBJECTIVES

1. Collect and reattach GPS collars to maintain sample sizes for addressing mule deer habitat use and behavior patterns in 4 study areas experiencing varying levels of energy development of the Piceance Basin, northwest Colorado.

2. Estimate early and late winter body condition of adult female mule deer in each of the 4 winter herd segments using ultrasound techniques.

3. Monitor over-winter fawn and annual adult female mule deer survival by daily ground tracking and bi-weekly aerial tracking.

4. Conduct Mark-Resight helicopter surveys to estimate mule deer abundance in each study area.

5. Complete habitat treatments for assessing efficacy of habitat improvement projects to mitigate energy development disturbances to mule deer.

6. Continue neonate survival evaluations to complete demographic parameters for assessing mule deer/energy development interactions.

INTRODUCTION

Extraction of natural gas from areas throughout western Colorado has raised concerns among many public stakeholders and Colorado Parks and Wildlife (CPW) that the cumulative impacts associated with this intense industrialization will dramatically and negatively affect the wildlife resources of the region. Concern is especially high for mule deer due to their recreational and economic importance as a principal game species and their ecological importance as one of the primary herbivores of the Colorado Plateau Ecoregion. Extraction of natural gas will directly affect the potential suitability of the landscape used by mule deer through conversion of native habitat vegetation with drill pads, roads, or noxious weeds, by fragmenting habitat because of drill pads and roads, by increasing noise levels via compressor stations and vehicle traffic, and by increasing the year-round presence of human activities. Extraction will indirectly affect deer by increasing the human work-force population of the region resulting in the need for additional landscape for human housing, supporting businesses, and upgraded road/transportation infrastructure. Additionally, increased traffic on rural roads will raise the potential for vehicle-animal collisions and additive direct mortality to mule deer populations. Thus, research documenting these relationships and evaluating the most effective strategies for minimizing and mitigating these activities will greatly enhance future management efforts to sustain mule deer populations for future recreational and ecological values.

The Piceance Basin in northwest Colorado contains one of the largest migratory mule deer populations in North America and also exhibits some of the largest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is expected to reach about 15,000 wells, many of which will occur in the Piceance Basin, which currently supports over 250 active gas well pads (http://cogcc.state.co.us; Fig. 1). Anderson and Freddy (2008*a*) in their long-term research proposal identified 6 primary study objectives to assess measures to offset impacts of energy extraction on mule deer population performance. During the past 5 years, we gathered baseline habitat utilization and demographic data from radiocollared deer across the Piceance Basin to allow assessment of habitat mitigation approaches that were completed April 2013. We are currently monitoring 2 control areas: 1 with development (0.6 pads & facilities/km^2; Ryan Gulch) and 1 without (North Ridge). The control areas will be compared with 2 treatment areas experiencing similar development intensities (South Magnolia, 0.9 well pads & facilities/km^2 and North Magnolia, 0.1 well pads & facilities/km^2), that also recently received habitat improvements (604 acres each). Habitat and mule deer responses to mechanical habitat treatments will be evaluated over the next 4-6 years to assess the success of this habitat mitigation strategy to benefit mule deer exposed to energy development disturbance. In addition, mule deer behavior patterns in relation to energy development activities in the Ryan Gulch area are being monitored to identify effective Best Management Practices (BMPs) for future energy development planning. This progress report describes the previous 5.5 years (Jan 2008–June 2013) of mule deer population performance during the pretreatment phase on 4 winter range herd segments, which includes monitoring habitat selection and behavior patterns of adult female mule deer; spring/summer neonate, overwinter fawn and annual adult female survival; estimates of adult female body condition during early and late winter, and annual late-winter abundance/density estimates.

STUDY AREAS

The Piceance Basin, located between the cities of Rangely, Meeker, and Rifle in northwest Colorado, was selected as the project area due to its ecological importance as one of the largest migratory mule deer populations in North America and because it exhibits one of the highest natural gas reserves in North America (Fig. 1). Historically, mule deer numbers on winter range were estimated between 20,000–30,000 (White and Lubow 2002), and the current number of well pads (Fig.1) and projected number of gas wells in the Piceance Basin over the next 20 years is about 250 and 15,000, respectively. Mule deer winter range in the Piceance Basin is predominantly characterized as a topographically diverse pinion pine (*Pinus edulis*)-Utah juniper (*Juniperus osteosperma*; pinion-juniper) shrubland complex ranging from 1,675 m to 2,285 m in elevation (Bartmann and Steinert 1981). Pinion-juniper are the dominant overstory species and major shrub species include Utah serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), Gamble's oak (*Quercus gambelii*), mountain snowberry (*Symphoricarpos oreophilus*), and rabbitbrush (*Chrysothamnus* spp.; Bartmann et al. 1992). The Piceance Basin is segmented by numerous drainages characterized by stands of big sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainages having been converted to mixed-grass hay fields. Grasses and forbs common to the area consist of wheatgrass (*Agropyron* spp.), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*), Indian rice grass (*Oryzopsis hymenoides*), arrowleaf balsamroot (*Balsamorhiza sagittata*), broom snakeweed (*Gutierrezia sarothreae*), pinnate tansymustard (*Descurainia pinnata*), milkvetch (*Astragalus* spp.), Lewis flax (*Linum lewisii*), evening primrose (*Oenothera* spp.), skyrocket gilia (*Gilia aggregata*), buckwheat (*Erigonum* spp.), Indian paintbrush (*Castilleja* spp.), and penstemon (*Penstemon* spp.; Gibbs 1978). The climate of the Piceance Basin is characterized by warm dry summers and cold winters with most of the annual moisture resulting from spring snow melt.

Wintering mule deer population segments we investigated include: North Ridge (53 km^2) just north of the Dry Fork of Piceance Creek including the White River in the northeastern portion of the Basin, Ryan Gulch (141 km^2) between Ryan Gulch and Dry Gulch in the southwestern portion of the Basin, North Magnolia (79 km^2) between the Dry Fork of Piceance Creek and Lee Gulch in the north-central portion of the Basin, and South Magnolia (83 km^2) between Lee Gulch and Piceance Creek in the south-central portion of the Basin (Fig. 1). Each of these wintering population segments has received varying levels of natural gas development: no development in North Ridge, light development in North Magnolia (0.14 pads & facilities/km^2), and relatively high development in the Ryan Gulch (0.60 pads & facilities/km^2) and South Magnolia (0.86 pads & facilities/km^2) segments (Fig. 1). Among the 4 study areas, North Ridge has served as an unmanipulated control site, Ryan Gulch will serve to address human-activity management alternatives (BMPs) that benefit mule deer exposed to energy development and as a developed control area for comparison to the developed treatment area receiving habitat improvements (South Magnolia), and North and South Magnolia will allow us to assess the utility of habitat treatments intended to enhance mule deer population performance in areas exposed to light (North Magnolia) and heavy (South Magnolia) energy development activities.

METHODS

Tasks addressed this period included mule deer capture and collaring efforts, monitoring neonate and overwinter fawn and annual adult female survival, estimating adult female body condition during early and late winter using ultrasonography, estimating mule deer abundance applying helicopter mark-resight surveys, and working with BLM and the contractor to complete mechanical habitat treatments by spring 2013. We employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to target 280 fawns in December 2012/January 2013, 170 adult females during early December 2012, and 140 adult females (mostly recaptures) during early March 2013. Once netted, all deer were hobbled and blind folded. Fawns were weighed, radio-collared and released on site, and adult females were transported to localized handling sites for recording body measurements and fitted with GPS collars (5 or 48 fixes/day; G2110D, Advanced Telemetry Systems, Isanti, MN, USA) and released. To provide direct measures of decline in overwinter body condition, we targeted 30adult females in each study area that were captured the previous December; Vaginal Implant Transmitters (VITs) were also inserted to assist with neonate capture and collaring efforts spring 2013. Fawn collars were spliced and fitted with rubber surgical tubing to facilitate collar drop between mid-summer and early autumn, and GPS collars were supplied with timed drop-off mechanisms scheduled to release early in April of the year following deployment. All radio-collars were equipped with mortality sensing options (i.e., increased pulse rate following 4–8 hrs of inactivity).

Mule Deer Habitat Use and Movements

We downloaded and summarized data from GPS collars deployed from December 2011 through April 2013. GPS collars maintained the same schedule of attempting to collect locations every 5 hours, except in Ryan Gulch where location rates were programmed for every 30 minutes to increase resolution of movement data for evaluation of deer behavior patterns in relation to differing development activities. We plotted deer locations and recorded timing and distance of spring and fall 2012 migrations for each study area. Mule deer winter concentration areas were created using composite GPS data (March 2010 through April 2011 from all deer; 5 location attempts/day) from each study area and mapped in ArcGIS (ver. 9.3) using Spatial Analyst (kernel probability density functions separated by quantiles). Mule deer resource selection analyses are pending completion of high resolution habitat data layers currently being developed by BLM.

Mule Deer Survival

Mule deer mortality monitoring consisted of daily ground telemetry tracking and aerial monitoring approximately every 2 weeks from fixed-wing aircraft on winter range and bi-weekly aerial monitoring on summer range. Once a mortality signal was detected, deer were located and necropsied to assess cause of death. We estimated weekly survival using the staggered entry Kaplan-Meier procedure (Kaplan and Meier 1958, Pollock et al. 1989). Capture-related mortalities (any doe/fawn mortalities occurring within 10 days of capture) and collar failures were censored from survival rate estimates. We estimated survival rates from 1 July 2012 through 30 June 2013 for adult females, from birth to mid December for neonates, and from early December 2012–mid June 2013 for fawns.

Adult Female Body Measurements

We applied ultrasonography techniques described by Stephenson et al. (1998, 2002) and Cook et al. (2001) to measure maximum subcutaneous rump fat (mm), loin depth (longissimus dorsi muscle, mm), and to estimate % body fat. We estimated a body condition score (BCS) for each deer by palpating the rump (Cook et al. 2001, 2007, 2009). We examined differences ($P < 0.05$) in nutritional status among study areas and between years using a two-sample *t*-test. We considered differences in body condition meaningful when mean rump fat or % body fat differed statistically between comparisons. Other body measurements recorded included pregnancy status (pregnant, barren) via blood samples, fetal counts using ultrasonagraphy, weight (kg), chest girth (cm), and hind-foot length (cm).

Abundance Estimates

We conducted 4 (North Ridge, North Magnolia, South Magnolia) or 5 (Ryan Gulch) helicopter mark-resight surveys (2 observers and the pilot) during early April to estimate deer abundance in each of the 4 study areas. We delineated each study area from GPS locations collected on winter range during the first 3 years of the study (Jan 2008 through April 2011). Two aerial fixed-wing telemetry surveys/study area were conducted during helicopter mark-resight surveys to determine which marked deer were within each survey area, and we confirmed adult female locations during surveys from GPS data acquired April 2013. We delineated flight paths in ArcGIS 9.3 prior to surveys following topographic contours (e.g., drainages, ridges) and approximating 500–600 m spacing throughout each study area; flight paths during surveys were followed using GPS navigation in the helicopter. Two approximately 12 x 12 cm pieces of Ritchey livestock banding material (Ritchey Livestock ID, Brighton, CO USA) were uniquely marked using color, number, and symbol combinations and attached to each radio-collar to enhance mark-resight estimates. Each deer observed during surveys was recorded as mark ID#, unmarked, or unidentified mark.

We used program MARK (White and Burnham 1999), applying the immigration-emigration mixed logit-normal model (McClintock et al. 2008), to estimate mule deer abundance and confidence intervals. For mark-resight model evaluations, we examined parameter combinations of varying detection rates with survey occasion and whether individual sighting probabilities (i.e., individual heterogeneity) were constant or varied ($\sigma^2 = 0$ or $\neq 0$). Model selection procedures followed the information-theoretic approach of Burnham and Anderson (2002).

RESULTS AND DISCUSSION

Deer Captures and Survival

The helicopter crew captured 277 fawns in Dec 2012–Jan 2013, 165 does in Dec 2012, and 138 does during March 2013. Eight fawn mortalities (2.9%; ultimate cause = 3 capture myopathy, 5 predation) occurred within the 10 day censorship period. Doe mortalities totaled 4 (2.5%; all capture myopathy) and 4 (2.9%; 3 capture myopathy, 1 predation) within 10 days of the December and March capture periods, respectively. Mortality rates, 10 days post capture, have varied between 2–3% for fawns and 0–3% for does since Jan 2008, except during the 2011–2012 capture season where myopathy rates were higher (3-6%) due to dry, warm conditions (Anderson and Bishop 2012).

Fawn survival from early December 2012 through mid June 2013 was similar ($P > 0.05$) among 3 study areas ranging from 0.75 to 0.85, but was lower in North Ridge (0.53; Table 1). General comparisons to previous years suggest relatively high fawn survival occurred during winters 2009–2010 and 2012–2013, and relatively low survival during winter 2010–2011 (Fig. 2), which correlates to some degree to winter severity. North Ridge exhibited lower survival during 2012–2013 (Fig. 2), which appeared to be driven by density dependent rather than climatic factors. Annual adult female survival varied from 0.73 (North Ridge) to 0.86 (North Magnolia; Table 1) during 2012–2013 and was comparable among study areas during 2012–2013 and to previous years ($P > 0.05$), with the exception of lower survival in North Magnolia during 2011–2012 ($\hat{S} = 0.68$, Anderson and Bishop 2012). Sample sizes for adult female survival do not allow statistical discrimination among years unless large differences are evident (e.g., >15–20%).

Spring Migration Patterns

Collaboration with Idaho State University to address mule deer migration patterns in developed and undeveloped landscapes (funded from energy company contributions) has recently been completed. Two manuscripts have been accepted for publication (Lendrum et al. 2012, Lendrum et al. 2013; Appendix A).

In addressing habitat selection during spring migration, Lendrum et al. (2012; Fig. 3) noted that mule deer migrating through the most developed landscapes exhibited longer step lengths (straight line distance between GPS locations) and selected habitats providing greater security cover than deer in undeveloped landscapes that migrated through more open areas that provided increased foraging opportunities. Migrating deer also selected areas closer to well pads, but avoided roads, except in the highest developed areas where road densities were likely too high for avoidance without significant deviations from traditional migration routes.

In the second manuscript (Lendrum et al. 2013), we addressed biological and environmental factors influencing spring migration and assessed how energy development influenced migratory behavior. Overall, spring migration was influenced by snow depth, temperature, and green-up on winter and summer range; increasing temperatures, snow melt and emerging vegetation dictated timing of winter range departure and summer range arrival. Duration of Piceance Basin mule deer migration was short, averaging 4–8 days among the 4 areas (straight line distance between seasonal ranges averaged 33 - 45 km). Deer in poor condition migrated later than deer in good condition, but condition was similar among areas regardless of development status. Migrating deer from developed study areas did not avoid development structures, but departed later, arrived earlier and migrated more quickly than deer from undeveloped areas. While large changes in timing of migration could have nutritional consequences and negatively influence reproduction and neonate survival, the relatively minor shift we observed should not result in long-term fitness consequences. Migratory deer in the Piceance Basin appear to avoid negative effects of energy development through behavioral shifts in timing and rate of migration.

Mule Deer Body Condition

Early-winter body condition measurements of adult female mule deer from North Ridge and Ryan Gulch were lower than from deer from North Magnolia ($P < 0.05$), but were comparable otherwise ($P > 0.05$, Fig. 4, Table 2). By late winter, however, body condition declined and deer from all study areas exhibited similar condition (Fig. 4, Table 2). These observations have been generally consistent throughout the study, where early winter condition is variable between study areas and typically follows the pattern of better condition in North and South Magnolia deer, respectively poorer condition in Ryan Gulch and North Ridge, and poor condition in all areas by late winter. Exceptions occurred during late winter 2010 and early winter 2011, where North and South Magnolia and Ryan Gulch and North Ridge deer, respectively, exhibited improved condition than during other time periods (Fig. 4). December fawn weights by study area were higher in Ryan Gulch during 2012–2013, but were lower and have declined recently in the other 3 study areas (Fig. 5). In general, seasonal moisture conditions appear to be driving differences in annual body condition within study areas, but other factors appear related to differences among study areas. We suspect density dependent factors (forage capacity relative to deer density) are related to observed differences in early winter body condition among study areas. More detailed analyses will be conducted to identify factors attributing to these observations.

Neonate Survival

To complete demographic parameters addressing mule deer–energy development interactions, CPW, Colorado State University, and ExxonMobil Production entered into a collaborative agreement to investigate neonate survival in developed and undeveloped landscapes (funded by ExxonMobil Production Co.) beginning spring 2012. Mark Peterson (GRA) and Paul Doherty (CSU professor) are assisting with this research, which will continue through 2014. Neonate capture and collaring efforts totaled 85 during spring 2012 and 67 during spring 2013. Estimated neonate survival through mid-December 2012 was 0.39 (95% CI = 0.28-0.50). Factors influencing neonate mule deer survival from developed and undeveloped landscapes will be addressed by late 2014.

Mule Deer Population Estimates

Mark-resight models that best predicted abundance estimates (lowest AIC_c; Burnham and Anderson 2002) exhibited variable sightability across surveys (P_t) for all study areas and homogenous individual sightability ($\sigma^2 = 0$) for South Magnolia deer and variable individual sightability ($\sigma^2 \neq 0$) for the other 3 areas. North Ridge exhibited the highest deer density (16.1/km^2), with comparably lower deer densities in the other 3 areas (8.9–10.4/km^2; Table 3, Fig. 6). Populations appeared to increase over the 5 year monitoring period in 3 of the study areas (from 6.5/km^2 to 10.1/km^2), with a recent decline in North Ridge since 2011 (from 22.8/km^2 to 16.1/km^2); the current North Ridge density is comparable to the first 2 years of the study (Fig. 6). The recent North Ridge decline was likely related to density dependent factors, which were also evident in lower early winter body condition (Fig. 4) and a recent increase in malnutrition mortalities of adult females (from 0 in 2010–2011 to 7 in 2012–13). Abundance estimates from 2013 were similarly precise from all 4 study areas with the mean Confidence Interval Coefficient of Variation (CICV) ranging from 0.15–0.16.

Magnolia Habitat Treatments

We proceeded with habitat improvements in high (South Magnolia) and low development areas (North Magnolia) during 2012–2013. We completed pilot habitat treatments in January 2011 (116 acres total; Anderson and Bishop 2011; Environmental Assessment: DOI-BLM-CO-110-2011-004-EA), mechanical treatment method comparison treatments (hydro-ax, roller-chop, chain) in January 2012 (54 acres), and hydro-axe habitat treatments in April 2013 (434 acres; Determination of NEPA Adequacy: DOI-BLM-CO-110-2012-0134-DNA), totaling 604 treated acres in each study area (Fig. 7). Vegetation response in the pilot treatment sites was visually evident by fall 2011 (Fig. 7), likely due to the moist conditions during the previous spring and summer. Early spring 2013 moisture has resulted in good vegetative responses from the most recently treated sites. Vegetation and mule deer responses will be documented for the next 4-6 years to assess the utility of this mitigation approach in benefiting mule deer exposed to energy development disturbance. All expenses addressing these habitat treatments will be covered through a Wildlife Management Plan agreement between CPW and ExxonMobil Production/XTO energy.

SUMMARY AND COLLABORATIONS

The long-term goal of this study is to investigate habitat treatments and energy development practices that enhance mule deer populations exposed to extensive energy development activity. The information presented here summarizes mule deer population parameters from the first 5.5 years of the pre-treatment period. The pretreatment period was completed during spring 2013, providing baseline data for comparison with intended improvements in habitat conditions and reduction in human development activities. Winter range habitat improvements resulting in 604 acres of mechanically treated pinion-juniper/mountain shrub habitats in each of 2 study areas were completed April 2013. Post-treatment monitoring will continue for 4–6 years to provide sufficient time to measure how deer respond to these changes. Based on data collected prior to habitat improvements (i.e., pretreatment phase): (1) annual adult survival was consistent among areas averaging 80-84% annually, but overwinter fawn survival was variable, ranging from 48% to 85% within study areas, with annual and study area differences primarily due to annual weather conditions and in some cases density dependent influences; (2) migratory mule deer selected for areas with increased cover and increased their rate of travel through developed areas, and avoided negative influences through behavioral shifts in timing and rate of migration, but did not avoid development structures; (3) mule deer body condition early and late winter was consistent within areas, with higher variability among study areas early winter, which was likely related to seasonal moisture within areas and relative forage capacity among areas; (4) mule deer densities appear to be increasing in 3 of 4 areas, with a recent decline in North Ridge, but the current North Ridge density is comparable the first 2 years of the study. Detailed habitat use analyses are pending for the pretreatment period. We will continue to collect the various population and habitat use data across all study sites to evaluate the effectiveness of habitat improvements on winter range. This approach will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less or non-impacted areas. In a recent project conducted on the Uncomphahgre Plateau, Bergman et al. (2009) found that habitat treatments implemented in pinion-juniper habitat in undeveloped areas increased overwinter survival of fawns by a magnitude of 1.15. We are also evaluating deer behavioral responses to varying levels of development activity. This will allow us to assess the effectiveness of certain BMPs for reducing disturbance to wintering mule deer.

Hay field improvements have been completed in the North Magnolia study area by WPX Energy to fulfill a Wildlife Management Plan (WMP) agreement with CPW; elk (*Cervus elaphus*) response has been evident but mule deer response has been minor. A similar WMP agreement between ExxonMobil/XTO Energy and CPW allowed completion and continued monitoring of mechanical habitat improvements in the Magnolia study areas. Additional collaboration with WPX Energy has resulted in a clustered development plan in the Ryan Gulch study area and new technologies will be implemented to further reduce human activity through remote monitoring of well pads and fluid collection systems. Collaborative research with Idaho State University and Colorado State University/ExxonMobil Production has produced 3 peer-reviewed publications addressing mule deer migration (Lendrum et al. 2012, 2013) and improved approaches to address animal habitat use patterns (Northrup et al. 2013); these publications are summarized in Appendix A. Additional funding and cooperative agreements will be necessary to sustain this project to completion (preferably through 2019). We anticipate the opportunity to work cooperatively toward developing solutions for allowing the nation's energy reserves to be developed in a manner that benefits wildlife and the people who value both the wildlife and energy resources of Colorado.

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Prepared by____
Charles R. Anderson, Jr., Mammals Research Leader

Table 1. Survival rate estimates ($\hat{S}$) of fawn (2 Dec. 2011–15 June 2013) and adult female (1 July 2012–30 June 2013) mule deer from 4 winter range study areas of the Piceance Basin in northwest Colorado.

Cohort Study area	Initial sample size (*n*)	March doe sample[a] (*n*)	$\hat{S}$ (95% CI)
Fawns			
Ryan Gulch	78		0.752 (0.655–0.849)
South Magnolia	54		0.778 (0.667–0.889)
North Magnolia	61		0.852 (0.763–0.941)
North Ridge	76		0.529 (0.416–0.643)
Adult females			
Ryan Gulch	32	57	0.799 (0.671–0.926)
South Magnolia	39	51	0.801 (0.675–0.927)
North Magnolia	37	60	0.863 (0.752–0.975)
North Ridge	42	58	0.726 (0.595–0.857)

[a] Adult female sample sizes following capture and radio-collaring efforts March, 2012.

Table 2. Mean rump fat (mm), Body Condition Score (BCS[a]), and % body fat (% fat) of adult female mule deer from 4 study areas in the Piceance Basin of northwest Colorado, March and December, 2009–2013. Values in parentheses = SD.

	March 2009			December 2009			March 2010		
Study Area	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	1.73 (1.78)	2.66 (0.55)	7.54 (1.80)	8.35 (6.36)	4.06 (1.13)	12.96 (4.53)	2.31 (1.44)	2.35 (0.48)	6.69 (1.58)
South Magnolia	1.47 (0.68)	2.50 (0.60)	7.26 (1.82)	10.05 (6.19)	4.07 (1.21)	13.46 (4.96)	3.12 (2.20)	2.64 (0.59)	7.70 (2.01)
North Magnolia	1.30 (0.79)	2.56 (0.68)	6.96 (2.23)	10.67 (5.76)	4.25 (0.96)	13.92 (3.92)	3.15 (2.34)	2.85 (0.53)	8.28 (1.86)
North Ridge	1.57 (1.22)	2.60 (0.56)	7.28 (1.66)	5.25 (5.65)	3.63 (1.11)	11.02 (4.54)	1.77 (1.11)	2.42 (0.49)	6.83 (1.50)

Table 2. Continued.

	December 2010			March 2011			December 2011		
Study Area	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	7.75 (6.15)	3.34 (0.98)	10.82 (4.32)	1.55 (0.60)	2.53 (0.42)	7.05 (1.20)	13.41 (6.93)	4.21 (1.17)	13.17 (3.64)
South Magnolia	9.85 (6.78)	3.30 (0.61)	11.21 (3.32)	1.65 (0.75)	2.35 (0.50)	6.56 (1.49)	7.53 (4.66)	3.37 (0.76)	9.95 (2.73)
North Magnolia	9.55 (6.49)	2.56 (0.68)	11.65 (4.86)	1.65 (0.67)	2.53 (0.49)	7.06 (1.35)	9.43 (6.41)	3.79 (0.93)	11.15 (3.57)
North Ridge	6.14 (5.29)	3.32 (0.82)	10.32 (3.39)	1.45 (0.76)	2.24 (0.49)	6.24 (1.45)	9.81 (5.81)	3.62 (1.00)	11.22 (3.38)

Table 2. Continued.

	March 2012			December 2012			March 2013		
Study Area	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	2.15 (1.44)	2.74 (0.44)	7.22 (1.16)	6.34 (4.35)	3.30 (0.77)	9.34 (2.43)	1.87 (0.90)	2.65 (0.37)	6.90 (1.59)
South Magnolia	1.71 (0.76)	2.58 (0.36)	6.97 (1.12)	8.13 (5.71)	3.41 (1.04)	10.22 (3.23)	2.03 (0.78)	2.62 (0.26)	7.17 (0.68)
North Magnolia	1.87 (0.78)	2.85 (0.33)	7.65 (0.94)	9.80 (6.35)	3.89 (1.17)	11.25 (3.60)	1.81 (0.91)	2.16 (0.41)	6.91 (1.08)
North Ridge	2.24 (1.58)	2.70 (0.35)	7.26 (1.05)	5.76 (4.10)	3.32 (0.82)	9.06 (2.31)	1.87 (0.73)	2.48 (0.34)	6.70 (1.12)

[a] Body condition score taken from palpations of the rump following Cook et al. (2009).

Table 3. Mark-resight abundance (*N*) and density estimates of mule deer from 4 winter range herd segments in the Piceance Basin, northwest Colorado, 1–6 April 2013. Data represent 4 helicopter resight surveys from North Ridge, North Magnolia, and South Magnolia and 5 resight surveys from Ryan Gulch.

Study area	Mean No. sighted	Mean No. marked	*N* (95% CI)	Density (deer/km^2)
Ryan Gulch	245	27	1,309 (1,131–1,530)	9.3
South Magnolia	182	24	743 (644–875)	8.9
North Magnolia	261	29	950 (824–1,111)	10.4
North Ridge	314	31	858 (753–1,006)	16.1

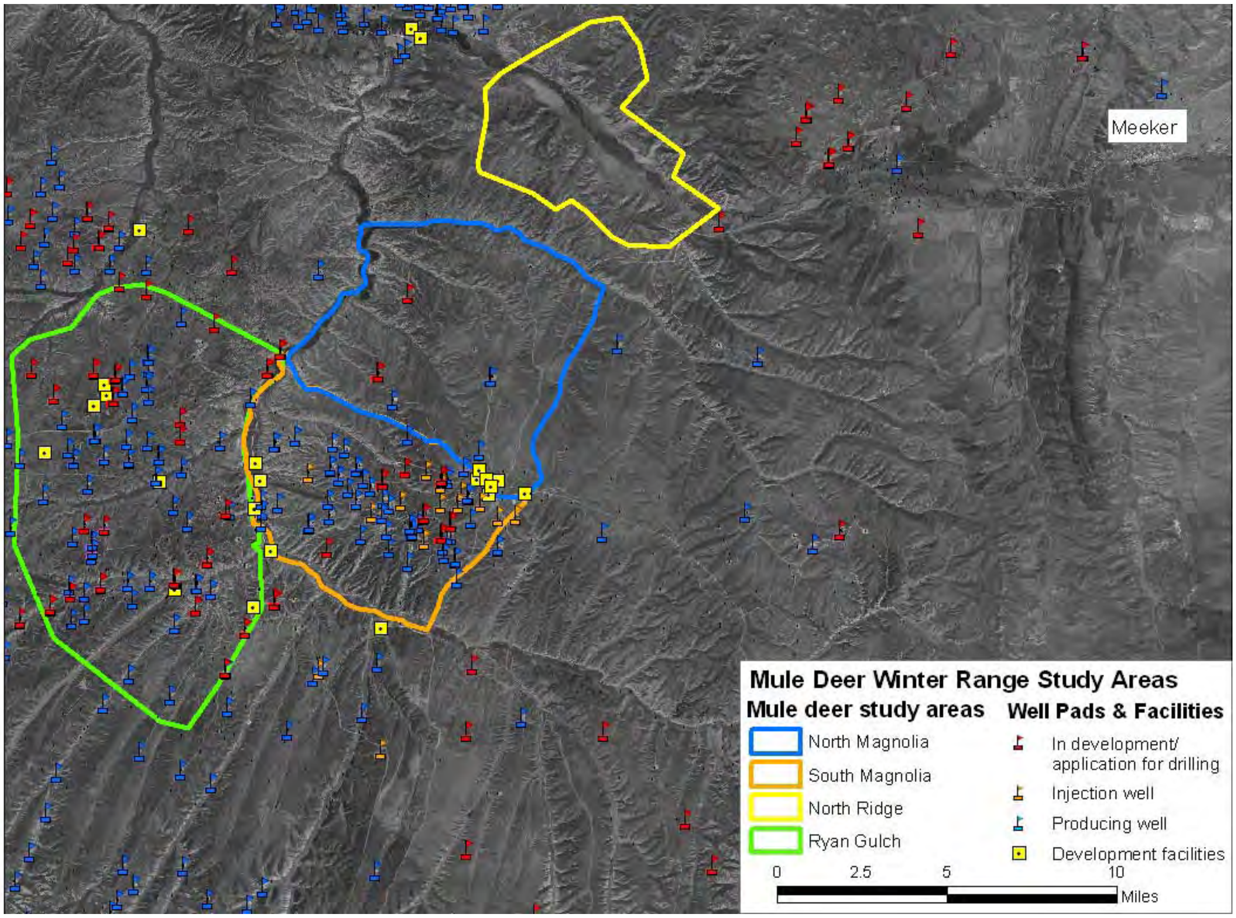
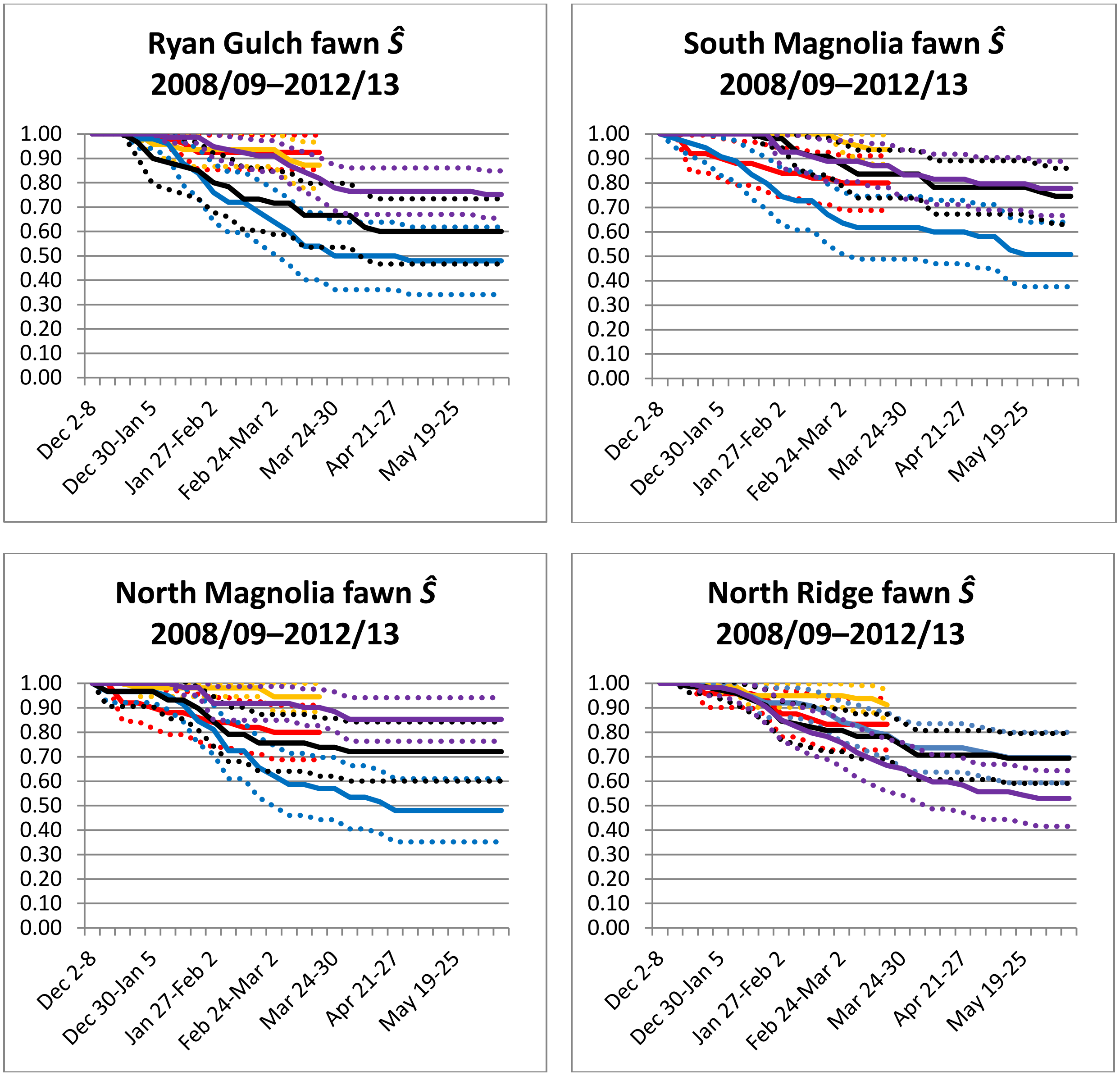


Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, summer 2013 (Accessed http://cogcc.state.co.us/ Aug. 19, 2013).



Ryan Gulch fawn $\hat{S}$ 2008/09–2012/13

South Magnolia fawn $\hat{S}$ 2008/09–2012/13

North Magnolia fawn $\hat{S}$ 2008/09–2012/13

North Ridge fawn $\hat{S}$ 2008/09–2012/13

Figure 2. Over-winter (Dec–Mar & June) mule deer fawn survival ($\hat{S}$) from 4 study areas in the Piceance Basin, northwest Colorado, 2008/09 (red lines), 2009/10 (orange lines), 2010/11 (blue lines), 2011/12 (black lines), and 2012/13 (purple lines). Solid lines = $\hat{S}$ and dashed lines = 95% CI. Comparable data among years December–March 2008–2009 and 2009–2010 due to premature collar drop and December–mid-June 2010–2011, 2011–2012, and 2012–2013.

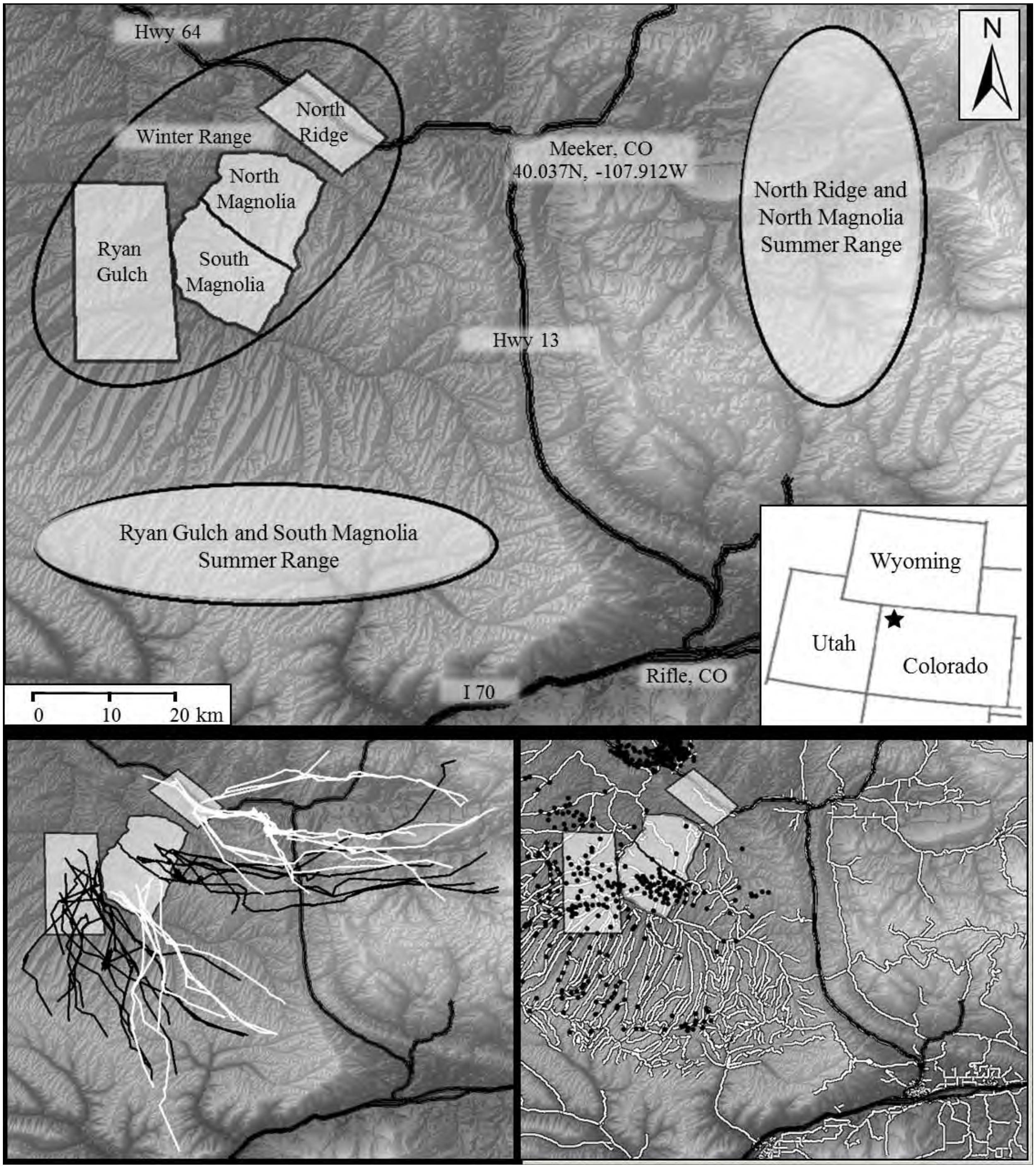


Figure 3. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer (*n* = 52; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from Lendrum et al. 2012).

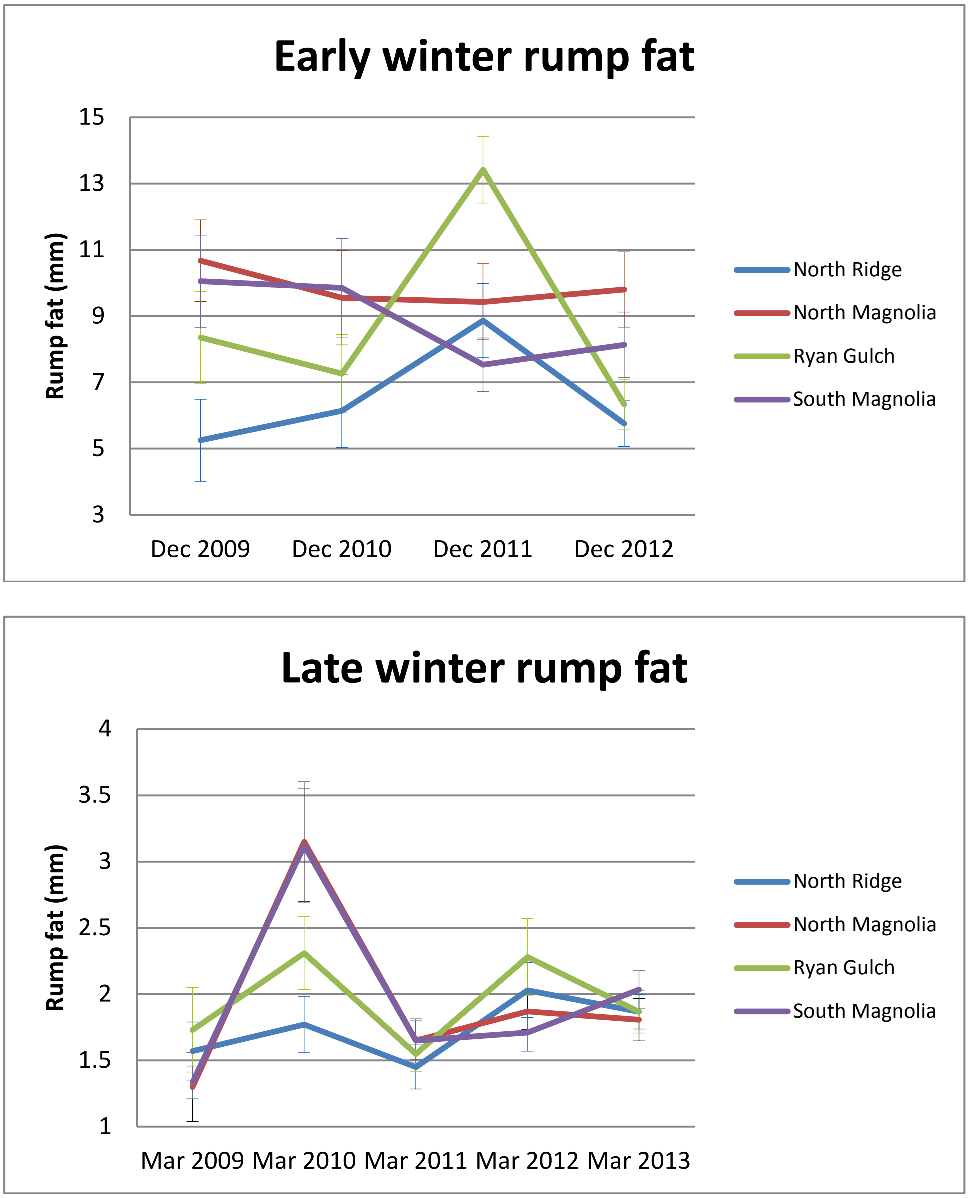
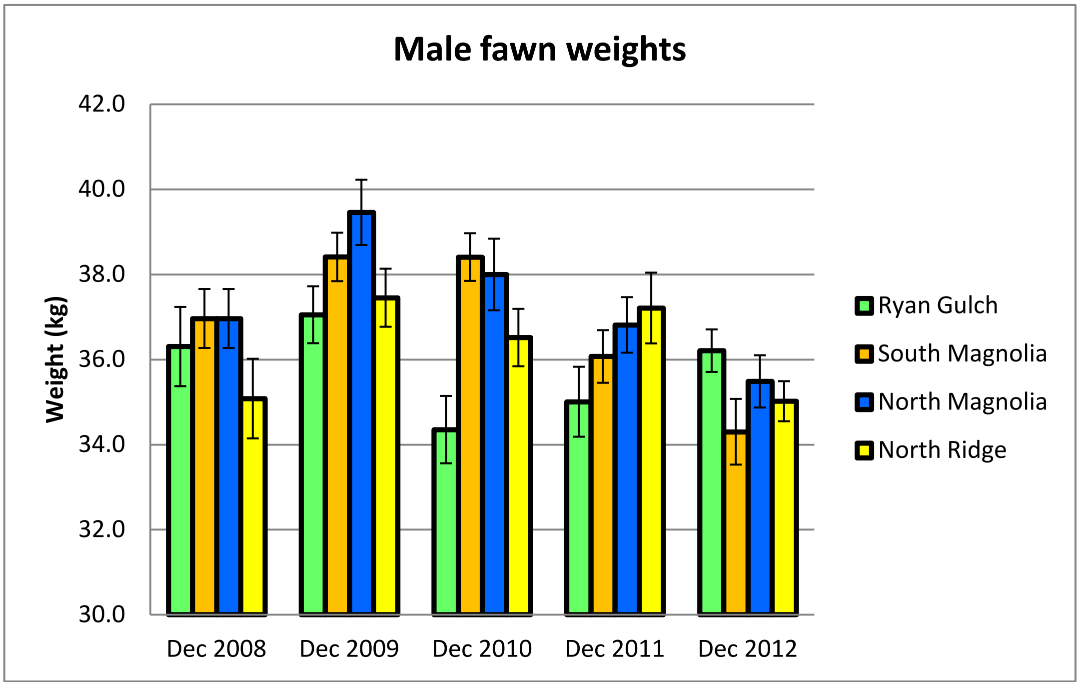


Figure 4. Mean early (early Dec., Top) and late winter (early Mar, Bottom) body condition (mm rump fat) of adult female mule deer from 4 winter range study areas in the Piceance Basin of northwest Colorodo, March 2009-March 2013. Error bars = 95% CI.



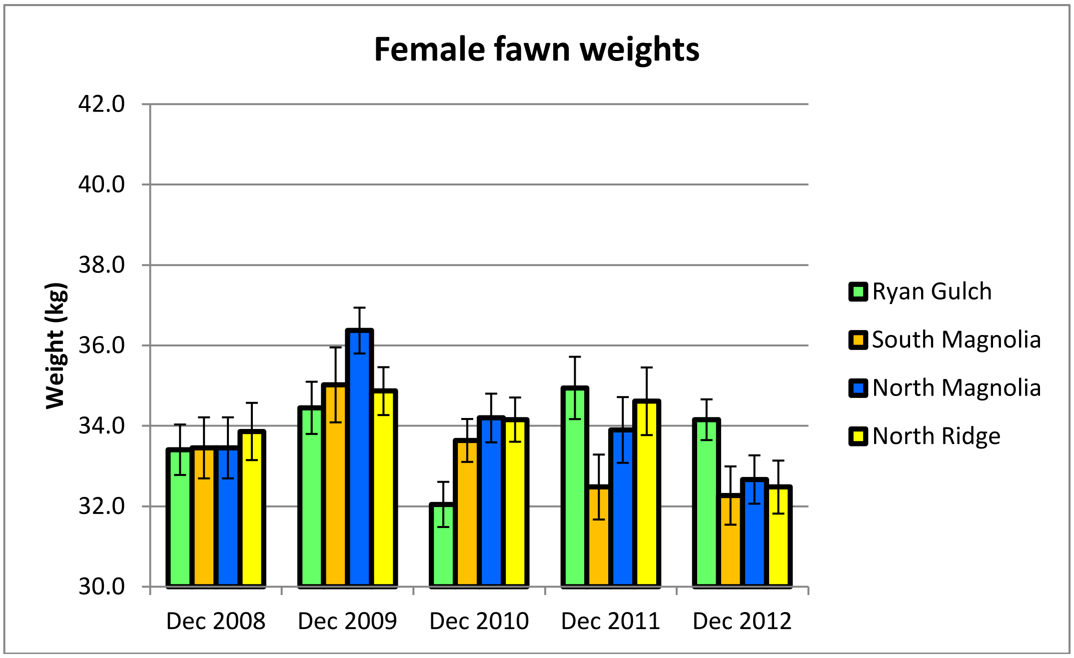


Figure 5. Mean male and female fawn weights and 95% CI (error bars) from 4 mule deer study areas in the Piceance Basin, northwest Colorado, December 2008–2012.

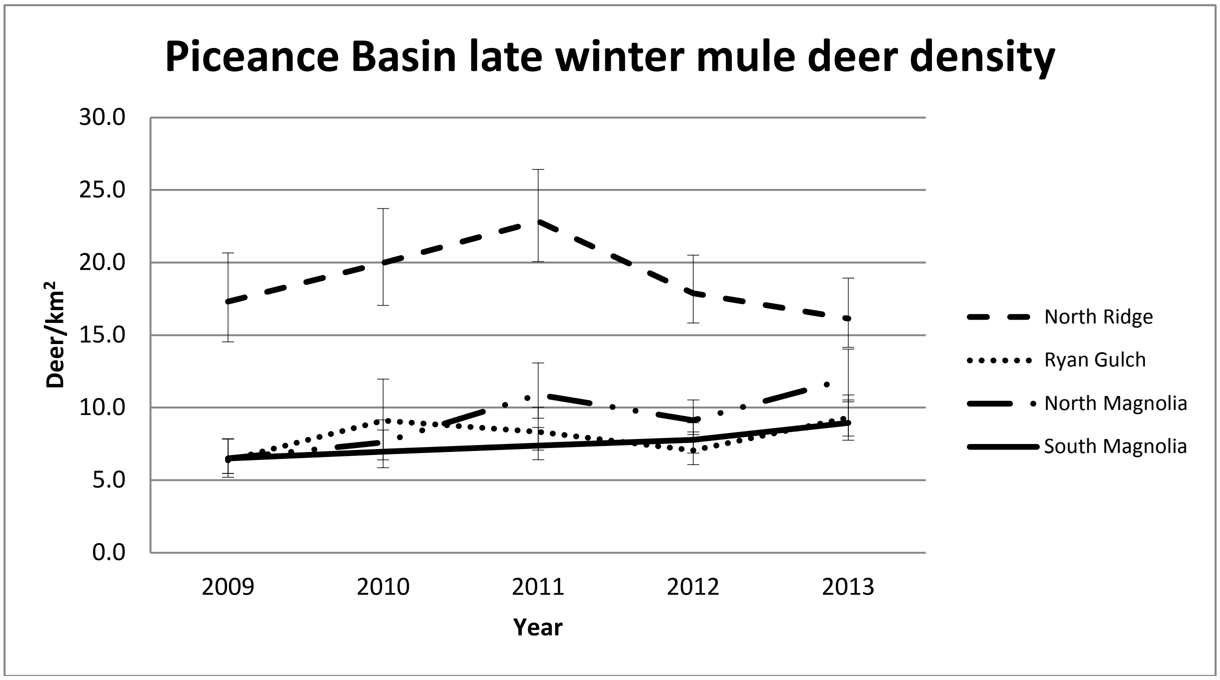


Figure 6. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2013.

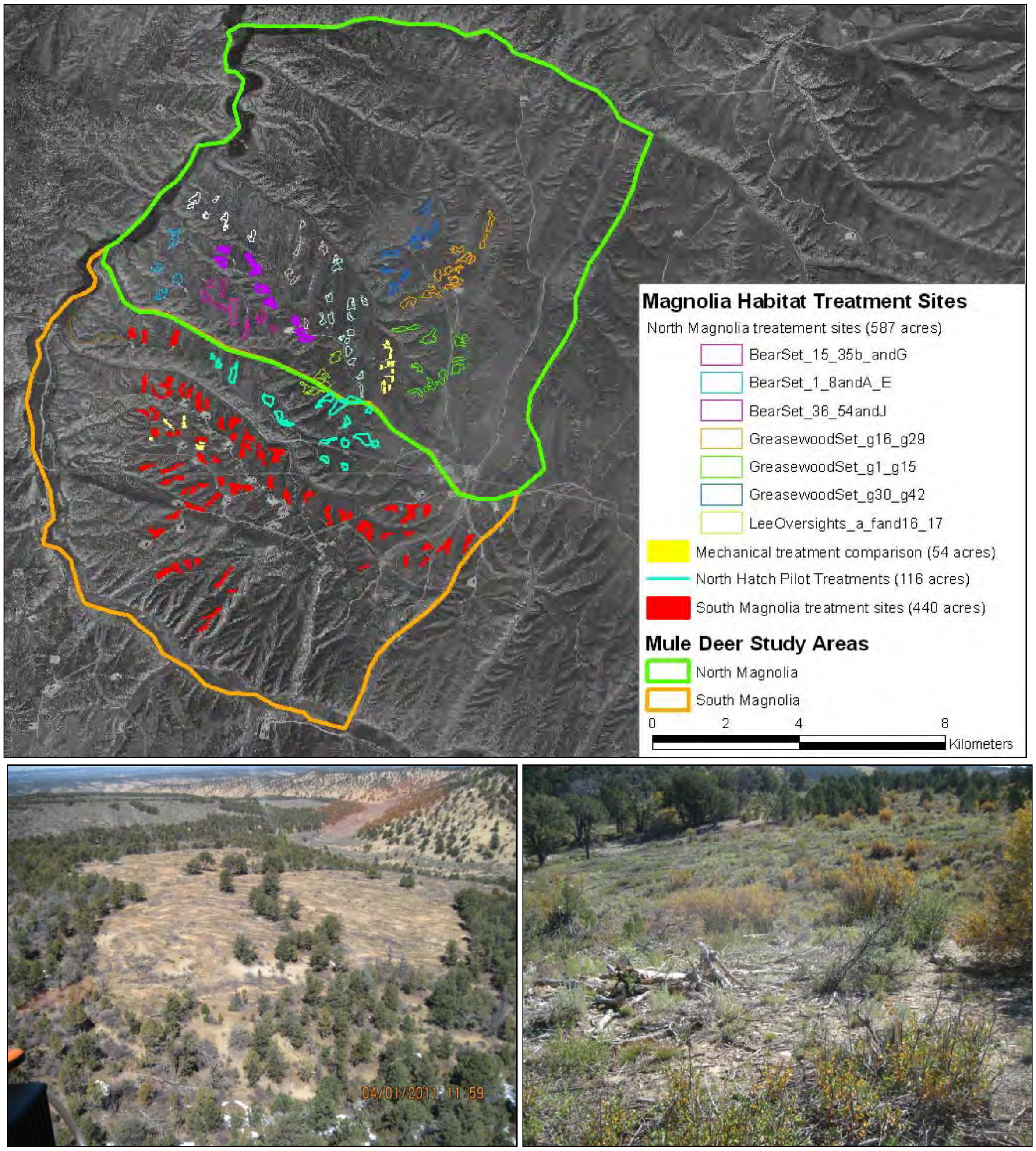


Figure 7. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan. 2011, yellow polygons completed Jan. 2012, and remaining polygons completed April 2013). January 2011 hydro-axe treatment-site photos from North Hatch Gulch during April (Lower left, aerial view) and October, 2011 (Lower right, ground view).

Appendix A. Abstracts of published manuscripts resulting from Piceance Basin mule deer/energy development interaction research collaborations. Abstract format specific to the respective journal requirements.

Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development

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Citation: Lendrum, P. E., C. R. Anderson, Jr., R. A. Long, J. G. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere 3(9):82. http://dx.doi.org/10. 1890/ES12-00165.1

Abstract. The disruption of traditional migratory routes by anthropogenic disturbances has shifted patterns of resource selection by many species, and in some instances has caused populations to decline. Moreover, in recent decades populations of mule deer (*Odocoileus hemionus*) have declined throughout much of their historic range in the western United States. We used resource-selection functions to determine if the presence of natural-gas development altered patterns of resource selection by migrating mule deer. We compared spring migration routes of adult female mule deer fitted with GPS collars (n = 167) among four study areas that had varying degrees of natural-gas development from 2008 to 2010 in the Piceance Basin of northwest Colorado, USA. Mule deer migrating through the most developed area had longer step lengths (straight-line distance between successive GPS locations) compared with deer in less developed areas. Additionally, deer migrating through the most developed study areas tended to select for habitat types that provided greater amounts of concealment cover, whereas deer from the least developed areas tended to select habitats that increased access to forage and cover. Deer selected habitats closer to well pads and avoided roads in all instances except along the most highly developed migratory routes, where road densities may have been too high for deer to avoid roads without deviating substantially from established migration routes. These results indicate that behavioral tendencies toward avoidance of anthropogenic disturbance can be overridden during migration by the strong fidelity ungulates demonstrate towards migration routes. If avoidance is feasible, then deer may select areas further from development, whereas in highly developed areas, deer may simply increase their rate of travel along established migration routes.

Migrating Mule Deer: Effects of Anthropogenically Altered Landscapes

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Citation: Lendrum, P. E., C. R. Anderson, Jr., K. L. Monteith, J. A. Jenks, R. T. Bowyer. 2013. Migrating Mule Deer: Effects of Anthropogenically Altered Landscapes. PLoS ONE 8(5): e64548. doi:10.1371/journal.pone.0064548

Abstract

Background: Migration is an adaptive strategy that enables animals to enhance resource availability and reduce risk of predation at a broad geographic scale. Ungulate migrations generally occur along traditional routes, many of which have been disrupted by anthropogenic disturbances. Spring migration in ungulates is of particular importance for conservation planning, because it is closely coupled with timing of parturition. The degree to which oil and gas development affects migratory patterns, and whether ungulate migration is sufficiently plastic to compensate for such changes, warrants additional study to better understand this critical conservation issue.

Methodology/Principal Findings: We studied timing and synchrony of departure from winter range and arrival to summer range of female mule deer (*Odocoileus hemionus*) in northwestern Colorado, USA, which has one of the largest natural-gas reserves currently under development in North America. We hypothesized that in addition to local weather, plant phenology, and individual life-history characteristics, patterns of spring migration would be modified by disturbances associated with natural-gas extraction. We captured 205 adult female mule deer, equipped them with GPS collars, and observed patterns of spring migration during 2008–2010.

Conclusions/Significance: Timing of spring migration was related to winter weather (particularly snow depth) and access to emerging vegetation, which varied among years, but was highly synchronous across study areas within years. Additionally, timing of migration was influenced by the collective effects of anthropogenic disturbance, rate of travel, distance traveled, and body condition of adult females. Rates of travel were more rapid over shorter migration distances in areas of high natural-gas development resulting in the delayed departure, but early arrival for females migrating in areas with high development compared with less-developed areas. Such shifts in behavior could have consequences for timing of arrival on birthing areas, especially where mule deer migrate over longer distances or for greater durations.

Practical guidance on characterizing availability in resource selection functions under a use–availability design

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Citation: Northrup, J. M., M. B. Hooten, C. R. Anderson, Jr., and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use–availability design. Ecology 94(7):1456-1463.

Abstract. Habitat selection is a fundamental aspect of animal ecology, the understanding of which is critical to management and conservation. Global positioning system data from animals allow fine-scale assessments of habitat selection and typically are analyzed in a use–availability framework, whereby animal locations are contrasted with random locations (the availability sample). Although most use–availability methods are in fact spatial point process models, they often are fit using logistic regression. This framework offers numerous methodological challenges, for which the literature provides little guidance. Specifically, the size and spatial extent of the availability sample influences coefficient estimates potentially causing interpretational bias. We examined the influence of availability on statistical inference through simulations and analysis of serially correlated mule deer GPS data. Bias in estimates arose from incorrectly assessing and sampling the spatial extent of availability. Spatial autocorrelation in covariates, which is common for landscape characteristics, exacerbated the error in availability sampling leading to increased bias. These results have strong implications for habitat selection analyses using GPS data, which are increasingly prevalent in the literature. We recommend that researchers assess the sensitivity of their results to their availability sample and, where bias is likely, take care with interpretations and use cross validation to assess robustness.

Colorado Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:	2	:	Evaluation of Winter Range Habitat Treatments On Over-winter Survival and Body Condition of Mule Deer
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2012 - June 30, 2013

Author: E.J. Bergman; project cooperators, C.J. Bishop, D.J. Freddy, G.C. White and P. Doherty

Personnel: C. Anderson, L. Baeten, D. Baker, B. Banulis, J. Boss, A. Cline, D. Coven, M. Cowardin, K. Crane, R. Del Piccolo, B. deVergie, B. Diamond, K. Duckett, S. Duckett, J. Garner, D. Hale, C. Harty, A. Holland, E. Joyce, D. Kowalski, B. Lamont, R. Lockwood, S. Lockwood, D. Lucchesi, D. Masden, J. McMillan, M. Michaels, G. Miller, Mike Miller, Melody Miller, C. Santana, M. Sirochman, T. Sirochman, M. Stenson, R. Swygman, C. Tucker, D. Walsh, S. Waters, B. Watkins, P. Will, L. Wolfe, V. Yavovich, K. Yeager, M. Zeaman, CPW, L. Carpenter - Wildlife Management Institute, D. Felix, L. Felix - Olathe Spray Service, P. Johnston, M. Keech, D. Rivers, J. Rowe, L. Shelton, M. Shelton, R. Swisher, S. Swisher - Quicksilver Air

All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the author. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

Between November 2004 and June 2009 we conducted a five year, multi-area study to assess the impacts of landscape level winter range habitat improvement efforts on mule deer population performance. This study took place on the Uncompahgre Plateau and in adjacent valleys in southwest Colorado. We measured over-winter fawn survival and deer abundance annually on 5 study areas. Four study areas were permanently located, whereas location of the fifth area varied each year to accommodate the variability in habitat treatments over the southern half of the Uncompahgre Plateau. Additionally, on 2 of the study areas we estimated late winter body condition of adult female deer. Compared to results from other research throughout the West, as well as on the Uncompahgre Plateau, survival estimates for 6-month old mule deer fawns were highly variable between areas, and tended to be near published long term averages. Estimated survival rates from this study ranged between 0.359 (SE = 0.0950) and 0.933 (SE = 0.0648). Survival models confirmed that areas that have received advanced habitat treatments have higher fawn survival. Deer abundance on the study areas varied between winters, but in general abundance estimates did not show increasing trends. A slight decrease in density between the first and last years of the study was observed in reference study units. Major fluctuations within abundance and density estimates were attributed to animal movements and winter severity. Based on estimates of total body fat for adult female deer, a distinction between treatment and reference study areas did occur, with higher late winter body condition of adult female deer from the treated study area. Finally, to put the

results of this research into context with historical research results, but also into context with recently observed declines within some western Colorado mule deer herds, a research review was conducted. This review largely discussed evidence of density dependence within Colorado's mule deer herds.

Results from overwinter fawn survival work have been submitted to the *Journal of Wildlife Management* for peer review. Results from the body condition portion of this research will be submitted for publication in *Ecological Applications*. Results from the abundance and density portion of this research will be submitted for publication in the *Journal of Applied Ecology*. The research review portion of this work will be submitted for publication in the *Wildlife Society Bulletin*. Abstracts for all 4 publications are provided.

The following abstract has been submitted to the Journal of Wildlife Management for publication.

Effect of habitat management on overwinter survival of mule deer fawns in Colorado

Eric J. Bergman, Chad J. Bishop, David J. Freddy, Gary C. White, and Paul F. Doherty, Jr.

Wildlife managers often utilize habitat management as a tool to bolster mule deer (*Odocoileus hemionus*) populations. Yet evaluation of this strategy in the form of deer vital rates has been lacking. To address this knowledge gap and to evaluate the effects of habitat management on a mule deer vital rate, we conducted a 4-year study that measured the overwinter survival of mule deer fawns on study units that had experienced different levels of habitat management efforts. Mule deer fawns that overwintered on areas that received both a traditional treatment as well as follow-up treatments experienced increased survival ($\hat{S}$= 0.768, SE = 0.0851) over fawns on winter range that had only received traditional treatments or no habitat treatments at all ($\hat{S}$ = 0.675, SE = 0.112). When partitioned into different levels of treatment intensity, mule deer fawns inhabiting winter range that received both traditional treatments and follow-up treatments experienced higher survival ($\hat{S}$ = 0.768, SE = 0.0849) than fawns on units that experienced only traditional treatments ($\hat{S}$ = 0.687, SE = 0.108), which in turn experienced higher survival than fawns in areas that had received no habitat treatments ($\hat{S}$ = 0.669, SE = 0.113). When study unit differences in overwinter fawn survival were incorporated into a population matrix model, finite population growth rates increased from 1.098 to 1.151 in study units that had received multiple habitat treatments. Our study provides a new piece of evidence supporting the use of habitat management as a tool to positively influence a key vital rate for mule deer in pinyon pine (*Pinyon edulis*) - Utah juniper (*Juniperus osteosperma*) ecosystems.

The following abstract will be submitted to Ecological Applications for publication.

Response of mule deer body condition to habitat manipulation in southwest Colorado

Eric J. Bergman, Paul F. Doherty, Chad J. Bishop, Lisa L. Wolfe, and Bradley A. Banulis

The relationships between habitat, body condition and life history characteristics are tightly interwoven and of interest to wildlife managers as they strive to better understand the role that habitat plays in regulating population dynamics. With the increased availability of portable ultrasound machines and the refinement of hormonal assays, assessment of ungulate body condition has become a more accessible monitoring strategy. We employed body condition scoring, estimation of % ingesta-free body fat (%IFBF) and assessment of thyroid hormones (FT4 and FT3) as metrics to determine if landscape-level habitat manipulation affected body condition of adult (≥1.5 years old) female mule deer *Odocoileus hemionus*. All body condition related metrics were measured on 2 study areas — a reference area that had received no habitat treatments and a treatment study area that had received mechanical removal of pinyon pine *Pinyon edulis* - Utah juniper *Juniperus osteosperma* forest, chemical control of weeds and reseeding with browse species. A consistent trend of higher %IFBF was observed in the treatment study area ($\widehat{\%IFBF} = 7.100$, SE = 0.455) than in the reference study area ($\widehat{\%IFBF} = 6.566$, SE = 0.455), although variation of estimates weakened our ability to draw strong conclusions. A similar pattern was observed with higher concentrations of thyroid hormones consistently being observed in the treatment study area, but large amounts variation within concentration estimates made it difficult to conclusively distinguish between study areas. Population-level impacts stemming from our observed differences in body condition parameters were likely nominal, although the consistent pattern of higher body condition related estimates in our treatment study area prevents complete dismissal of our methods as viable population monitoring strategies.

The following abstract will be submitted to the Journal of Applied Ecology for publication.

Response of mule deer density to habitat management in Colorado

Eric J. Bergman, and Paul F. Doherty, Jr.

The suite of demands competing for wildlife management funds necessitates direct assessment of management decisions, especially when these decisions have both direct and tangible opportunity costs. A specific example of such a decision includes habitat management for mule deer (*Odocoileus hemionus*), for which the opportunity cost of delivering habitat treatments may be the acquisition of new lands or conservation easements that increase the quantity of habitat. Estimating direct effects of management decisions on mule deer density has also been difficult. However, recent advancements in abundance estimation methodologies have made estimating abundance and density more reliable than in the past. We conducted a mark-resight study that estimated mule deer density across multiple study units that had been exposed to different intensities of habitat treatments on the eastern slope of the Uncompahgre Plateau and in neighboring drainages of the San Juan mountain range in southwest Colorado. Our treatments were comprised of common habitat management techniques including hydro-axe and roller-chopper disturbances, as well chemical control of weeds and reseeding with desirable mule deer browse species. Reference study units received no habitat management treatments. Resighting probabilities (range 0.070–0.567) were best modeled as an interactive function of study unit and year, although sampling method was also important. Total deer densities varied between 20–84 deer/km^2 in southern study units and 4–12 deer/km^2 in northern study units. A consistent pattern of higher deer density on advanced treatment study units was not observed despite its being the primary hypothesis of the study. We recommend that if population density is to be used as a population response variable, it only be used in tandem with other, possibly more sensitive parameters, such as overwinter survival or late winter body condition.

The following abstract will be submitted to the Wildlife Society Bulletin for publication.

Density Dependence in Colorado's Mule Deer

Eric J. Bergman, and Paul F. Doherty, Jr.

Biologists, managers and hunters have expressed concern over a recent decline in some western Colorado mule deer (*Odocoileus hemionus*) herds, but whether this decline is part of a regional pattern or unique to Colorado is unclear. Similarly, the underlying cause of this decline is yet to be determined. In response to this management concern, a review of scientific evidence on Colorado's mule deer population dynamics is warranted. To be most beneficial, such a review should be done in the context of a conceptual model that portray population growth as a function of population size, per-capita growth rate and population carrying capacity. Similar declines that occurred during the 1960s and early 1990s resulted in similar reviews that also identified future research and management studies that would benefit mule deer. These topics included: harvest, predation, intraspecific competition, disease, interspecific competition, and habitat loss and degradation. Between the late 1990s and present time, many of these topics have been addressed with research, but the new knowledge and information has not been compiled in a review. The conventional working hypothesis in Colorado is that mule deer herds are limited by winter range habitat. However, I identify new gaps in knowledge and suggest potential, future research topics. These topics include density reduction experiments to address competition and focused experiments to address the role of mountain lion and black bear predation.

Colorado Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

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Cost Center: 3430 : Mammals Research
Work Package: 3001 : Deer Conservation
Task No. 8 : Development of an Automated Device
: for Collaring and Weighing Mule Deer Fawns
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ABSTRACT

We designed and produced a trap-like device for mule deer that would automatically attach a radio collar to a ≥6-month-old fawn and record the fawn’s weight and sex, without requiring physical restraint or handling of the animal. Our passive collaring device is designed to allow biologists and researchers to radio-collar, weigh, and identify sex of ≥6-month-old mule deer fawns with minimal expense and labor when compared to traditional mule deer capture techniques. This technique should significantly reduce stress that is typically associated with capture and handling and eliminate capture-related mortality. We collaborated with students and faculty in the Mechanical Engineering Department at Colorado State University to produce a conceptual model and early prototype. We then worked with professional engineers at Dynamic Group Circuit Design in Fort Collins, Colorado, to produce a fully-functional prototype of the device.

We conducted an extensive field evaluation of the device with free-ranging mule deer during October-March, 2010-11, and January-March, 2012. We successfully collared, weighed, and identified sex of 6 different mule deer fawns across 4 winter range locations along Colorado’s northern Front Range during winter 2010-11. Collars were purposefully made to shed from deer within several weeks or months of being collared. Two fawns were successfully re-collared after they shed the first collars they received. Thus, we observed 8 successful collaring events involving 6 different fawns in 2010-11. Most fawns demonstrated minimal response to collaring events, either remaining in the device or calmly exiting. We successfully collared, weighed, and identified sex of 2 different mule deer fawns in the Piceance Basin of northwest Colorado during February-March 2012. We collared fewer fawns in winter 2011-12 than the

previous winter in part because of a shortened evaluation period (i.e., 3 instead of 6 months). Winter conditions were mild overall during 2011-12, which likely contributed to the lower collaring rate since deer had ample foraging options and may not have been as strongly attracted to bait. During 2010-11, certain components of the collaring device failed to function optimally when temperatures dropped below approximately –15° C, while other components did not adequately withstand mule deer use under field conditions. Also, certain behaviors of mule deer when approaching and using the device created circumstances where it was possible to collar the same animal twice, which happened on one occasion. We incorporated a series of device modifications during summer-fall 2011 necessary to address these various issues. The device functioned well under field conditions during January-March 2012, indicating the modifications were effective. Our automated collaring device allowed mule deer fawns to be remotely collared, weighed, and sexed with minimal or no stress to the animals. However, fawns typically required one or more weeks of exposure to the device before they entered and accessed the bait. This slow acclimation period limited utility of the device when compared to traditional capture techniques used to collar fawns. During 2012-13, focus was on additional device modifications and altered baiting strategies that decrease fawn acclimation period, and in turn, increase collaring rates.

WILDLIFE RESEARCH REPORT

DEVELOPMENT OF AN AUTOMATED DEVICE FOR COLLARING AND WEIGHING MULE DEER FAWNS

CHAD J. BISHOP, MATHEW W. ALLDREDGE, ERIC J. BERGMAN, DANIEL P. WALSH, AND CHARLES R. ANDERSON, JR.

OBJECTIVE

Colorado Parks and Wildlife (CPW) captures and radio-marks 6-month-old mule deer (*Odocoileus hemionus*) fawns each year to support research and management of mule deer. Approximately 240 deer fawns are captured annually to monitor survival among 4 populations distributed across western Colorado and an additional 100–350 deer fawns are captured as part of ongoing research studies. Other state agencies in the western United States capture large numbers of mule deer fawns annually also. Most capture is accomplished with net-guns fired from helicopters (Barrett et al. 1982, van Reenen 1982, Webb et al. 2008), which is becoming increasingly expensive (i.e., >$500 per captured deer). Also, net gunning is inherently dangerous with a small market, which at times limits availability of contractors. Drop nets (Ramsey 1968, Schmidt et al. 1978), clover traps (Clover 1956), drive nets (Beasom et al. 1980), and darting (Wolfe et al. 2004) are used occasionally in the western United States to capture deer, but these techniques can be time consuming and labor intensive. Many biologists lack time and resources given other job requirements to conduct such capture operations for any length of time. The increasing cost of helicopter net-gun capture coupled with increasing demand for capturing and radio-collaring 6-month-old fawns has created a need for another capture alternative. Specifically, there is need for a capture technique that is relatively inexpensive to employ considering both operating and personnel costs.

In response to CPW's capture needs, we conceived the idea of an automated marking device for ≥6-month-old deer fawns that would attach a radio collar and record weight and sex without physically restraining the animal or requiring handling. The idea of automatically attaching radio transmitters to animals is not new, although to our knowledge, there are no proven methods or devices for use on deer or other ungulates. Even a relatively expensive trap or device (e.g., $3,000–5,000 ea.) would reduce CPW's capture costs assuming the device could be reused over time with few maintenance expenses. Such a device would enable seasonal wildlife technicians or graduate students to radio-collar samples of deer fawns independently or with little assistance from researchers and biologists because no animal handling would be required. We want the device to record weight and sex because these variables are useful covariates in survival analyses and are typically measured when fawns are captured and handled.

A passive marking device would minimize animal stress associated with capture and should have virtually no potential to cause capture-related mortality. The large-mammal capture techniques described above place considerable, temporary stress on animals as part of netting and handling. Roughly 2-3% of animals typically die from capture-related injuries or stresses under routine capture conditions. Thus, successful development of a passive marking system would reduce CPW's operating expenses and improve animal welfare.

Our study objective is to develop and evaluate a trap-like device for mule deer that would automatically attach a radio collar to a ≥6-month-old deer fawn and record the fawn's weight and sex, without requiring physical restraint or handling of the animal.

STUDY AREA

We conducted field evaluations with free-ranging deer along Colorado’s Front Range between Boulder and Fort Collins, in the Piceance Basin in northwest Colorado, and on the Uncompahgre Plateau in western Colorado.

METHOD

Device Specifications

We identified an array of specifications to guide design of the automated collaring device, which we divided into 3 categories: 1) collaring device, 2) radio collar, and 3) controls. Collaring device refers to the overall trap-like device and its various components. Our radio collar specifications reflect 6-month-old fawn radio collars that are currently used by CPW. Our intent was to avoid design of a more costly radio collar and to ensure that biologists and researchers could use radio collars readily available on the market without making substantive changes. If radio collar costs increased significantly, the automated collaring device would fail to be cost-effective and have much less utility to biologists and researchers accustomed to using helicopter net-gunning. We were less concerned about cost of the collaring device because it would be a one-time expense that would support repeated fawn captures. Our third specification category, controls, refers to those aspects of the device requiring automation.

Collaring Device

1. Device remotely attaches radio collar around the neck of a ≥6-month-old deer fawn; most ≥6-month-old fawns range in size from 50–100 lbs.
2. Device deters adult deer or other larger animals from entering but does not deter entry of fawns.
3. Device allows fawns to easily exit in multiple directions at any time.
4. Device must not cause injury to animals.
5. Device incorporates a place for bait, which will lure the animals to the device.
6. The collapsed device should fit in the back of a typical full-size pickup truck.
7. Device should be of a generalized design that could be modified in the future to target different ages and species of animals (e.g., adult deer, calf elk, adult elk, lamb sheep, adult sheep, etc.)

Radio collar

1. Collar accommodates fawn neck sizes ranging from 11 to 16 inches in circumference.
2. Width of collar neckband ranges from 0.5 to 3 inches.
3. Collar sheds from the deer 6–12 months after being placed on the animal using surgical tubing or comparable mechanism that does not increase the overall cost of a radio collar.
4. Use existing radio transmitters that are presently available on the market.

Controls

1. Restrict collaring to animals that weigh 47–103 lbs (i.e., guarantee that only fawns receive radio collars).
2. Prevent the same fawn from being collared more than once.
3. Measure and record animal weight.
4. Measure and record animal sex.
    a. Fawn deer sexing options include:
        i. Gonads (most reliable)
        ii. Antler stubs (less reliable)
5. Obtain photo of captured animal.

Device Design

Working with engineering students and faculty at Colorado State University, we designed the device in stages using a series of prototypes. For example, we initially constructed the device frame out of cheap material and evaluated it using captive deer at the Foothills Wildlife Research Facility in Fort

Collins, CO. We observed deer interactions with the prototype to evaluate device dimensions and placement of the radio collar within the device (Figs. 1, 2). We then modified the prototype accordingly and reevaluated until we were comfortable the dimensions were adequate. Once staged prototype testing was completed, we constructed the various device components using materials we believed were suitable for employing the device in winter field conditions. The initial device frame was constructed from steel and coated to prevent rust and to lessen wear and tear. We later changed the device frame to aluminum (Fig. 3). The sides of the device comprise one-gay gates, which prevent entry from outside the device yet allow deer to exit the device at any point they choose. The one-way gates were constructed from aluminum and are being mounted with hinges and springs to allow one-way movement. Deer will enter the device through a 14” x 32” opening in the front of the device; entry dimensions were derived from experience feeding deer fawns in Idaho (G. Scholten, Idaho Department of Fish and Game - retired, personal communication).

The radio collar and collaring mechanism will be positioned at the rear of the device and in front of the bait compartment. To access the bait, a deer will be required to extend its head and neck through an expandable collar in the fully expanded position (Fig. 4). The radio collar was made expandable using springs, which was patterned after an expandable adult buck collar designed by Michael Sirochman (Colorado Parks and Wildlife, personal communication). The springs prevent the collar from being too loose on a small fawn while not being too tight on a large fawn. Expandable fawn collars are not a new concept and have been commonly used elsewhere on 6-month-old fawns and are sold by telemetry companies. The floor of the device will comprise a scale to estimate the animal’s weight. The animal’s weight will be correctly recorded no matter where the animal stands within the device. A door will close and prevent access to the collaring mechanism/bait compartment if an animal is heavier than 103 lbs, which will allow us to target fawns and prevent older deer from sticking their head through the expanded collar. To be collared, a deer must extend its head through the collar and break an infrared beam positioned immediately above the bait container. The collar will not release unless an animal is heavier than 43 lbs (and less than 103 lbs), which will prevent small animals that may access the bait from triggering the collar. When the IR beam is broken and the animal is in the correct weight range, a solenoid will be activated that causes the collar to release around the deer’s neck (Fig. 4).

To prevent double-collaring, radio frequency identification (RFID) tags will be attached to all fawn collars. An antenna will be positioned around the opening of the device and connected to an RFID reader. When a previously collared fawn enters the device, the RFID reader will detect the tag and cause the door to the collaring mechanism/bait compartment to close. Digital cameras will be positioned in several locations in the device to photograph the animal when the collar is released.

RESULTS AND BENEFITS

A passive collaring device, as described above, would allow biologists and researchers to radio-collar, weigh, and identify sex of ≥6-month-old mule deer fawns with minimal expense and labor when compared to traditional mule deer capture techniques. Such a technique would significantly reduce stress that is typically associated with capture and handling and would eliminate capture-related mortality. We do not expect our collaring device to replace other capture techniques. Rather, we expect the device to provide biologists and researchers with an efficient, cost-effective technique to mark a portion of their targeted fawn samples, thereby keeping helicopter net-gunning requirements and associated costs at viable levels.

In winter 2011-12 we completed a second year of field evaluation of a fully-functional prototype device (Figs. 5, 6). During this evaluation, we accumulated hundreds of hours of field observation of mule deer interacting with the device and we noted device components that warranted modification for optimal performance. We incorporated these modifications and conducted a follow-up field evaluation with free-ranging deer during winter 2012-13 on the Uncompahgre Plateau. We also constructed a second prototype for field testing based on the final design of the first prototype. All animals were released from the device with functioning radio collars and were monitored one week post-collaring and every few weeks thereafter. Collars had surgical tubing between the transmitter and the springs, thereby allowing the collar to drop-off when the surgical tubing degraded. We used surgical tubing because it is the standard technique used to collar 6-month-old fawns in Colorado, and thus we wanted to test deployment of collars that would actually be used with this device. However, we did make small cuts in the surgical tubing to cause the collars to shed from the animals within a few months of being deployed.

We designed and fabricated the collaring device in such a manner as to prevent inadvertent collaring of non-target species, thereby preventing any possibility that a threatened, endangered, or candidate species could be harmed. The floor of the collaring device is a scale that continuously records weight and informs the device. The collar can only be released when an appropriately-sized animal is in the device. Animals are attracted to the device with bait, contained in a separate compartment at one end of the device. To access the bait, animals must extend their head and neck through an expanded collar into the bait compartment. The collar can only be released when an animal is accessing the bait, thereby breaking an infrared beam, which further informs the device. We are not familiar with any animals in these study areas that fit the weight range of a deer and could simultaneously access the bait. The only possible animal is a black bear, although it is unlikely the bear could access the bait. However, black bears will be hibernating during the winter months when the collaring device will be employed. Finally, even if a non-target animal accessed the device, there is ample opportunity for the animal to leave the device without being harmed. The sides of the device consist of one-way gates, such that an animal in the device can exit at any time through the entrance or sides. Finally, in the extreme unlikely event that a non-target animal were radio-collared, the expandable collar does not pose a threat to any animal that can fit its head through the expanded collar. The device, therefore, poses no threat to non-target species, including threatened, endangered, and candidate species listed under the Endangered Species Act because none are similar in size or behavior to deer. Also, all travel will occur on established roads throughout the study areas, preventing any chance of damaging a listed plant species.

SUMMARY

As part of our field evaluation, we recorded numbers of fawns successfully radio-collared and measured relative to person-hours expended setting and moving the device. We planned to contrast costs and efficiency with other fawn capture techniques. However, successful capture of fawns was extremely limited, so at this point other capture techniques would be more efficient. During the final winter of investigation no fawns were collared and only a few actually entered the device. This concludes this project.

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Figure 1. Prototype evaluation of collar and bait placement, and validation that a deer would extend its head and neck through an expanded collar to access the bait.

Figure 2. Prototype evaluation of entrance and cage dimensions with captive deer.

Figure 3. Device frame. The sides of the device comprise one-way gates that prevent entry to the device yet allow animals to easily exit once inside. Animals will be required to enter the device through a 14” x 32” opening in the front, which is adjustable. The rear portion of the device is a bait compartment fabricated from aluminum. A door on the rear of the bait compartment will allow biologists to easily add bait in the field and access controls.

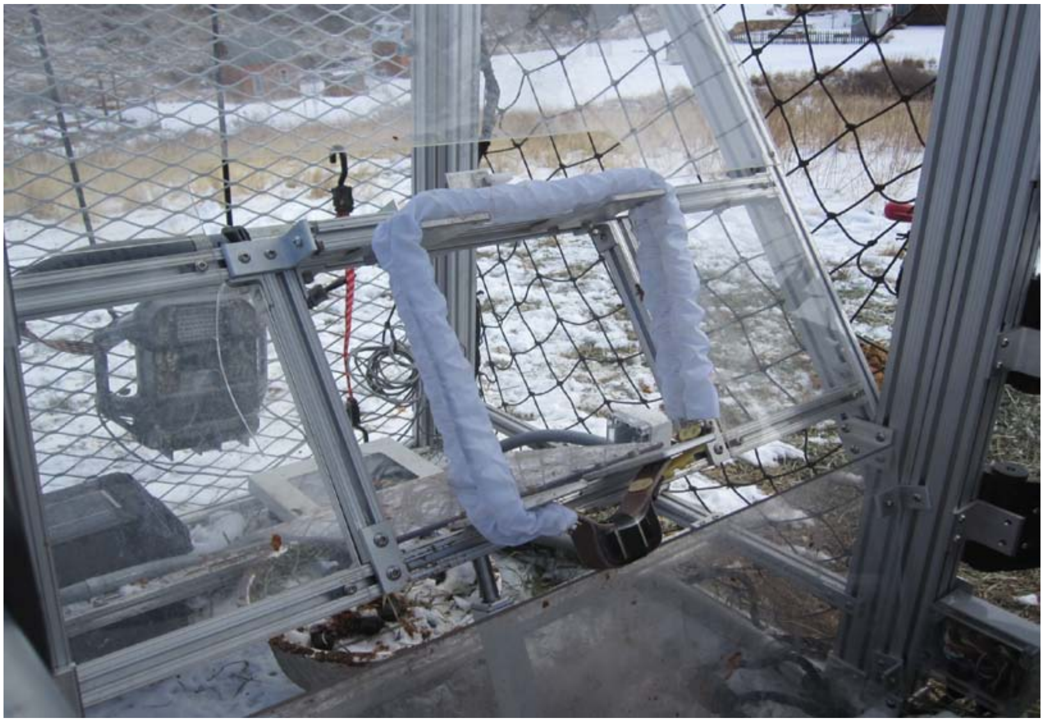

Figure 4. The bait compartment. Deer will be required to extend their head and neck through an outstretched expandable radio collar in order to reach the bait.

Figure 5. Mule deer fawn in process of being collared.

Figure 6. Mule deer fawn at the moment of the collar being released.

Colorado Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

State of: Colorado : Parks and Wildlife
Cost Center: 3430 : Mammals Research
Work Package: 3002 : Elk Conservation
Task No. : Evaluating solutions to reduce elk and mule deer
: damage on agricultural resources
Federal Aid
Project No.

Period Covered: July 1, 2012 – June 30, 2013

Author: H.E. Johnson; project cooperators, P. Dorsey, M. Hammond, C. Bishop, K. VerCauteren, D. Walter, C. Anderson, and J. Fischer.

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ABSTRACT

Elk and mule deer provide important recreational, ecological, and economic benefits, but they can also cause substantial damage to agricultural resources in rural environments. This situation has generated significant challenges for wildlife agencies that are responsible for maintaining viable ungulate populations while also minimizing crop damage. One of the most severe areas of ungulate damage in Colorado has been the sunflower fields around Dove Creek. In this region, roughly a quarter of million dollars were annually paid to farmers between 2007 and 2009 for depredation caused by elk and deer. The main management tool used by Colorado Parks and Wildlife (CPW) to reduce ungulate damage has been the allocation of kill permits, distribution hunts, and private land only doe/cow hunts; however, tolerance for these permits has been low among hunters and the general public. Pressure from local sunflower growers over crop damage, and frustration from the public over kill permits, generated the need for CPW to evaluate other management options for reducing elk and deer crop depredation. As a result, CPW partnered with wildlife damage researchers from the National Wildlife Research Center to find science-based solutions for reducing crop damage. Collaboratively, our goals are to 1) experimentally test a suite of non-lethal exclusion and repellent techniques to minimize crop damage, 2) examine elk and deer distribution and migration patterns around agricultural areas to design public hunting opportunities to reduce depredation, and 3) map and model landscape characteristics associated with ungulate damage to specify more effective site-specific management techniques. During FY12-13 we conducted the second and final year of an experiment to test exclusionary techniques for reducing elk and deer damage (objective 1), and submitted a scientific manuscript for publication on the results (Appendix 1). We also monitored collared elk and deer on a monthly basis to collect location information and to retrieve GPS collars from mortalities (data required to meet objectives 2 and 3).

WILDLIFE RESEARCH REPORT

EVALUATING SOLUTIONS TO REDUCE ELK AND MULE DEER DAMAGE ON AGRICULTURAL RESOURCES

HEATHER E. JOHNSON

PROJECT NARRITIVE OBJECTIVES

To conduct a study on elk and mule deer around the agricultural fields of Dove Creek that 1) experimentally tests a suite of non-lethal exclusion and repellent techniques to minimize crop depredation, 2) examines wild ungulate distribution patterns to design public hunting opportunities to reduce crop damage, and 3) maps and models landscape characteristics associated with damage to specify more effective site-specific management practices.

SEGMENT OBJECTIVES

1. Implement the second (and final) year of an experiment to assess non-lethal techniques to exclude or repel deer and elk from sunflower fields in the vicinity of Dove Creek.
2. Conduct data analysis on the exclusionary treatment experiment and submit a scientific manuscript with research results (Appendix 1).
3. Monitor collared deer and elk on a monthly basis for movements, survival and collar retrieval.

INTRODUCTION

Elk and deer provide important recreational, ecological, and economic benefits, but they can also cause substantial damage to agricultural resources in rural areas (Austin et al. 1998, Wisdom and Cook 2000). In Colorado, elk and deer crop depredation accounts for a majority of the wildlife damage claims in the state, and CPW is obligated to pay for those lost resources. In recent years, the agency has spent approximately $500,000 on an annual statewide basis to compensate farmers for ungulate depredation. This situation has generated significant challenges for CPW and other wildlife agencies that are responsible for maintaining viable ungulate populations while also minimizing crop damage (Wagner et al. 1997, Van Tassell et al. 1999, Hegel et al. 2009, Walter et al. 2010).

Elk and deer crop depredation results from a combination of factors including the seasonal distribution and abundance of local forage resources, landscape configuration, and herd density patterns (Vecellio et al. 1994; Yoder 2002; Hegel et al. 2009). Damage can be highly variable within and among growing seasons, as local patterns in precipitation and temperature will alter the availability of native forage and the motivation of ungulates to feed on agricultural fields (Walter et al. 2010). The juxtaposition of cropland and wildland has also been found to be particularly important in driving damage rates, as those cultivated fields closer to cover experience more damage (Nixon et al. 1989, Hegel et al. 2009). Additionally, studies have found that ungulate damage is often caused by only a subset of individuals in the population, depending on the spatial and social structuring of the herd. These observations have critical implications for wildlife managers, as 1) management practices may be differentially effective based on the variability of native forage conditions and the spatial juxtaposition of other habitat features, and 2) management techniques targeted at specific animals may be more effective than implementing those techniques on the population at large (Blejwas et al. 2002, Hegel et al. 2009). As a result, it is important to understand both the spatial configuration of seasonal resources and the resource selection patterns of different segments of local ungulate populations to successfully identify strategies to reduce elk and deer crop damage (Hegel et al. 2009).

One of the most significant hotspots of elk and mule deer depredation in Colorado has been in the vicinity of Dove Creek, where CPW paid roughly a quarter of million dollars annually to farmers between 2007 and 2009. High damage in this region has been primarily attributed to a recent switch in the crops that are locally grown. Farmers traditionally grew beans, spring and winter wheat, oats, alfalfa and grass hay which had minimal damage by wild ungulates. In recent years, however, local growers have planted sunflowers, a high-value seed oil crop used to produce biofuels, and a crop that is highly desirable to wild ungulates. In addition to this recent switch in crops, ungulate damage around Dove Creek is exacerbated by the spatial distribution of sunflower fields in relation to the surrounding wildlands (e.g., sagebrush-mixed shrublands and piñon-juniper woodlands). The region is fractured with deep canyons that provide refugia for elk and deer, and fields adjacent to the canyon rims experience the greatest amount of depredation. With the substantial increase in biofuel production in the U.S. (World Resources Institute 2008), the agricultural conversion observed around Dove Creek will likely become common, as high-priced crops replace more traditionally-grown, lower-cost crops (Walter et al. 2009).

The main management tool available to CPW to reduce ungulate sunflower damage has been to increase harvest through the use of kill permits, distribution hunts, and private land only (PLO) doe/cow hunts, however tolerance for these permits has been low among hunters and the general public. Permits are typically allocated to farmers between June and August, when calves and fawns are still dependent on their mothers, reducing the acceptability of female hunts. Additionally, local elk and deer populations are near or below management objectives, creating a paradox where CPW ultimately wants to increase ungulate herds, but reduce crop depredation. Hunting is also economically important around Dove Creek, so there is a strong desire in the local community to have increased public hunting opportunities and reduced PLO damage hunts.

Given pressure by farmers over elk and deer sunflower damage, and frustration by hunters and the public over kill permits, CPW wildlife managers were interested in finding alternative solutions for reducing sunflower depredation. As a result, personnel from CPW partnered with wildlife-damage researchers from the National Wildlife Research Center (NWRC) to find non-lethal, science-based solutions for reducing sunflower depredation. Collaboratively, we developed a proposal to 1) test a suite of non-lethal exclusionary techniques to minimize crop depredation, 2) identify public hunting strategies that reduce crop damage, and 3) map and model landscape characteristics associated with damage behavior to specify more effective site-specific management practices (Johnson et al. 2011). Results from this study should enable CPW and local growers to reduce ungulate crop depredation, leading to a decrease in compensation payments, a decrease in kill permits/distribution hunts, and an increase in public hunting opportunities.

In FY 2012-13 we completed objective 1, and continued to monitor collared elk and deer for objectives 2 and 3. Specifically, we conducted the second (and final) year of the experiment to assess non-lethal exclusion and repellent techniques for reducing elk and deer damage. We analyzed data from the experiment (collected during the growing seasons of 2011 and 2012) and submitted a scientific manuscript with research results for publication (currently in revision, Appendix 1). We also monitored collared elk and deer on a monthly basis to collect information about local movement and distribution patterns, and to retrieve collars from mortalities (GPS collar data will be used to meet objectives 2 and 3).

STUDY AREA

The area around Dove Creek, Colorado (Montezuma, San Miguel and Dolores counties) is comprised of a mixture of agricultural and public lands. This project focuses on the north half of CPW Game Management Unit 72 and the west half of 711 (the portion west of the Dolores River). The area is generally characterized as mountain shrubland interspersed with irrigated and dryland agricultural fields, ranging from 1,981 to 2,590 m in elevation. The mountain shrub habitat type is primarily composed of serviceberry (*Amelanchier alnifolia*), bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus montanus*), squaw apple (*Peraphyllum ramosissimum*) and black sagebrush (*Seriphidium novum*). Sunflower fields around Dove Creek are spatially juxtaposed to deep canyons that provide refugia for elk, exacerbating ungulate damage on agricultural crops (see Appendix 1, Figure 1).

METHODS

Testing the effectiveness of different exclusionary treatment types for reducing ungulate damage

During the sunflower growing seasons (Jul-Oct) of 2011 and 2012, we constructed experimental plots to test the effectiveness of three non-lethal exclusion and repellent techniques for reducing elk and deer damage: a polyrope electric fence, a temporary "winged" fence, and an organic repellent. These methods differ from traditional exclusionary fencing for elk and deer, in that they are cheaper to construct and can be easily moved among fields over time, as farmers grow sunflowers on a rotational basis. Each exclusionary treatment is described below:

- Polyrope electric fence – The polyrope electric fence acts primarily as psychological barrier for elk and deer based on learned behavioral, avoidance conditioning (McKillop and Sibly 1988). The fences consists of conductive wires which are woven into synthetic electric "ropes" that are more durable, visible, and easy to install than traditional electric fences (Appendix 1, Figure 2; Hygnstrom and Craven 1988, VerCauteren et al. 2006). Avoidance conditioning occurs when an animal contacts the fence, often with the nose or tongue, and receives a powerful electric shock. Polyrope fences have had success in reducing deer damage (Hygnstrom and Craven 1988, Seamans and VerCauteren 2006), but have not been experimentally tested for reducing elk damage. We constructed polyrope fences approximately 1.8 meters tall with 5 strands to discourage passage under, through, or over the fence. The polyrope was powered by a Speedrite™ 3000 energizer (Tru-Test Incorporated, San Antonio, Texas) using a 12-volt deep-cycle battery with a solar-panel recharger.
- Temporary winged fence - For seasonal agricultural resources, such as sunflowers, temporary fences may be sufficient to provide protection from wild ungulates and are inexpensive, lightweight, and easy to erect and remove (Rosenberry et al. 2001, VerCauteren et al. 2006). We tested the effectiveness of a temporary "winged" fence made of polypropylene mesh (Appendix 1, Figure 2). The fence is installed completely on one side of the target field, and partially installed on two other sides having 50-100 meter "wings" that extend perpendicular from the full fence line. This design was found to reduce deer damage in corn fields (Hildreth et al. 2012) but has not yet been tested on elk or on deer with crops other than corn. On those plots receiving winged-fence treatments, we installed the fence such that the side receiving complete protection was along the crop/wildland interface. The fence was made of 2.4 meter tall black barrier material (e.g., Guardian Warning Barrier, Tenax Corporation, USA, Baltimore, Maryland) for increased height and visual deterrence.
- Plantskydd - Repellents are nonlethal substances that can be used to deter ungulates by decreasing a plant's palatability (Walter et al. 2010). We tested the effectiveness of a relatively new product, Plantskydd, for reducing sunflower damage around Dove Creek. This product was developed in Sweden to decrease mammalian wildlife damage on commercial forests. It works by emitting an odor that animals associate with predator presence, repelling the animal before it forages on crop plants. There is great interest in the success of this product as it can be easily applied to vegetation by ground and aerial spraying, used on both organic and conventionally grown sunflowers, and is cost-effective for growers. That said, the effectiveness of Plantskydd has not been experimentally tested, only anecdotally reported. To test this method, Plantskydd treatment plots were ground sprayed in a swath around the plot perimeters after germination had begun (as directed by the manufacturer). Plantskydd was reapplied to treatment plots once/month

throughout the growing season as the repellent may wash off or decompose over time and needs to be reapplied to new plant material.

We constructed treatment plots based on a randomized block design. We identified 5 sunflower fields to serve as replicates in 2011 and 4 fields in 2012 (~160-200 acres in size); all fields had previously suffered high ungulate crop damage. Within each field we specified 4 10-acre plots, one for each experimental treatment type (polyrope fence, temporary winged fence, chemical repellent fence) and a control. The 4 plots were randomly assigned within each field, such that each field (block) contained one replicate of all treatments (Gotelli and Ellison 2004). This design allowed us to statistically account for environmental heterogeneity, as we expected that damage would be variable among fields. Within the fields, study plots were spaced as far apart as possible, to account for plot independence. Plots were also placed along the agriculture/wildland boundary, where depredation was expected to be concentrated. Fences were installed during the end of June and early July after sunflowers had germinated.

Experimental plots were monitored from mid-July through mid-October (just prior to harvest). Treatment and control plots were examined for 2 key response variables: sunflower damage and the number of elk and deer tracks that crossed plot perimeters. We used the variable-area-transect method for estimation of crop damage (Engeman and Sugihara 1998; Engeman and Sterner 2002; Gilsdorf et al. 2004a, b), conducting final damage assessments immediately before harvest (mid-Oct). In 2011 we assessed damage on 15 transects/plot, and in 2012 we increased the number to 30 transects/plot. For each transect, we randomly (with replacement) identified a starting location within the plot and inspected a row of sunflowers, counting the total number of sunflower plants, and the number of plants that were damaged by deer or elk. Typical damage was characterized by the removal of the terminal bud, consumption of the seed head and trampling of the plants, verified by accompanying cervid tracks. If 5 cervid-damaged sunflowers were tallied within 100 m, we recorded the distance traveled to the fifth damaged plant (<100 m) and the total number of sunflower plants observed within that distance. If 5 cervid-damaged sunflowers were not tallied within 100 m, the observer recorded the total number of sunflowers and the number of cervid-damaged plants counted within that distance. If the end of the sunflower row was reached before completing a transect, the observer would randomly select an adjacent row (i.e., right or left row) to complete the transect.

We calculated mean proportion of end-of-season damage for each treatment and control plot, and mean number of elk and deer tracks traversing plot perimeters for each plot across the growing season. We used a generalized linear mixed model to identify whether exclusion or repellent treatment types were effective in reducing cervid damage to sunflower plots (Pinheiro and Bates 2000). Because damage data were recorded for each transect as the number of damaged plants/total plants, we used a binomial distribution with a logit link function. To evaluate the influence of exclusion techniques on deer and elk tracks traversing plot perimeters, we used generalized linear mixed models with Poisson distributions and log link functions. We generated separate models for predicting the number of tracks by deer and elk, as we hypothesized that treatments may vary in their effectiveness among cervid species. We used model coefficients to assess the direction and magnitude of different treatment types on cervid damage and plot use (95% confidence intervals non-overlapping zero).

Collaring elk and deer to collect information on movement and distribution

To obtain data on ungulate movement and distribution patterns, we captured and collared adult female elk and mule deer using a net gun from a helicopter in fall 2011 (Krausman et al. 1985). Females were the target of collaring efforts because they cause a majority of the crop depredation and should provide valuable insight into herd distributions. Captured elk and deer were hobbled and blindfolded, fitted with a global positioning system (GPS) collar, aged, measured and released. GPS collars were programmed to collect a location every 4 hours for 2 years, and then drop off the animals in fall 2013. The collars are “store-on-board,” meaning that the data can only be downloaded once the collar is retrieved from the field. Until collars drop-off, we are conducting monthly aerial telemetry flights to obtain some general location information and to monitor mortalities so collars can be retrieved from the field.

Once GPS collar data has been retrieved, elk and mule deer locations will be used to map seasonal distribution and migration patterns in ArcGIS. This should allow CPW to design public hunts that will target conflict elk and mule deer, while minimizing the need for PLO hunts and kill permits. Animal location data will also be used to model ungulate damage potential in relation to field locations, surrounding habitat types, human development, and topography. These variables have been important in explaining rates of ungulate depredation, as damage tends to increase closer to cover, further from roads, and depending on crop palatability (Grover and Thompson 1986, Nixon et al. 1989, Hegel et al. 2009). Information about the location of a crop field in the context of the overall landscape will allow CPW to work with local growers to identify appropriate management tools, and the timing of their implementation, to reduce game damage. Data analysis for this portion of the project will be primarily conducted by collaborators at the USDA National Wildlife Research Center.

RESULTS AND DISCUSSION

Exclusion and Repellent Treatments - During summers 2011 and 2012, we conducted 3,288 damage transects and 233 track surveys across all treatment plots. The percentage of sunflowers damaged by cervids across plots and years ranged from 0.0% to 72.6% ($\bar{x}$ = 8.3%, SE = 0.8). The mean bimonthly number of deer tracks crossing plot perimeters ranged from 0 to 149.8 ($\bar{x}$ = 23.0, SE = 5.3) and the mean number of elk tracks ranged from 0 to 21.6 ($\bar{x}$ = 5.3, SE = 1.1). Mean percentage sunflower damage and number of deer tracks were greater in 2012 than in 2011 (damage: t = -3.300, df = 29, P = 0.003 [Fig. 3a]; deer tracks: t = -4.512, df = 34, P < 0.001; Fig. 3b), but mean values for elk tracks were similar between years (t = 0.371, df = 34, P = 0.713). In 2011, treatment and control plots averaged 0.9% sunflower plant damage at the end of the growing season, and a bimonthly average of 6.0 deer and 5.7 elk tracks crossed plot boundaries. Conversely, 2012 plots had an average of 17.1% of plants damaged at harvest and an average of 44.4 deer tracks and 4.9 elk tracks crossed plot boundaries on a bimonthly basis.

We found that electric fencing was the only treatment that significantly reduced damage and plot use by deer and elk (see Appendix 1 for details). Across years, the mean proportion of damaged plants on electric fence plots was 0.01 (95% CI: 0.00 – 0.03), on control plots was 0.05 (95% CI: 0.00 – 0.33), on repellent fences was 0.04 (95% CI: 0.01 – 0.15) and on winged fences was 0.04 (95% CI: 0.01 – 0.15). The average bimonthly number of deer tracks that crossed plot perimeters on plots with electric fencing was 0.6 (95% CI: 0.3 – 1.1), on control plots was 18.5 (95% CI: 3.8 – 91.5), on repellent fence plots was 18.4 (95% CI: 11.4 – 29.7), and on winged plots was 16.8 (95% CI: 10.4 – 27.0). Electric fences also reduced the number of elk that crossed plot perimeters on a bimonthly basis, but the effect was lesser than for deer. An average of only 0.1 elk tracks crossed electric fence plot boundaries (95% CI: 0.0 – 0.2), while 4.3 crossed control plots (95% CI: 1.8 – 10.3), 3.4 crossed repellent plots (95% CI: 2.2-5.2) and 3.7 crossed winged plots (95% CI: 2.4 – 5.7).

For wildlife agencies seeking non-lethal management options for reducing elk and deer damage to high-value agricultural crops, we found that 5-strand polyrope electric fencing was effective. Polyrope is easy to assemble/disassemble, cost-effective relative to permanent fencing, and can be used on a temporary basis to minimize damage for certain crops grown on rotation or during years when natural forage for cervids is scarce. In areas where management agencies are working to maintain or increase deer and elk populations, but reduce cervid damage, the application of an effective exclusion technique like polyrope electric fencing could protect high-value crops, decrease the need for compensation payments and lethal cervid depredation permits, and increase satisfaction of producers and the public. Wildlife agencies will need to continue to work with producers to test and apply management techniques for crop protection based on the wildlife species present, population densities, crop types, landscape configuration, and abundance of local forage.

Monitoring Collared Deer and Elk - We conducted monthly aerial telemetry flights for collared animals to track survival and general movement patterns. Three deer and one elk died during FY12-13 from unknown causes. GPS collars were retrieved from all mortalities so that the data could be downloaded and processed. This information will be used during FY13-14 to map and model seasonal ungulate distributions, game damage potential, and management options for sunflower producers.

SUMMARY AND FUTURE PLANS

During FY12-13 we completed the non-lethal, exclusionary treatment experiment, analyzed ungulate damage and use on plots by treatment type, submitted a scientific manuscript for publication with experiment results (Appendix 1), and monitored collared elk and deer in the study area. In FY13-14 we will continue to monitor the survival and movements of collared animals on a monthly basis using aerial telemetry, collect collars in the field once they drop off animals in fall 2013, and map and model GPS location data. The benefits of this project include the identification of non-lethal techniques for successfully reducing ungulate damage to sunflowers and other crops, gaining knowledge about local elk and deer movements and distribution relative to agricultural fields, and the development of models to identify areas highly susceptible to damage based on landscape characteristics.

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Appendix 1

Evaluating techniques to reduce cervid damage

Evaluation of techniques to reduce deer and elk damage to agricultural crops

Colorado Parks and Wildlife and US Dept. of Agriculture,

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Evaluation of techniques to reduce deer and elk damage to agricultural crops

RH: Johnson et al. • Evaluating techniques to reduce cervid damage

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KEY WORDS *Cervus elaphus nelsoni,* crop damage, electric fence, elk, mule deer, *Odocoileus hemionus,* repellent, sunflowers, wildlife damage management, winged fence.

ABSTRACT

Mule deer (*Odocoileus hemionus*) and Rocky Mountain elk (*Cervus elaphus nelsoni*) provide important recreational, ecological, and economic benefits, but can also cause substantial damage to agricultural crops. Cervid damage to agriculture creates challenges for wildlife agencies responsible for minimizing crop depredation while maintaining healthy deer and elk populations. Sunflower producers in southwestern Colorado have experienced high deer and elk damage and were interested in temporary methods to reduce damage that were cost-effective for rotational crops. To address this challenge we investigated three temporary, non-lethal exclusion and repellent techniques for reducing deer and elk damage to sunflowers: 1) a polyrope electric fence, 2) the chemical repellent Plantskydd™, and 3) a winged fence. During July through October 2011 and 2012, we used a randomized block design to test the efficacy of these techniques by quantifying cervid damage to sunflowers and the number of deer and elk tracks traversing treatment and control plot boundaries. Using generalized linear mixed models we found that polyrope electric fences reduced deer and elk damage and presence within plots, while the repellent and winged fences did not reduce ungulate activity. Polyrope electric fences may be a suitable tool in areas where wildlife management agencies want to maintain deer and elk populations but reduce seasonal damage by cervids to high value crops. In Colorado, use of an effective exclusion technique like polyrope electric fence could also decrease the need for lethal depredation permits and damage compensation payments, and increase satisfaction among producers and the public.

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Mule deer (*Odocoileus hemionus*) and Rocky Mountain elk (*Cervus elaphus nelsoni*) provide important recreational, ecological, and economic benefits, but also can cause substantial damage to agricultural crops (Austin et al. 1998, Wisdom and Cook 2000). Because crops are typically more digestible and contain higher levels of crude protein than native grasses and browse species, they are often selected and consumed by wild cervids (Mould and Robbins 1982). Agricultural producers have reported more damage by elk and deer (*Odocoileus sp.*) than any other wildlife species, and damage by deer alone has been projected to exceed 100 million dollars annually in the U.S. (Conover 2002). Cervid damage to crops has created significant challenges for wildlife management agencies, as agencies are often responsible for both maintaining cervid population sizes for recreation while minimizing damage to agriculture (Wagner et al. 1997, Hegel et al. 2009, Van Tassell et al. 1999, Walter et al. 2010).

Agricultural producers often experience varying amounts of crop depredation caused by cervids depending on the seasonal distribution, abundance and landscape configuration of local food resources (Vecellio et al. 1994, Yoder 2002, Hegel et al. 2009). Damage also can be variable both within and among growing seasons, as local precipitation and temperatures will alter the availability of native forage and the motivation of deer and elk to feed on agricultural products (Walter et al. 2010). The proximity of cropland and wildland is also important in predicting patterns of damage, as cultivated fields closer to wildlife cover experience greater depredation (Nixon et al. 1989, Hegel et al. 2009). As a result, the effectiveness of management practices to reduce cervid damage may vary based on native forage availability, proximity of cover, and other habitat features (Hegel et al. 2009).

Common management tools used to reduce cervid damage to crops include permanent fencing and lethal removal of animals through depredation permits (Walter et al. 2010); however, there are drawbacks to each approach. Permanent cervid-proof fencing is effective but often cost-prohibitive for producers that have large tracts of land (VerCauteren et al. 2006) or grow crops on a rotational basis where only one crop type experiences high rates of damage. Permanent fencing is also a concern as it can interfere with wildlife movements and reduce access to nearby habitat. Wildlife agencies use depredation permits to lethally remove animals causing damage, but tolerance for these permits is often low among hunters, some producers, and the general public (Colorado Parks and Wildlife [CPW], unpublished data). Hunters often perceive depredation permits as reducing hunting opportunity (Fritzell et al. 1995, Horton and Craven 1997), particularly when local deer and elk population sizes are below agency management objectives. Depredation permits are also often unpopular with the public, particularly when lethal removal includes female cervids with dependent young.

Identifying cost-effective, non-lethal methods that reduce cervid damage to agricultural crops is of particular interest in Colorado. Deer and elk account for about 50% of wildlife damage claims on agriculture, and CPW is mandated to pay all eligible claims. These compensation payments are costly (i.e., $458,760 was paid in compensation for deer and elk damage in 2012; CPW 2012), thus, CPW is interested in methods to reduce cervid depredation and associated payments. While damage to agriculture is a management concern, many of Colorado's deer and elk populations are at or below their management objectives, making depredation permits highly unpalatable to local hunters and the general public. Because deer and elk often depend upon private lands for habitat, finding cost-effective, non-lethal solutions to prevent cervid depredation is also essential to encourage private landowner tolerance of wildlife and to build effective agency-landowner partnerships.

To identify cost-effective, non-lethal strategies for reducing deer and elk damage to crops, our objective was to experimentally test three temporary techniques: 1) a 5-strand polyrope electric fence (hereafter electric), 2) an organic chemical repellent (Plantskydd™; hereafter repellent), and 3) a winged or partial fence (hereafter winged). These methods are less expensive than permanent fencing and can be implemented on a temporary basis to account for crop rotation (VerCauteren et al. 2006, Walter et al. 2010). While these methods have received some testing on white- and black-tailed deer (*Odocoileus virginianus*, *O. h. columbianus*; Nolte 1998, Seamans and VerCauteren 2006, Hildreth et al. 2012), little is known about their effectiveness in reducing mule deer or elk damage to agriculture.

STUDY AREA

We tested temporary exclusion and repellent techniques for deer and elk near Dove Creek, Colorado, USA (Dolores County; 37°45'58.05" N, 108°54'21.10"W; Fig. 1). Experimental plots were placed in agricultural fields growing sunflowers that were spatially juxtaposed to native vegetation and wildland canyons, and which had previously experienced cervid damage (CPW, unpublished data). All sunflower fields were located on private property, but the region is generally comprised of a mix of private and public lands.

Elevation in the study area ranges from 1,981 to 2,590 m, and vegetation is characterized as mountain shrub and pinyon-juniper woodlands, interspersed with irrigated and dryland agriculture. The native vegetation is primarily composed of serviceberry (*Amelanchier alnifolia*), bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus montanus*), squaw apple (*Peraphyllum ramosissimum*), black sagebrush (*Seriphidium novum*), pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteoperma*). Between 1996 and 2012 mean annual precipitation was 26.7 cm, which is typically received during late summer rains and as snow during winter (Weather Station DVCO1, Colorado Agricultural Meteorological Network 2012). Mean annual minimum and maximum temperatures were -0.4°C and 16.6°C, respectively (Colorado Agricultural Meteorological Network 2012). Since 1998 estimated deer population sizes have been consistently below CPW's management objectives, while estimated elk population size has been above or within management objectives (CPW, unpublished data).

The study area has experienced high rates of mule deer and elk agricultural damage in association with a recent switch in the types of crops that are grown. Farmers traditionally grew dry beans, spring and winter wheat, and grass hay which experienced minimal damage by cervids. Since 2007, however, many farmers started growing sunflowers on a rotational basis, a high-value seed oil crop used for biofuel, and have experienced up to 100% depredation on fields in some years. Sunflowers in the region are generally grown on a 3 to 4-year rotation with other crops (e.g., winter wheat, pinto beans) that experience minimal damage and thus, producers were interested in exclusion or repellent techniques that could be moved between fields in different years. Cervid damage in this area was also exacerbated by the spatial juxtaposition of agricultural fields alongside wildland canyons that provided refugia for deer and elk (Fig. 1).

METHODS

Exclusion and Repellent Methods Evaluated

Electric – We tested a polyrope electric fence (ElectroBraid™ Fence Limited, Yarmouth, Nova Scotia, Canada; approximately $5-10/m for materials), which acts primarily as a psychological barrier based on learned behavioral and avoidance conditioning (Fig. 2a; McKillop and Sibly 1988, VerCauteren et al. 2012). The fence consisted of conductive copper wires woven into synthetic "ropes" that are more durable, visible and easier to install than traditional electric fence designs (Hygnstrom and Craven 1988, Seamans and VerCauteren 2006, VerCauteren et al. 2006, Fischer et al. 2011). We constructed fences 1.8 m high, with wooden h-brace assemblies placed approximately every 100 m and metal t-posts spaced every 15 m. Five polyrope lines were attached to the fence posts at 20, 56, 89, 135, and 183 cm above ground to discourage deer and elk incursions. Avoidance conditioning occurs when an animal contacts the fence, often with the nose or tongue, and receives an electric shock. Polyrope fences have reduced white-tailed deer damage to crops (Hygnstrom and Craven 1988, Seamans and VerCauteren 2006), but have not been experimentally tested for reducing mule deer or elk damage. The polyrope fence used a Speedrite™ 3000 energizer (Tru-Test Incorporated, San Antonio, Texas) which had a maximum pulse output of 3.0 joules and was operated from a 12-volt deep-cycle battery with a solar-panel recharger.

Repellent - We tested the effectiveness of Plantskydd™ (Tree World Plant Care Products Inc, St. Joseph, Missouri, USA) for reducing deer and elk damage. This repellent can be used on conventional and organic crops and can be applied by ground or aerial spraying. Plantskydd™ was developed in Sweden for reducing mammalian wildlife damage on commercial forests. The active ingredient is dried bloodmeal, which the manufacturer asserts works by emitting an odor that wildlife associate with predator presence. We mixed Plantskydd™ powder with water following the manufacturer's directions for severe damage (14.8 kg of Plantskydd™/plot perimeter). The manufacturer recommends spraying a swath ≥10 m around plot perimeters, and we sprayed an 18 m swath around treatment plot perimeters, the maximum distance that could be covered with an industrial ground sprayer (Model 4720, John Deere, Deere and Company, Moline, Illinois, USA). Given materials and application, this treatment cost ≤ $1/m of field perimeter spraying. Plantskydd™ was applied monthly throughout the growing season (Jul – Sept) to account for the repellent washing off or degrading, and to spray new plant growth. Plantskydd™ has reduced damage to tree seedlings caused by black-tailed deer (Nolte 1998, Wagner and Nolte 2001), but has been not been tested on mule deer or elk.

Winged fence –Hildreth et al. (2012) recently experimented with "winged" or "partial" fences designed to reduce white-tailed deer access along field edges adjacent to cover. The fence is completely installed on the field side that borders native vegetation, and partially installed on the perpendicular sides, creating "wings" that extend around a portion of the field (Fig. 2b; approximately $6/m for materials). This fence is highly economical as only a portion of the field needs to be enclosed and materials can be easily erected and removed depending on crop rotation. We installed winged fences following Hildreth et al. (2012), where the side of the treatment plot closest to the crop/wildland interface received complete protection. We erected fences 2.1 m in height which consisted of UV-stable polypropylene high-strength mesh (Benner's Gardens, Phoenixville, PA) secured to 3 m metal t-posts spaced every 7 m using cable ties. Two strands of 12.5 gauge high-tensile wire were placed 0.8 m and 2.1 m above ground, so the mesh could be suspended and anchored to the wire with circular staples along the length of the fence for support. The fence also had a 0.2 m apron extending outward from the field, secured with 0.3 m steel stakes, to further reduce elk and deer access. Corners and ends of the winged fence were supported with metal t-post angled h-brace assemblies. The fence wings extended 50 m along the two sides of the treatment plots that were adjacent to the fully installed side of the fence.

Experimental Design

We used a randomized block design (Gotelli and Ellison 2004) where each “block” was a sunflower field (~65-80 ha in size) that had previously experienced cervid crop damage, and which was directly adjacent to the wildland boundary where damage was expected to be greatest (Fig. 1). Within each field we delineated 4 4-ha treatment plots. Treatment plots were randomly assigned to receive one of the following treatments: no exclusion or repellent method (control), electric fence, repellent, or winged fence. We used this design to account for environmental heterogeneity, as we expected damage to vary among fields. We monitored 5 replicate fields during 2011 (Fields A-E) and 4 replicate fields in 2012 (Fields F-I); because sunflowers were grown on rotation the same fields were not tested in both years. Fences were constructed in late June and early July after sunflowers had germinated to ensure planting was successful, as pests or low soil moisture can cause failure in germination. The corners of all plots were marked with easily visible metal stakes to facilitate data collection.

Monitoring Fence Effectiveness

Plots in each field were monitored for two response variables: damage to sunflower plants and number of deer and elk tracks traversing plot boundaries (entry/exit into plots). We used the variable-area-transect method for estimation of crop damage (Engeman and Sugihara 1998; Engeman and Sterner 2002; Gilsdorf et al. 2004a, b), conducting final damage assessments immediately before harvest (mid-Oct). In 2011 we assessed damage on 15 transects/plot, and in 2012 we increased the number to 30 transects/plot. For each transect, we randomly (and with replacement) identified a starting location within the plot and inspected a row of sunflowers, counting the total number of sunflower plants, and the number of plants that were damaged by deer or elk. Typical damage was characterized by the removal of the terminal bud, consumption of the seed head and trampling of the plants, verified by accompanying cervid tracks. If 5 cervid-damaged sunflowers were tallied within 100 m, we recorded the distance traveled to the fifth damaged plant (<100 m) and the total number of sunflower plants observed within that distance. If 5 cervid-damaged sunflowers were not tallied within 100 m, the observer recorded the total number of sunflowers and the number of cervid-damaged plants counted within that distance. If the end of the sunflower row was reached before completing a transect, the observer would randomly select an adjacent row (i.e., right or left row) for completing the transect.

Each treatment and control plot was also monitored for deer and elk tracks that traversed plot boundaries on a bimonthly basis throughout the growing season (mid-Jul through mid-Oct). An observer would walk the perimeter of each plot, counting the total number of deer and elk tracks that crossed the plot perimeter. Cervid tracks were raked or stamped out after each observation to avoid double-counting in subsequent sampling periods.

Statistical Approach

We calculated mean proportion of end-of-season damage for each treatment and control plot, and mean number of elk and deer tracks traversing plot perimeters for each plot across the growing season. We also calculated mean values separately for fields monitored in 2011 and 2012, as cervid damage was uncharacteristically low in 2011. We did not include end-of-season damage values from the repellent plot of one field (Field F in 2012) because cervid damage occurred in that plot before the first application of the repellent. Similarly, end-of-season damage information from all treatment plots of a field in 2012 (Field I) were removed from data summaries and analyses because substantial depredation occurred after germination but before fence construction.

We used a generalized linear mixed model to identify whether exclusion or repellent treatment types were effective in reducing cervid damage to sunflower plots (Pinheiro and Bates 2000). Because damage data were recorded for each transect as the number of damaged plants/total plants, we used a binomial distribution with a logit link function (Bolker et al. 2009). Treatment was included in the model as a categorical fixed effect (control plots were considered the reference class) and we nested plot within field within year for the random effects model structure. We used model coefficients to assess the direction and magnitude of different treatment types on cervid damage (95% confidence intervals non-overlapping zero).

To evaluate the influence of exclusion or repellent types on deer and elk tracks traversing plot perimeters, we used generalized linear mixed models with Poisson distributions and log link functions. As with the damage models, we included treatment type as a categorical fixed effect and nested plot within field within year for the random effects portion of the model. We generated separate models for predicting the number of tracks by deer and elk, as we hypothesized that treatments may vary in their effectiveness among cervid species (e.g., VerCauteren et al. 2006, Walter et al. 2010). As with the damage model, we used model coefficients, and their 95% confidence intervals, to assess the direction and magnitude of treatment effects on the number of tracks traversing plot boundaries. We used the package "lme4" in program R for all statistical modeling (R Core Team 2012).

RESULTS

Cervid damage and tracks varied across treatment and control plots. Just prior to harvest, the percentage of sunflowers damaged by cervids across plots and years ranged from 0.0% to 72.6% ($\bar{x}$ = 8.3%, SE = 0.8). The mean bimonthly number of deer tracks crossing plot perimeters ranged from 0 to 149.8 ($\bar{x}$ = 23.0, SE = 5.3) and the mean number of elk tracks ranged from 0 to 21.6 ($\bar{x}$ = 5.3, SE = 1.1). Mean percentage sunflower damage and number of deer tracks were greater in 2012 than in 2011 (damage: t = -3.300, df = 29, P = 0.003 [Fig. 3a]; deer tracks: t = -4.512, df = 34, $P < 0.001$; Fig. 3b), but mean values for elk tracks were similar between years (t = 0.371, df = 34, P = 0.713). In 2011, treatment and control plots averaged 0.9% sunflower plant damage at the end of the growing season, and a bimonthly average of 6.0 deer and 5.7 elk tracks crossed plot boundaries. Conversely, 2012 plots had an average of 17.1% of plants damaged at harvest and an average of 44.4 deer tracks and 4.9 elk tracks crossed plot boundaries on a bimonthly basis. Despite differences in damage between years, plots protected with electric fencing consistently received the least amount of cervid damage and tracks (Fig. 3).

The only treatment type that reduced damage to sunflowers was the electric fence (Table 1). Treatment effects on damage and plot use across both years, however, showed limited biological effect given that more data were collected in 2011 when minimal damage occurred. Across years, the mean proportion of damaged plants on electric fence plots was 0.01 (95% CI: 0.00 – 0.03), on control plots was 0.05 (95% CI: 0.00 – 0.33), on repellent fences was 0.04 (95% CI: 0.01 – 0.15) and on winged fences was 0.04 (95% CI: 0.01 – 0.15).

Electric fencing was also the only treatment type that reduced cervid activity within sunflower plots (Table 1). The average bimonthly number of deer tracks that crossed plot perimeters on plots with electric fencing was 0.6 (95% CI: 0.3 – 1.1), on control plots was 18.5 (95% CI: 3.8 – 91.5), on repellent fence plots was 18.4 (95% CI: 11.4 – 29.7), and on winged plots was 16.8 (95% CI: 10.4 – 27.0). Electric fences also reduced the number of elk that crossed plot perimeters on a bimonthly basis, but the effect was lesser than for deer. An average of only 0.1 elk tracks crossed electric fence plot boundaries (95% CI: 0.0 – 0.2), while 4.3 crossed control plots (95% CI: 1.8 – 10.3), 3.4 crossed repellent plots (95% CI: 2.2-5.2) and 3.7 crossed winged plots (95% CI: 2.4 – 5.7).

DISCUSSION

As wildlife management agencies look for methods to reduce cervid damage to agricultural crops while maintaining deer and elk population sizes, non-lethal methods of crop protection will become increasingly important. We tested three methods for reducing deer and elk damage to sunflowers, a high-value crop, but found that only polyrope electric fencing significantly reduced damage and use by deer and elk. Investigators have found different polyrope electric fence designs to be successful at reducing white-tailed deer damage to crops (Hygnstrom and Craven 1998, Seamans and VerCauteren 2006), but to our knowledge, this is the first study to test the 5-strand polyrope fence design on mule deer or elk. Polyrope appears to be effective at reducing deer and elk damage to sunflowers, providing a temporary and cost-effective option for producers to reduce depredation through non-lethal means.

While the chemical repellent Plantskydd™ is advertised to imitate predator presence and induce fear in cervids, it was not consistently effective in our evaluation. Fear inducing repellents are generally more successful than repellents with other strategies (i.e., aversive taste or pain inducing; Wagner and Nolte 2001), and studies have found this repellent to reduce black-tailed deer damage to tree seedlings (Nolte 1998, Wagner and Nolte 2001). In our sunflower plots, however, the repellent did not reduce mule deer or elk damage or tracks, a result which may be influenced by numerous factors including: animal habituation, availability of native forage, local weather conditions, animal nutritional state, repellent concentration, or the frequency of repellant application (Kimball et al. 2009, Walter et al. 2010, Elmeros et al. 2011). Indeed, drought conditions in 2012 may have increased motivation by deer and elk to forage on sunflowers, despite the repellent odor. We applied repellent once/month to treatment plots. While >1 application/month may have increased effectiveness of the treatment, such a high frequency of applications would not be feasible for most sunflower producers, and therefore, not particularly useful as a routine damage management tool.

The winged fence we used also did not decrease deer and elk damage and use of the plots. In contrast, Hildreth et al. (2012) found winged fencing reduced white-tailed deer depredation to corn by 13.5%. Based on profits from the yield of corn and the cost of fence construction, Hildreth et al. (2012) concluded that corn producers could save approximately $205/ha/annually by using a winged fence along the agriculture-wildland interface. In our experiment, damage in winged plots was lesser than control plots in 7 of 8 fields, but did not have a strong treatment effect. We often observed elk and deer tracks along the partial portion of the fence to cross into the plot at the termination of the wing. DeVault et al. (2008) reported similar results in which white-tailed deer (*Odocoileus virginianus*) traveled around partial fences at an airport runway to gain access to crop fields. Animal habituation and motivation, crop palatability, and wing length may all influence the success of this approach. We placed the fully fenced treatment side against the dominant wildland boundary, but the complex juxtaposition of agricultural fields and canyons in southwestern Colorado may reduce the utility of this approach in this region. This exclusionary method may perform better in a more homogenous landscape.

Given that the number of elk tracks remained fairly consistent between years, while the number of deer tracks was greater in 2012, it appears that the greater damage rates in 2012 were primarily attributable to deer crop depredation. Elk in the vicinity of Dove Creek migrate seasonally, often arriving at agricultural areas during summer, and spending the remainder of the year in secluded, wildland canyons (CPW, unpublished data). In contrast, mule deer often inhabit agricultural areas year-round (CPW, unpublished data), potentially increasing their habituation to novel structures and odors. In the case of electric fencing, smaller bodied deer are more likely able to breach the strands of polyrope, an obstacle which may be more effective at inhibiting larger-bodied elk. Despite differences in habitat-use patterns, behavior and morphology of deer and elk, polyrope electric fences were effective at reducing crop damage for both species.

We tested three techniques for reducing damage to sunflowers during 2011 and 2012, years when crop depredation was dramatically variable. In 2011, deer and elk damage to sunflowers averaged 1%, well within tolerance levels for farmers as evidenced by no damage claims filed by farmers that year (CPW, unpublished data). Spring and summer (Mar-Aug) precipitation was exceedingly high during 2011 (Weather Station DVCO1, Colorado Agricultural Meteorological Network 2012), ~153% of normal, and it appears that the availability of abundant natural forage likely reduced damage by deer and elk. In 2012, however, the Dove Creek region experienced a drought, receiving about 60% of spring and summer precipitation, and only 30% of average spring (Mar-Jun) rainfall, a critical time for dryland farming in southwest Colorado. Soil moisture was so low in 2012 that few producers planted sunflowers, and the majority of seeds planted in some fields never germinated. We suspect that observed differences in plot damage and use between 2011 and 2012 were largely driven by differences in weather, and the resulting effects on the native vegetation for deer and elk.

High temporal and spatial variability in cervid damage, as observed in this study, is particularly challenging for producers and wildlife management agencies seeking solutions to reduce depredation. Such variability may reduce the motivation of producers to protect crops and alter priorities of wildlife managers, depending on whether cervid damage is severe or minimal in a particular year or area. This variability in damage also highlights the utility of a temporary method, like polyrope electric fence, for protecting crops when damage is expected to be high (e.g., in drought years). Ultimately, however, the decision to invest in a tool like polyrope electric fencing will depend on field size, expected amount of damage, crop prices, and the frequency and duration a producer will need to use the fencing, particularly for rotational crops.

MANAGEMENT IMPLICATIONS

For wildlife agencies seeking non-lethal management options for reducing deer and elk damage to high-value agricultural crops, we found that 5-strand polyrope electric fencing was effective. Polyrope is easy to assemble/disassemble, cost-effective relative to permanent fencing, and can be used on a temporary basis to minimize damage for certain crops grown on rotation or during years when natural forage for cervids is scarce. In areas where management agencies are working to maintain or increase deer and elk populations, but reduce cervid damage, the application of an effective exclusion technique like polyrope electric fencing could protect high-value crops, decrease the need for compensation payments and lethal cervid depredation permits, and increase satisfaction of producers and the public. Wildlife agencies will need to continue to work with producers to test and apply management techniques for crop protection based on the wildlife species present, population densities, crop types, landscape configuration, and abundance of local forage.

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Table 1. Coefficients for fixed effects from generalized linear mixed models evaluating the effectiveness of different treatment types for reducing cervid sunflower damage and the number of deer and elk tracks traversing experimental plot boundaries.

Model	Variable	β	SE	*P*	L 95% CI	U 95% CI
Damage	Intercept*	-3.020	1.169	<0.010	-5.311	-0.729
	Treatment					
	Electric*	-2.227	0.943	0.018	-4.075	-0.379
	Repellent	-0.296	0.806	0.713	-1.876	1.284
	Winged	-0.108	0.709	0.879	-1.498	1.282
Deer Tracks	Intercept*	2.919	0.815	<0.001	1.322	4.516
	Treatment					
	Electric*	-3.451	0.302	<0.001	-4.043	-2.859
	Repellent	-0.005	0.244	0.982	-0.483	0.473
	Winged	-0.100	0.244	0.684	-0.578	0.378
Elk Tracks	Intercept*	1.468	0.441	<0.001	0.604	2.332
	Treatment					
	Electric*	-4.052	0.416	<0.001	-4.867	-3.237
	Repellent	-0.249	0.222	0.262	-0.684	0.186
	Winged	-0.163	0.221	0.460	-0.596	0.270

*Statistically significant at $\alpha = 0.05$ level.

Figure 1. Location of experimental treatment fields near Dove Creek, Colorado where exclusion and repellent methods for cervids were evaluated.

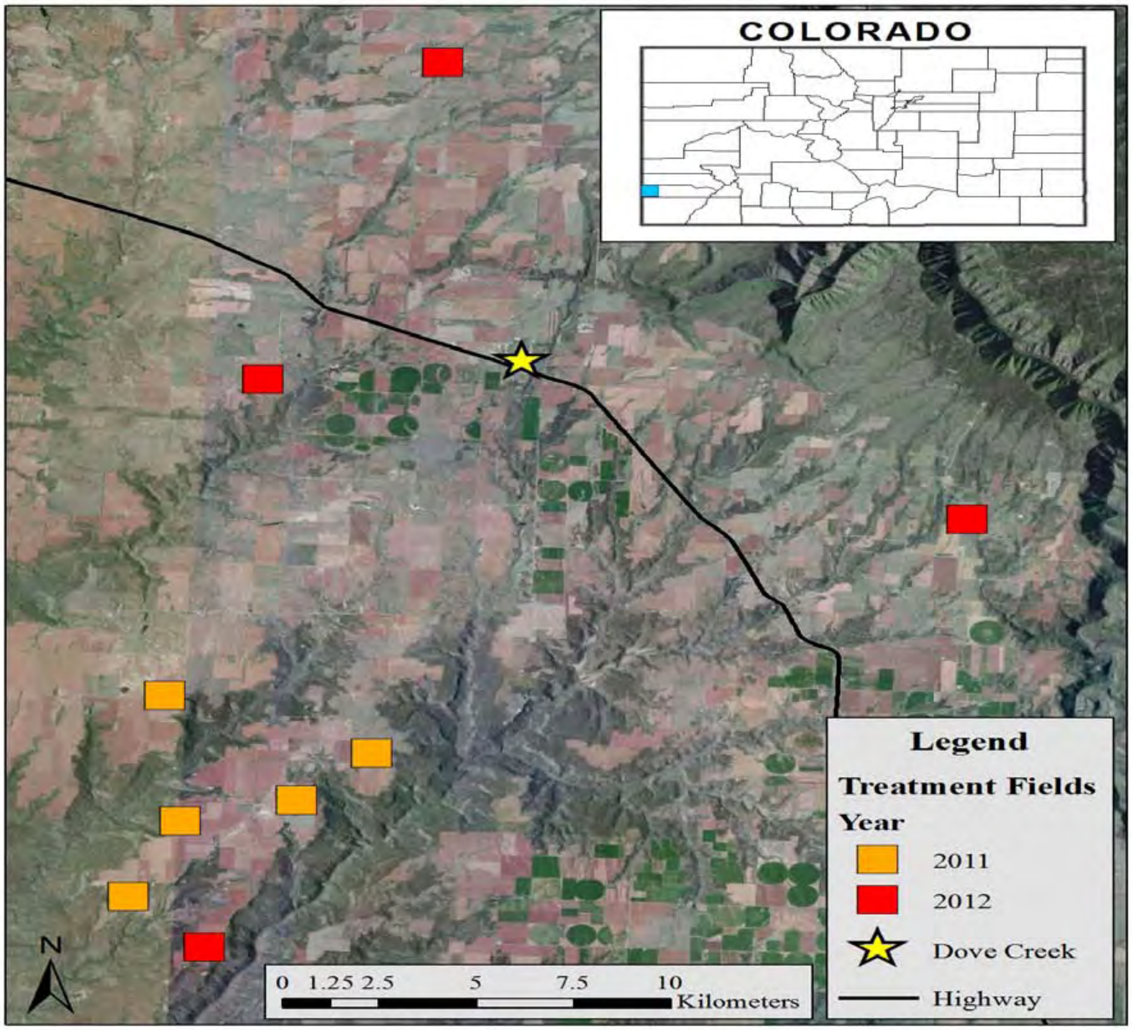


Figure 2. A polyrope electric fence (A) and a partial winged fence (B) for excluding deer and elk from agricultural fields.

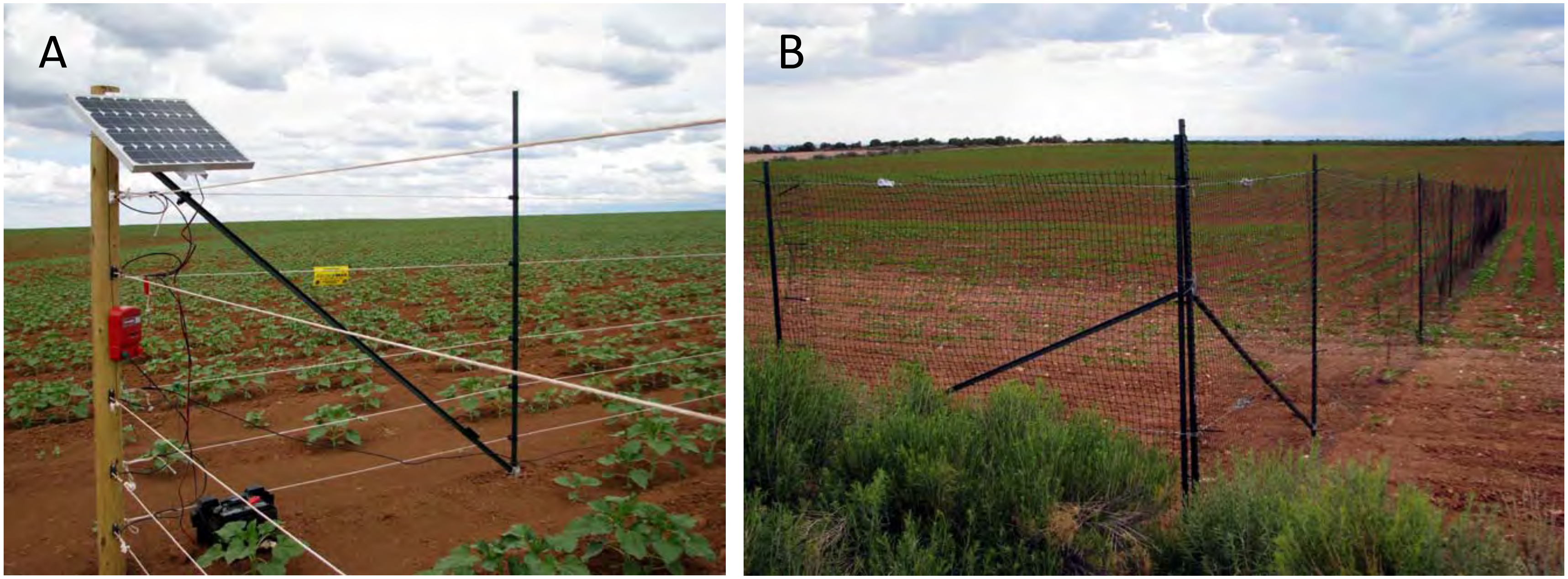
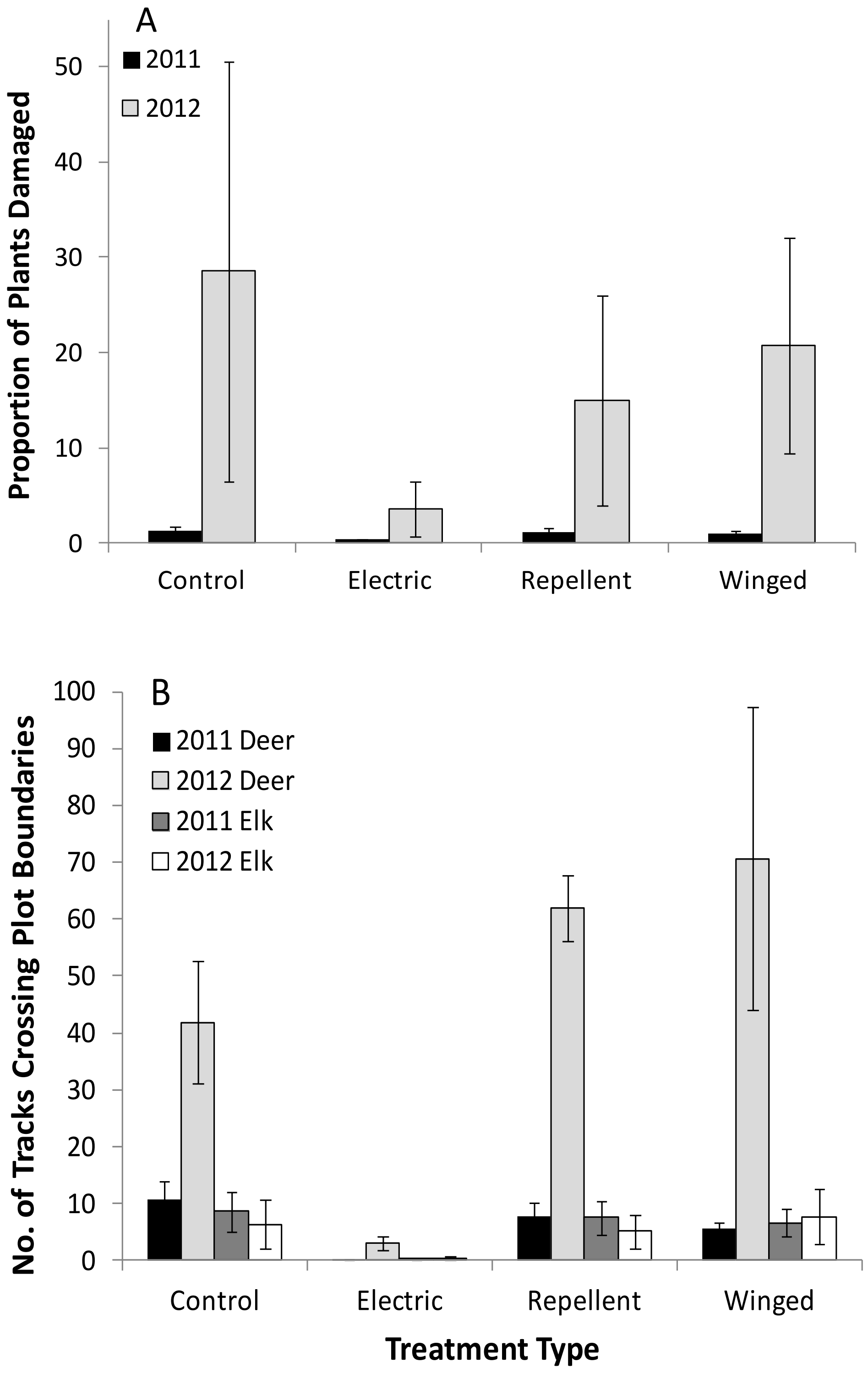


Figure 3. Proportion of sunflower plants damaged at time of harvest (A) and number of deer and elk tracks that crossed plot boundaries (B), summarized across plots ($\bar{x}$ and SE) for each treatment type, Dove Creek, Colorado, 2011 and 2012



Colorado Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3004	:	Other Ungulates
Task No.:	1	:	Evaluation and incorporation of life history traits, nutritional status, and browse characteristics in Shira's moose management in Colorado
Federal Aid Project No.			

Period Covered: July 1, 2012 - June 30, 2013

Author: E.J. Bergman

Personnel: C. Anderson, K. Fox, D. Bilyeau Johnston, A. Holland

All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the author. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

Beginning in October 2013, a large scale moose research project will be initiated in 3 study areas in Colorado. Study areas will be located in the northwest, northeast, and souwthwest regions. During FY 2012–2013 the study plan for this research project was developed and reviewed.

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2012-13

State of:	Colorado	:	Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:		:	
Task No.		:	
		:	
Federal Aid Project No.			

Evaluation and Incorporation of Life History Traits, Nutritional Status, and Browse Characteristics in Shira's Moose Management in Colorado

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Field Operations Staff, Northwest Region, Colorado Parks and Wildlife
Field Operations Staff, Northeast Region, Colorado Parks and Wildlife
Field Operations Staff, Southwest Region, Colorado Parks and Wildlife
Terrestrial Biologists, Colorado Parks and Wildlife

STUDY PLAN APPROVAL

Prepared by:	Eric J. Bergman	Date:	28 June 2013
Submitted by:	Eric J. Bergman	Date:	28 June 2013
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PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH

Evaluation and Incorporation of Life History Traits, Nutritional Status, and Browse Characteristics in Shira's Moose Management in Colorado

A Study Plan Proposal Submitted by:
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A. NEED

Wildlife managers are commonly confronted with the challenge of meeting multiple conservation needs under the constraint of finite resources. In example, financial resources can be invested on a plethora of management activities including: land acquisition, species translocations, population monitoring, law enforcement, or research. Likewise, species management focus also competes for the same limited funds. Managers may opt to invest resources proportionate to species abundance, according to endangered or threatened status, or according to the revenue that a species generates. Thus, the decisions as to how resources are allocated are complex and the development of more efficient processes is an inherent goal of applied research.

An example of such an allocation process can be found in the population and harvest management of Colorado's big game species: elk (*Cervus elaphus*), mule deer (*Odocioleus hemionus*), white-tailed deer (*Odocoileus virginanus*), pronghorn antelope (*Antilocapra americanus*), moose (*Alces alces*), Rocky Mountain bighorn sheep (*Ovis canadensis Canadensis*), desert big horn sheep (*Ovis Canadensis nelsoni*), and mountain goats (*Oreamnos americanus*). While none of these ungulates pose a conservation risk, they all require deliberate harvest management decisions. However, allocation of resources towards the management of these species is not uniform. Mule deer and elk represent the 2 most abundant ungulate species in Colorado and provide the majority of big game hunting opportunity. Subsequently, these 2 species are the primary focus of Colorado's big game population management investments. On the other end of this spectrum, moose are far less abundant than mule deer and elk, and contribute only nominally to Colorado's big game hunting opportunity. Accordingly, the relative investment, in terms of effort and money, in moose population management has been low. Despite this, demand for the moose hunting licenses that Colorado offers is exceptionally high, and of equal importance, moose receive a great deal of attention from wildlife watchers and wildlife enthusiasts. Thus, while moose management necessitates direct and deliberate decisions by biologists and managers, annual management decisions are not typically informed by consistent data collection or standardized procedures.

Big game herds in Colorado are managed according to herd management plans (a.k.a., DAU plans), with stated objectives for overall abundance and overall male:female sex ratios. Alignment between herd management plans and on-the-ground herd status is achieved via modeled estimates of abundance for individual herds. The population models used by Colorado Parks and Wildlife (CPW) rely on parameters that are estimated from field data: the ratio of young (i.e., fawns and calves) to adult females, the ratio of adult males (i.e., bucks and bulls) to adult females, annual hunter harvest, and in select locations, survival of adults and young (White and Lubow 2002). For the majority of herds, modeled abundance estimates mirror the perceived abundance that hunters, biologists, and managers gather from field activities. Thus, this approach to herd management is effective and defensible, especially for deer, elk and antelope. However, exceptions to this pattern exist. In the absence of data, the ability of biologists to effectively model populations becomes tenuous. In particular, the absence of data can lead to both bias and imprecision of modeled abundance estimates. Specifically, the lack of precision limits the utility of population models. For lesser abundant species, such as moose, these essential population data needed to improve the accuracy and precision of population models are rarely collected. Accordingly, modeled abundance estimates for moose are viewed with uncertainty. However, as noted above, allocation of resources to collect moose population data has historically been inconsistent, and allocation of additional resources in the future is unlikely. Likewise, sampling based abundance estimation for moose is difficult. This difficulty is driven by the fact that moose densities tend to be low, but also because the majority of Colorado's moose herds utilize closed canopy habitats, making aerial observation difficult.

In summary, the fact that moose do not fill a keystone role in Colorado's big game hunting opportunity, but still require explicit harvest management decisions exemplifies the need for alternative and more efficient management strategies. Even if additional population monitoring funds were consistently available, it is uncertain whether dramatic improvements in moose abundance modeling would be realized. Ultimately, the combination of: 1) low prioritization for funding, 2) practical constraints surrounding abundance estimation methodologies, and 3) the need for data and information to support herd management decisions, presents both a management dilemma and opportunity.

B. OBJECTIVES

In the absence of abundance data, this project will address the need for information and alternative decision making processes to support Colorado's moose herd management. We will develop and refine metrics to evaluate moose herd performance in relation to current habitat conditions. Additional metrics, such as the efficiency of hunters to encounter and harvest animals, and the average age of harvested animals, will also be investigated to evaluate their utility for informing future harvest and population management decisions. Finally, due to opportunities stemming from the capture and handling of moose, data on disease and wildlife health related issues will be collected and evaluated.

C. EXPECTED RESULTS OR BENEFITS

1) Estimation of process and geographic variation in survival rates of adult female moose.
2) Evaluation of Shira's moose life history characteristics, including pregnancy and twinning rates, in Colorado.
3) Estimation and incorporation of current annual growth utilization and off-take of preferred moose browse species into moose population management.
4) Development of moose herd harvest and population management models based on vegetative and harvest related metrics.

D. APPROACH

Shira's Moose Ecology and Conceptual Model Development

As noted, the primary objective of this research is the development and validation of a moose harvest management process that is not structured around abundance estimation or abundance modeling. While not intuitive, in the absence of abundance estimates or knowledge of range carrying capacity, ecological cues on the interaction between moose herd productivity and the ability of the vegetative landscape to support more animals can still be gathered and utilized. The perspective that wildlife populations experience a sequential set of survival and reproductive adjustments as they approach the carrying capacity for their range has been present in the literature for several decades. While the original hypotheses about the sequence of these density-dependent effects were made for marine mammals (Eberhardt 1977a, 1977b), they have subsequently been applied to several ungulate species (Gaillard et al. 1998, Gaillard et al. 2000). A body of evidence from Alaska, Canada, and Europe has further evaluated relationships between habitat condition, animal nutrition, and reproductive output (Sæther and Andersen 1996, Keech et al. 2000, Boertje et al. 2007, Paragi et al. 2008), thus providing the opportunity to capitalize on life history characteristics in the moose population management process. This body of evidence has identified several attributes that moose populations near their carrying capacity demonstrate as resources available to individual animals decline. Specifically, the cascading effects of nutritional limitation can: 1) cause declines in the survival rates of calves (0–12 month old animals), 2) result in reduced body weights of 10-month old animals, 3) cause reduced pregnancy rates of yearling animals (12–24 months old), 4) cause reductions in the twinning rates of mature animals (≥25 months old), 5) cause declines in the pregnancy rates of mature animals, and ultimately, 6) reduce the survival of adult animals. While it is neither realistic nor practical to measure all of these parameters, some offer the potential to cost-effectively inform management decisions. However, as noted above, the majority of research establishing the link between moose life history characteristics, nutritional status, and habitat conditions has been conducted on the Alaskan (a.k.a, Yukon and Tundra) subspecies (*Alces alces gigas*) and the Eurasian subspecies (*Alces alces alces*) of moose. While these relationships are expected to be consistent for the Shira's (a.k.a., Yellowstone) subspecies (*Alces alces shirasi*) that inhabits Colorado, the ecological relationships of interest need to be validated as part of refining Colorado's moose population and harvest management processes.

Of particular interest in Colorado, and based on examples of moose management elsewhere (Paragi et al. 2008, Seaton et al. 2011), the parameters warranting validation are: 1) survival of adult females (>12 months old), 2) pregnancy rates of adult females, 3) early-winter body condition of adult females, 4) fine scale habitat use, 5) twinning rates of mature females (≥24 months old), and 6) utilization of current-annual-growth (CAG) for key browse species. Once the relationships between these ecological parameters are validated, they can be incorporated into a harvest management model (Figures 1 and 2). In addition to these ecological considerations, effective population and harvest management accommodates social desires. Within hunted species in which licenses are highly coveted and difficult to obtain, managers typically strive to maximize opportunity by increasing the number of available licenses, while also managing for high quality hunts that are defined by high encounter rates with legally harvestable animals, low encounter rates with other hunters, and the opportunity to harvest trophy animals that are typified by older age class animals with more developed antler structure. These social factors of moose management can also be incorporated into harvest management decisions by setting clear objectives for each factor and collecting data to inform how well those objectives are being met. Data such as the unit of effort needed to harvest an animal (catch per unit effort; CPUE), average age of harvested animals, and antler characteristics of harvested animals are already collected as part of the mandatory check process that moose hunters must comply with as part of Colorado's moose hunting regulations. Thus, data on these social factors can be built into harvest management models that will provide a more informed decision making process (Figures 1 and 2).

Model Inputs

Survival of Adult Females — As noted for many ungulate species, the survival of adult females is typically high (Gaillard et al. 1998, Gaillard et al. 2000). Similarly, the year-to-year variation (i.e., process variation) among estimates for many large herbivores is commonly low (Gaillard et al. 1998, Gaillard et al. 2000). This provides evidence that as animals reach the adult age class, survival rates become less sensitive than those of younger animals. However, spatial variation among estimates may be higher. Preliminary evidence from Colorado suggests that moose herds in the northern part of the state may benefit from higher survival rates than those in the southern part of the state (Kufeld and Bowden 1996, Olterman and Kenvin 1998). While survival rates in all regions of Colorado are expected to be high, this hypothesis is in need of validation. Likewise, documented geographic variation in Colorado's moose survival rates are not robust and any differences are in need of direct validation.

Adult Female Pregnancy Rates — As is the case with survival of adult females, evaluation of pregnancy rates in the literature provides evidence that rates tend to be relatively constant ($\bar{x}$ = 84.2%) and resilient among years (Boer 1992). Despite this, it was not intuitive as to why annual pregnancy rates were not higher (Boer 1992). Based on this evidence, we speculate that a biologically meaningful difference in pregnancy rates will not be observed among moose herds in Colorado. However, if large differences in overall population dynamics among herds in the northern and southern parts of Colorado are observed, it is expected that spatial variation in pregnancy rates may be a key source of variation.

Early Winter Body Condition — The evaluation of moose body condition using ultrasonagraphy was developed in the early 1990s and since that time has proven to be useful as a research technique (Stephenson et al. 1998, Keech et al. 2000, Cook et al. 2010). The use of ultrasonagraphy in Colorado has primarily been focused on mule deer, and more specifically, as a tool for evaluating late-winter body condition (Bishop et al. 2009a, Bishop et al. 2009b, Bergman 2013). When body condition scores, based on hand palpation, are combined with estimates of rump fat, estimates of total ingesta-free body fat can be derived (Stephenson et al. 1998, Cook et al. 2010). While preliminary data don't exist, it is expected that the majority of moose in Colorado are capable of surviving through winter while maintaining measurable levels of rump fat (R. Cook, National Council for Air and Stream Improvement – J. Crouse, Alaska Fish and Game –T. Stephenson, California Fish and Game; personal communication). However, it is also expected that by the end of winter, the majority of moose will have similar levels of fat reserves remaining. Alternatively, based on the plasticity of moose reproduction and the differences in lactation and energetic burdens faced by adult females with 0, 1, 2, or 3 calves, it is expected that the widest range in moose rump fat will be observed during early winter periods (R. Cook, J. Crouse, and T. Stephenson, personal communication). Nutritional status, as defined by body condition and rump fat measurements, will be collected on 2 subsets of moose. The first subset will be comprised of individual moose who will be captured during every year of the study, thereby allowing the tracking of individual nutritional status through time and allowing that status to be linked to past habitat use and past reproductive output. These measurements will help validate the relationship between nutritional condition, browse availability (discussed below), and reproductive success (discussed below). The second subset of moose to be sampled for nutritional status will be comprised of individuals who are captured a single time during the course of the study. The assessment of body condition and rump fat from this second subset of randomly selected individuals will minimize bias due to the lack of randomization that occurs from repeatedly sampling the first subset of individuals. These unbiased estimates will thereby allow for population level estimation of nutritional status on an annual basis.

Habitat Use — Documenting fine scale habitat use by adult female moose will be a fundamental step in validating the relationship between life history traits and range conditions. In order to link individual reproductive success to on-the-ground habitat conditions, we need to insure that the areas used by moose define the spatial sampling frame from which browse data are collected. This assessment is further necessitated by the fact that moose habitat across Colorado is diverse, ranging from monotone willow communities to upland shrub communities.

Twinning Rates — The sensitivity of moose twinning rates to changes in the vegetative environment, and subsequently to maternal nutritional condition, has been expressly noted as part of multiple studies (Franzmann and Scwartz 1985, Boer 1992, Schwartz and Hundertmark 1993, Boertje et al. 2007). Accordingly, the utility of this parameter has been highlighted in regards to moose harvest and population management (Boertje et al. 2007). While in need of validation in Colorado and for the Shira's subspecies, the use of this parameter in Colorado's moose management holds particular promise. Specifically, annual data from twinning rates can be obtained as part of road surveys, but it can also be collected as ancillary data from aerial surveys that are flown for deer and elk management purposes. Similarly, recent literature has identified the utility of hunter observation surveys as a tool for making inference about moose herds (Solberg et al. 2010). While none of these approaches emulate the unbiased results that stem from sampling based population survey strategies, their overall lack of cost warrants evaluation and possible inclusion in Colorado's moose harvest and population management decision making.

Current Annual Growth and Removal of Current Annual Growth— The use of browse measurements as an indicator of moose abundance, relative to carrying capacity, has gained the attention of biologists, managers, and researchers as a way to corroborate nutritional indices with animal ecology (Seaton 2002, Paragi et al. 2008, Seaton et al. 2011). Traditional carrying capacity models combine estimates of forage production within a defined area (kg/ha), with the nutritional requirements of moose, to estimate the maximum density of animals that can be supported by the landscape (Crête 1989, Kufeld and Steinart 1990, Dungan et al. 2010). While yielding a theoretical maximum abundance for the area of interest, these models frequently over-estimate the realized abundance of animals that is observed. As noted by Kufeld and Steinart (1990), the theoretical carrying capacity of moose in North Park, Colorado (78 animals/ sq. mile), as defined by willow (*Salix spp.*) production, greatly exceeded the maximum reported densities for other systems. Likewise, these traditional models do not accommodate changes in the environment. Crête (1989) highlighted this latter characteristic by identifying potential sources of environmental variation: 1) snow depth and its ability to constrict forage availability on an annual basis, 2) rainfall and its ability to influence forage quality on an annual basis, and 3) the role of plant succession (i.e., variation in plant palatability and production due to age and seral stage of plants).

As they relate to moose population management, quantification of CAG utilization as described by Seaton et al. (2011),

$$Proportional\ browse\ biomass\ removal = \left(\frac{\sum biomass\ removed\ from\ plants\ sampled}{\sum CAG\ biomass\ produced\ on\ all\ plants\ sampled}\right)$$

has potential to be an informative parameter. In particular, Seaton et al. (2011) provide evidence of an indirect, and likely non-linear relationship between removal of CAG and twinning rates of adult female moose (Figure 3). The vegetation component of this research will specifically be focused on utilization as opposed to documenting landscape-scale production.

Capture Per Unit Effort (CPUE) — In addition to biological parameters, successful population and harvest management of big game species is also dependent on meeting the desires and expectations of hunters. In Colorado, hunters are allowed to harvest one adult male moose during their life. Based on drawing odds, the probability of a hunter drawing an adult male moose license on any given year is <1%. Thus, when tags are drawn, hunters have the expectation that they will have a high probability of harvesting a mature animal (e.g., an animal ≥3 years old), and ideally, they will have the opportunity to observe several legal animals during the course of their hunt. To accommodate these expectations, metrics that pertain to animal maturity, such as age and antler structure, but also metrics that account for hunter effort, such as CPUE, can be built into any modeling and decision making process.

As opposed to statewide success rates for elk and deer, which are ~20% for elk and ~50% for deer, hunter success is typically >90% for moose hunters. Thus, the traditional metric of hunter success is not an informative parameter. Likewise, there is a wide range in hunter desires. Some hunters are willing to harvest the first legal animal they encounter, whereas other hunters specifically target trophy animals. Similarly, some hunters utilize the services of paid outfitters and guides, who typically put in scouting effort to locate animals and identify potential trophy harvest opportunities for upcoming seasons. From an ecological perspective, annual variation in the overlap of timing between hunting seasons and the moose rut may also increase variation in the effort needed to harvest an animal. Thus, while a metric such as CPUE can be informative in the population management process (Hatter 2001, Schmidt et al. 2005, Boyce et al. 2012), it needs to be refined and modified to have a the greatest utility in Colorado. In particular, many harvest models rely on CPUE as an index towards animal abundance. A shortcoming of these models is that they assume that hunter effectiveness is constant. However, this assumption is violated if hunters can change the intensity of their effort based on encounter rates or observations they make in the field. While better documented in fisheries management (Hilborn et al. 1995), the fact that hunting moose in Colorado is typically a once-in-a-lifetime experience adds to the potential for hunter effort to be highly dynamic.

Average Age of Harvest and Antler Characteristics — For one subset of moose hunters, the opportunity to harvest any legal animal satisfies their criteria for a high quality hunting experience. However, a different subset of hunters are focused on harvesting a trophy animal that is typified by highly developed antler structure. For moose, annual antler structure progressively develops through the first 4–5 years of life (Franzmann and Schwartz 2007). Thus, a direct relationship between animal age and trophy quality exists. However, this relationship may not be robust during the first 1–3 years of life, nor during the later years of life (≥14 years old) during which senescence in antler structure can occur (Franzmann and Schwartz 2007). In managing for trophy quality, the most effective approach would be to set objectives based on antler structure. However, this approach isn't practical as it fails to recognize factors such as genetics, nutrition, and weather, all of which influence antler growth (Solberg and Sæther 1994, Schmidt et al. 2007, Monteith et a. 2013). As such, age can be used as a surrogate parameter for quality. Moose hunters in Colorado are already required to participate in a mandatory harvest reporting process, which could potentially result in age and antler measurement data for all harvested moose. These data can be used to validate the relationship between age and antler structure, ideally leading to incorporation of age of harvested animal into herd management plans.

Field Methods

Capture and Handling — As part of this study, moose will be captured via ground darting and aerial darting from helicopters. Regardless of method, all captures will occur during the late-fall and early-winter time periods. The majority of ground captures and all helicopter based captures will be conducted after the 4th rifle hunting season which occurs in mid-November. Captures prior to this date will be ground-based and will occur between the 2nd and 3rd, and 3rd and 4th rifle hunting seasons. Timing of all captures are intended to maximize the amount and utility of data that can be collected from each animal, but also to minimize disruption of big game hunters.

Ground based capture will be conducted by a team of 2–4 individuals. Adult female moose (>12 months of age) will be targeted. Moose will be located from vehicles and on foot. Once an individual moose is located and identified as a suitable candidate for capture, it will be stalked and darted by 1 person. After delivery of the dart, but prior to induction, all members of the capture team will observe the individual from a safe distance, thereby minimizing disturbance and the potential for flight of the animal. Once anesthetized, all individuals of the capture team will move to the animal to help with processing. During ground based captures, all moose will be darted with 1 of 3 potential drug combinations: 1) AcMe: a combination of butorphanol (52 mg), azaperone (24 mg), medetomidine (BAM), 2) a combination of acepromazine (15 mg) and medetomidine (10 mg), or 3) either thiafentanil (10mg) or carfentanil (4mg) in combination with either xylazine (50–100mg) or midazolam (25–100mg). After handling, capture drugs will be antagonized with: 1) antisedan (2.5 mg/mg of medetomadine) and tolazine (4mg/kg), 2) xylazine will be anatagonized with tolazine (4mg/kg), and 3) thiafentanil and carfentanil will be antagonized with naltrexone (400mg, 100kg administered via intravenous injection and 300mg administered via subcutaneous injection). Whenever possible, a wildlife veterinarian and/or a member of the wildlife health staff will be a member of the capture team.

Helicopter capture will be conducted by a team of 2–4 individuals. During all aerial captures, in addition to the capture helicopter, a spotter plane will ideally be used to locate animals in advance (thereby minimizing search and pursuit times) and to observe captures for safety purposes. As with ground capture, any adult female moose (>12 months of age) will be targeted. Once an individual moose is located and identified as a suitable candidate for capture, the helicopter will briefly land at a temporary staging area to prepare the pilot and gunner for capture and to unload unnecessary personnel and equipment for the capture process. Active pursuit of individual animals will be restricted to <5 minutes, but is expected to be <2 minutes. After dart delivery, but prior to induction, the helicopter will return to the staging area to collect the remaining members of the team and equipment. During this time, if within site of the staging area, darted animals will remain under the observation of the helicopter. If the staging area is out of site of the staging area, animals will remain under the observation of the spotter plane. Depending on the drug combination selected, capture location, and visibility, telemetry darts may be used to expedite locating captured animals or darts that missed targeted animals. Once anesthetized, the helicopter will return to the animal with all members of the capture team. During helicopter-based captures, all moose will be darted with either thiafentanil (50–100mg) or carfentanil (4mg) in combination with either xylazine (50–100mg) or midazolam (25–100mg). After handling, thiafentanil and carfentanil will be antagonized with naltrexone (400mg, 100mg administered via intravenous injection and 300mg administered via subcutaneous injection). Due to the classification of drugs needed during aerial capture, a wildlife veterinarian will always be a member of aerial capture teams.

Regardless of capture method, all animals will be handled in the same way. All animals will be fitted with either a VHF radio-collar (subset 1 of the sample) or a GPS collar (subset 2 of the sample). Due to the potential for growth, all yearling animals (<24 months old) will automatically be assigned to subset 2 and will be fitted with GPS collars that will be removed and refitted as part of subsequent captures during the following years of the study. In the event that recapture of animals wearing GPS collars isn't possible, these collars will also be fitted with timed drop-off mechanisms. These devices will be a safeguard against the loss of data, but also prevent moose from wearing collars that have exceeded their battery life and are no longer transmitting VHF signals or collecting GPS location data. All remaining animals (>24 months old) will be randomly assigned to either subset 1 or subset 2. Once anesthetized, animals will be positioned sternally recumbent with the head above the torso, thereby minimizing the potential for aspiration and inhalation of rumen contents. Body condition of all animals will be evaluated using hand palpation techniques, and rump fat measurements will be collected via ultrasonagraphy (Stephenson et al. 1998, Cook et al. 2010; training and standardization of hand palpation techniques were also provided for CPW employees as part of training provided by R. Cook). Up to 50ml of blood will be drawn from all animals to evaluate various health attributes including concentration of thyroid hormones, concentrations of trace elements such as selenium, but also presence of elaeophora (*Elaeophora schneideri*). Also, in order to detect presence of elaeophora, skin biopsies will be taken from the top of the head and from the ear using a 4–6mm biopsy punch. The biopsy site will be cleaned with a chlorhexidine solution and intradermal lidocaine (<2cc) will be injected into the area. Ear tags will be placed through the ear punch site and the forehead biopsy will be closed with 2/0 monocryl using a simple interrupted or cruciate pattern. Biopsy samples will be placed in 10% formalin. Feces will also be collected in order to detect the presence or absence of lungworm larvae. Tick presence will be documented and quantified using a modified line-transect sampling approach (Sine et al. 2009). Pregnancy status will be determined via pregnancy specific protein B (PSPB; Wood et al. 1986). Upon completion of data collection, capture drugs will be immediately antagonized and the capture team will depart the area. The status and alertness of animals will be periodically monitored during the remainder of the day and during subsequent days by field crews or the spotter plane. Total handling time will likely be 20–25 minutes.

In the event that a moose is mortally injured as part of the capture process, in order to alleviate pain and suffering, that individual will be immediately euthanized. When necessitated by these circumstances, moose will be killed via gunshot to the head or chest.

Field Sampling — Survival rates of adult females will be estimated every 2 weeks. Aerial telemetry flights will be conducted every 10–14 days to facilitate these estimates. All mortalities that are detected via telemetry will be investigated as quickly as possible (<3 days) to determine the cause of death, but also to improve chances of collecting biological samples for disease and health related purposes.

Vegetation sampling will be conducted during the spring and summer period (April through August). Sampling methods will be tailored after the methods of Zimmerman (2001) and Seaton et al. (2011). Final vegetation sampling methods will be developed as part of this project. Vegetation sampling will be probability based, directed towards rapid assessment, with interest towards evaluating plant architecture and CAG utilization.

Twinning rate data will be collected 2 times per year. The first time will be during June, shortly after parturition, and the second time will be during the autumn (September and October). Twinning rate data will be collected by observation of radio-collared animals and estimating the number of calves-at-heel. It is unlikely that we will have time to sample all animals every year, thus, the 2nd subset of animals (i.e., those collared with GPS radio-collars) will be targeted as priorities. The early twinning rate estimates will be used as a surrogate for parturition rates. In the absence of *in utero* fetal counts or vaginal-implant-transmitters, any bias in these estimates is expected to be low due to the fact that neonate mortalities during the first few weeks of life will not be observed, but also due to miscounts that can stem from missing calves that were alive but not observed. Autumn counts are expected to be unbiased as calves will be substantially larger and more detectable, but still closely linked to maternal females. Sequential counts of calves will provide a way to estimate the lactation requirements that adult females face each summer and leading into the early-winter body condition and rump fat estimates that will be collected for the 2nd subset of animals. Sequential counts will also provide the opportunity to estimate moose calf survival during the summer months (Lukacs et al. 2004)

Sample Size

Survival — Existing data on adult female moose survival in Colorado are sparse. However, survival rates documented by Olterman and Kenvin (1998) in southern Colorado ($\hat{s} = 0.839$, SE = 0.111) are lower than the rates reported by Kufeld et al. (1996) for northern Colorado ($\hat{s} = 0.961$, SE = 0.022). Based on these data, measuring the survival of 40 moose/area will provide a satisfactory level of power for detecting a 10%–12% difference in survival between study areas (Figure 4). Due to the desire to sample moose in each of 3 geographic regions (discussed below), this is an underestimate of statistical power. In the absence of geographic variation in survival, measuring the survival of 120 moose/year (40 moose in each of 3 study areas) will result in the ability to estimate survival with the approximate precision of ±7%, assuming a survival rate of 88%.

Study Duration — Due to financial constraints, the full sample of 40 moose per study area is not expected to be achieved until the 4th year of the study (Table 1). Once the full sample is achieved, 5 additional years are needed to evaluate ecological and life history relationships. Moose wearing VHF radio collars upon completion of the study will continue to be monitored for survival. Rule-of-thumb calculations indicate that ≥10 years of survival data are necessary to estimate process variation for survival rates of adult female ungulates (J. Runge, CPW biometrician, personal communication). While the number of animals being monitored will decline after year 9 of the study, enough animals are expected to remain alive to facilitate estimation of the spatial and process variation for the species.

E. Location

Colorado moose management is currently broken into 5 herds that are spread between 3 geographic regions. This research will follow that pattern by establishing 1 study area in each of those 3 regions (Figure 5). As noted above, preliminary evidence suggests that differences may occur between herds located in different parts of the state. In particular, published survival rates suggest that adult survival may be lower in southwestern Colorado. Evaluating and validating these differences will be a key component to this research and is ultimately necessary as part of developing any new harvest management strategies.

The study area located in northwest Colorado will be centered on the Rabbit Ears mountain range that stretches between Muddy Pass and Willow Creek Pass (Figure 6). Moose will be captured in drainages flowing north into North Park, and to the south into Middle Park. As needed, moose will also be captured in North Park along the Illinois River, in Middle Park along the foothills of the Gore Range and in the Williams Fork River area. If needed to meet sample size requirements, moose may also be captured along creeks feeding into the Fraser Valley from the Beyer's Peak Wilderness area.

The study area located in northeast Colorado will be centered along the Laramie River drainage, but also in the upper portions of the Cache la Poudre River (Figure 7). Moose will be captured in drainages to flowing east out of the Rawah Mountains, but also in the vicinity of Pingree Park and Crown Point. Areas locally known as Dead Man and Sand Creek (located to the east of the Laramie River) will also be a focal point for the northeast study area (M. Vieira, CPW Wildlife Biologist, personal communication).

The study area located in the southwest region will be centered on the upper portions of the Rio Grande River, but also in the vicinity of Creede and stretching as far south as South Fork. Moose will also be captured in the vicinity of Lake City, along the headwaters of Cebolla Creek and further east in the northern portions of the San Luis Valley (Figure 8).

In addition to the 3 study areas that will be the direct focus of this research, 2 additional moose management studies are being implemented during the autumn of 2013. The first of these will be located at the southern end of Summit County and in the northern portions of South Park (Kirk Oldham and Shannon Schwab, CPW Wildlife Biologists, personal communication). The specific purpose of this management study is to evaluate moose dispersal into a novel environment as moose colonize the South Park area. The second of these management studies will be located on the Grand Mesa, which was the release site of several moose translocation efforts during the early 2000s. The specific purpose of this study is to develop and implement a population monitoring and harvest management plan for a growing moose herd that primarily uses non-traditional moose habitat (i.e., Gambel's oak (*Querqus gambellii*) and Utah serviceberry (*Ameelanchier utahnsis*) communities; Stephanie Duckett, CPW Wildlife Biologist, personal communication). In the case of each of these management studies, integration with this research will be possible, thereby increasing the overall sample size, but also the geographic range of the study.

F. Schedule of Work

Activity	Date
Complete Study Plan and ACUC Approval Process	June 2013–August 2013
Preliminary Vegetation Surveys	July 2013–October 2013
Moose Capture; Capture ½ of Desired Sample in Each Study Area	November 2013–December 2013
Collect Twinning Rate and CAG Production/Removal Data	Summers (June–September) Ongoing: 2014–2021
Moose Captures: Build Towards Final Sample Size	November–December Ongoing: 2014–2016
Moose Capture: Recaptures Only, or New Captures to Replace Mortalities	November–December Ongoing: 2017–2021

G. Estimated Costs

	Category			
Fiscal Year	Personnel		Operating[1]	
FY 13-14	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$0
	DWMs	0.01		
FY 14-15	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$160,000
	DWMs	0.01		
FY 15-16	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$65,000
	DWMs	0.01		
FY 16-17	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$67,000
	DWMs	0.01		
FY 17-18	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$70,000
	DWMs	0.01		
FY 18-19	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$72,000
	DWMs	0.01		
FY 19-20	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$74,000
	DWMs	0.01		
FY 20-21	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$77,000
	DWMs	0.01		
FY 21-22	Bergman	0.90		
	Wildlife Health	0.03	Federal Aid	$124,430
	Area Biologists	0.01	External Grants	$79,000
	DWMs	0.01		

[1] Current operating expenses are projected, based on full study implementation. Funding from federal aid or game cash, administered by the mammals research program, partially covers radio collar and capture costs. Additional funds, necessary for field crews and additional equipment are currently unidentified and will be solicited via external grants.

H. Related Federal Projects

Our research will be conducted on federal (i.e., BLM, USFS) and state lands. The study does not involve formal collaboration with any federal agencies, nor does the work duplicate any ongoing federal projects.

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J. Tables and Figures

Table 1. Proposed capture schedule and timeline for moose research in Colorado. Data and proposed capture reflected in the table would be replicated in each of 3 study areas.

		2013	2014	2015	2016	2017–2021[1]
Capture Type:	New	20	10	5	5	0
Capture Type:	Recapture	0	10	15	15	20
Collars on Air:	VHF	10	15	20	20	20
Collars on Air:	GPS	10	15	15	15	20

[1] Capture numbers assume no mortality. Mortality rates of 10%–15% are possible. Each Mortality will result in 1 additional capture in the study area where the mortality occurred.

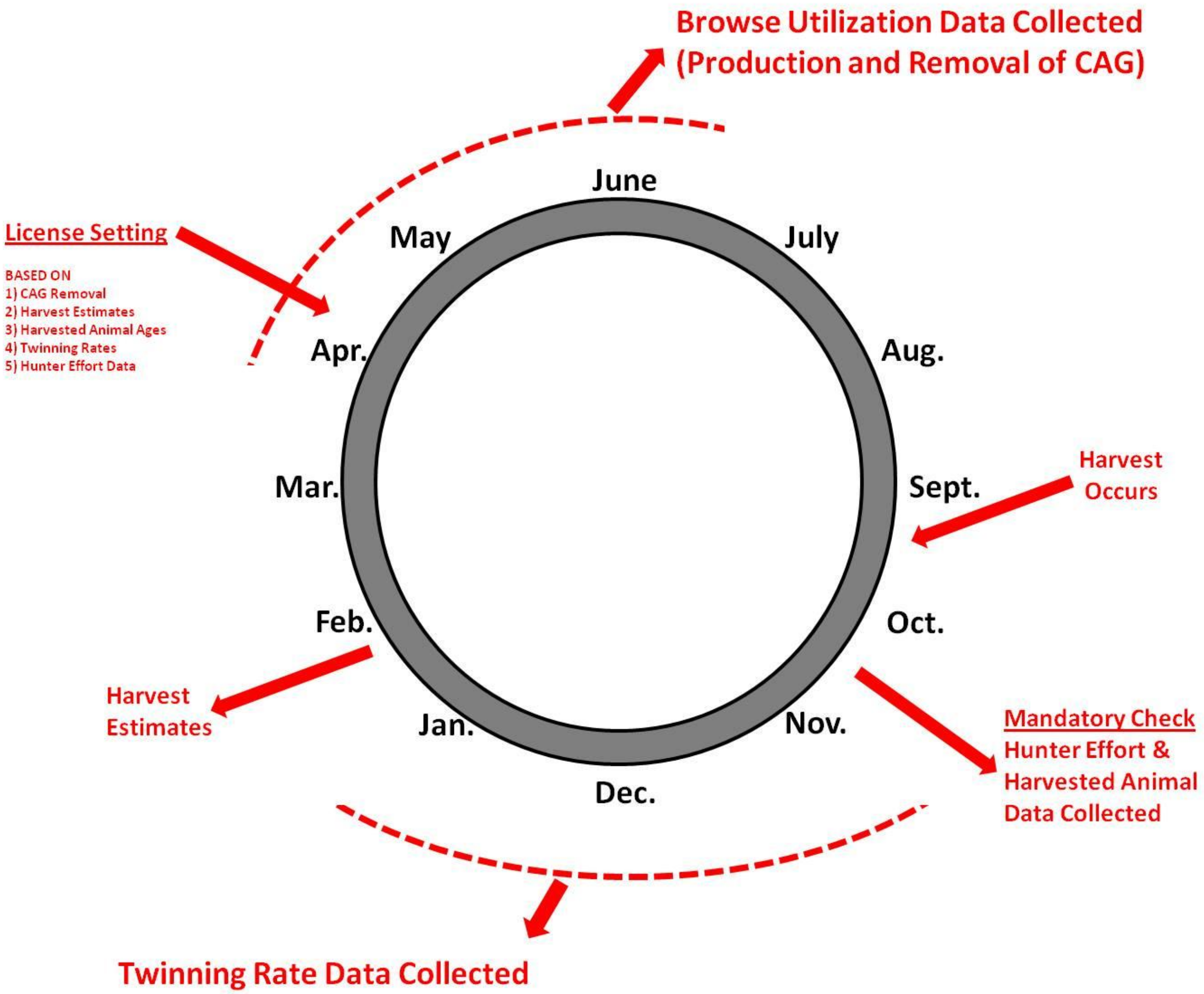
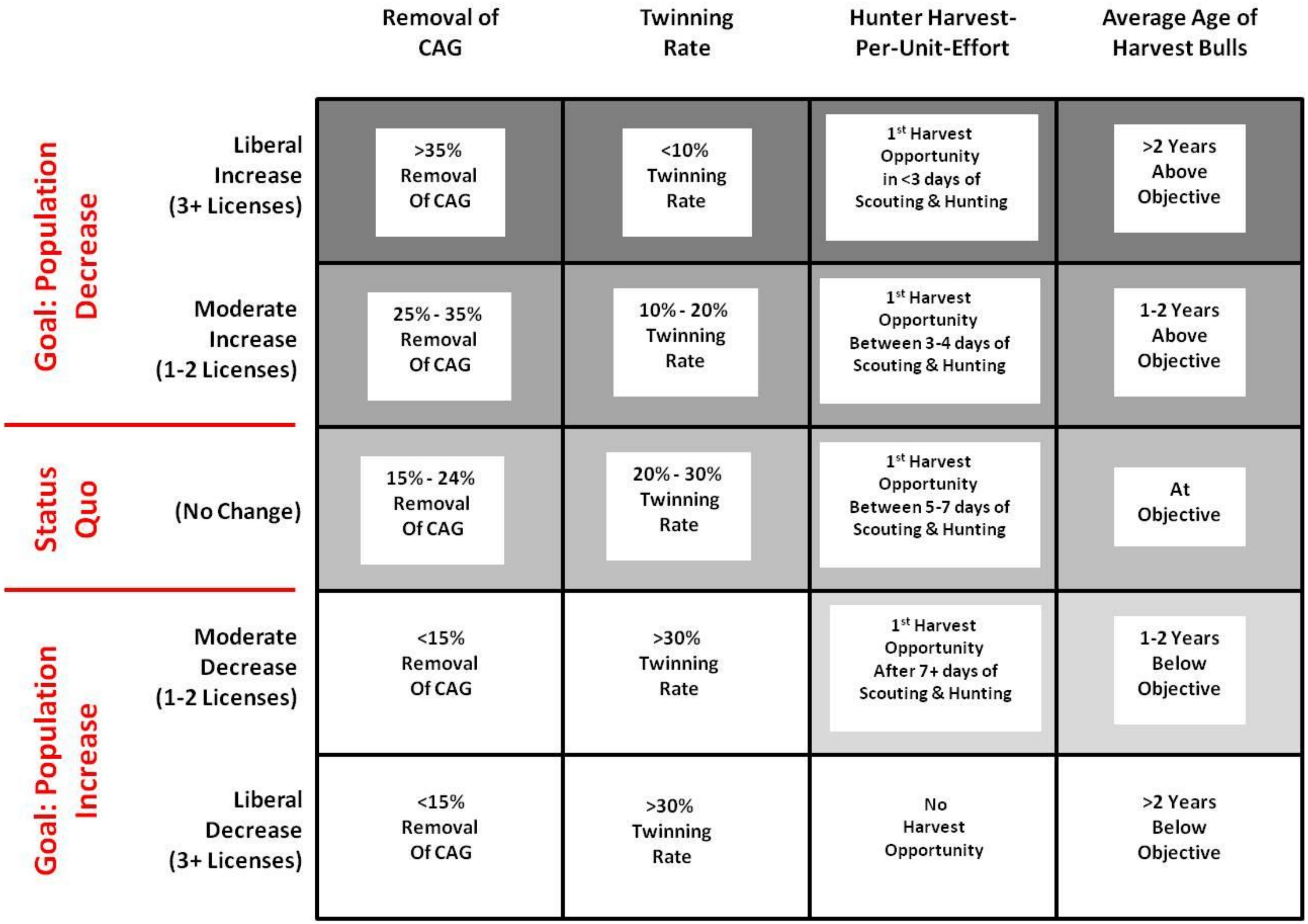


Figure 1. A conceptual model of ecological data, and timing of collection, to help inform moose harvest management decisions. Arrows pointing inward reflect decisions or actions that directly impact population dynamics, arrows pointing outward reflect data collected for each moose herd.



		Removal of CAG	Twinning Rate	Hunter Harvest-Per-Unit-Effort	Average Age of Harvest Bulls
Goal: Population Decrease	Liberal Increase (3+ Licenses)	>35% Removal Of CAG	<10% Twinning Rate	1st Harvest Opportunity in <3 days of Scouting & Hunting	>2 Years Above Objective
	Moderate Increase (1-2 Licenses)	25% - 35% Removal Of CAG	10% - 20% Twinning Rate	1st Harvest Opportunity Between 3-4 days of Scouting & Hunting	1-2 Years Above Objective
Status Quo	(No Change)	15% - 24% Removal Of CAG	20% - 30% Twinning Rate	1st Harvest Opportunity Between 5-7 days of Scouting & Hunting	At Objective
Goal: Population Increase	Moderate Decrease (1-2 Licenses)	<15% Removal Of CAG	>30% Twinning Rate	1st Harvest Opportunity After 7+ days of Scouting & Hunting	1-2 Years Below Objective
	Liberal Decrease (3+ Licenses)	<15% Removal Of CAG	>30% Twinning Rate	No Harvest Opportunity	>2 Years Below Objective

Figure 2. A conceptual structured decision making matrix to facilitate moose harvest management decisions in Colorado. Ecological metrics and harvest management recommendations depict hypothetical values that could be used, final values and goals for metrics would be developed for each moose herd.

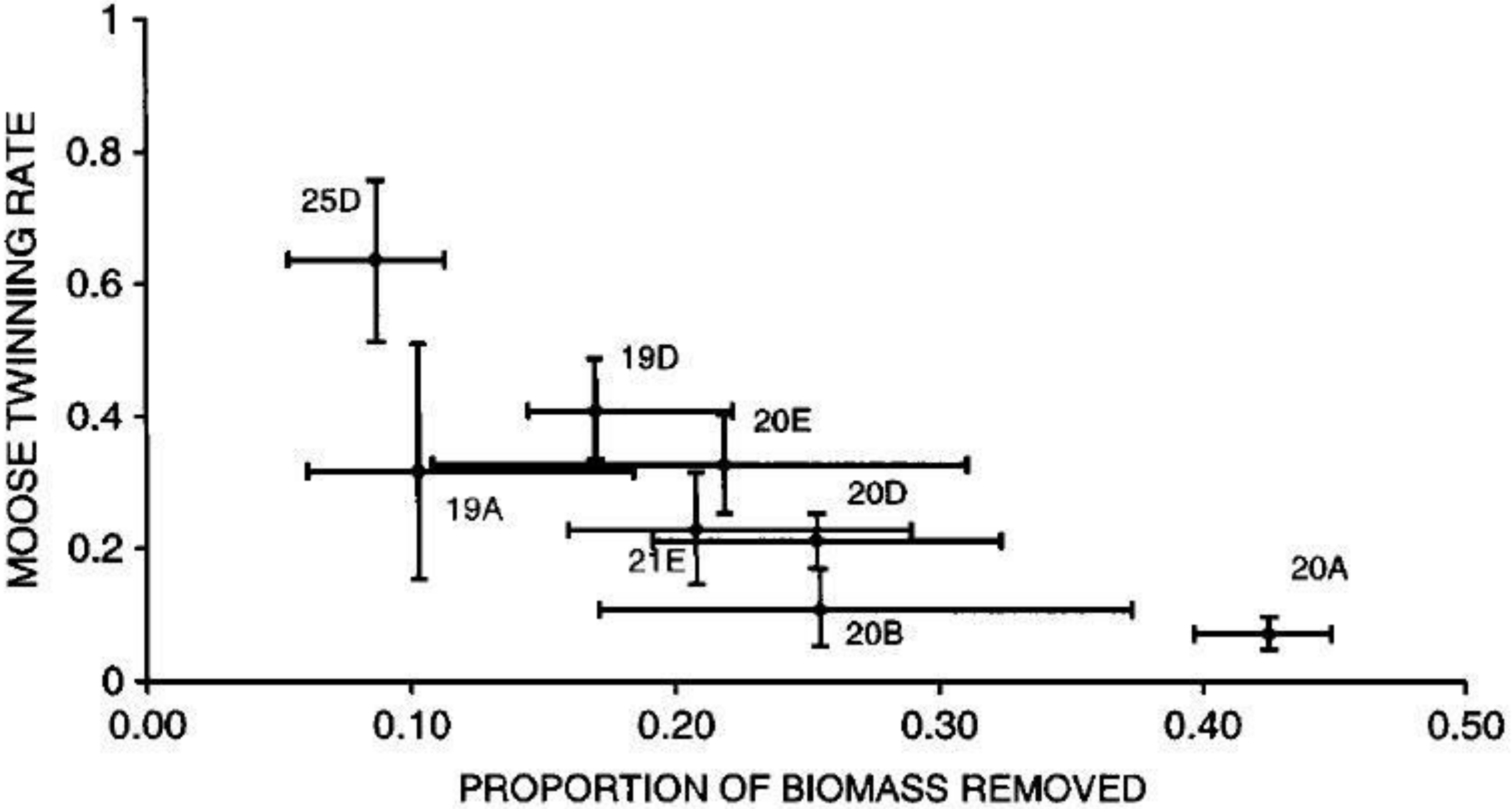


Figure 3. Evidence of the relationship between twinning rate and proportion of biomass removed, for different study areas located in Alaska. Figure is from Seaton et al. (2011).

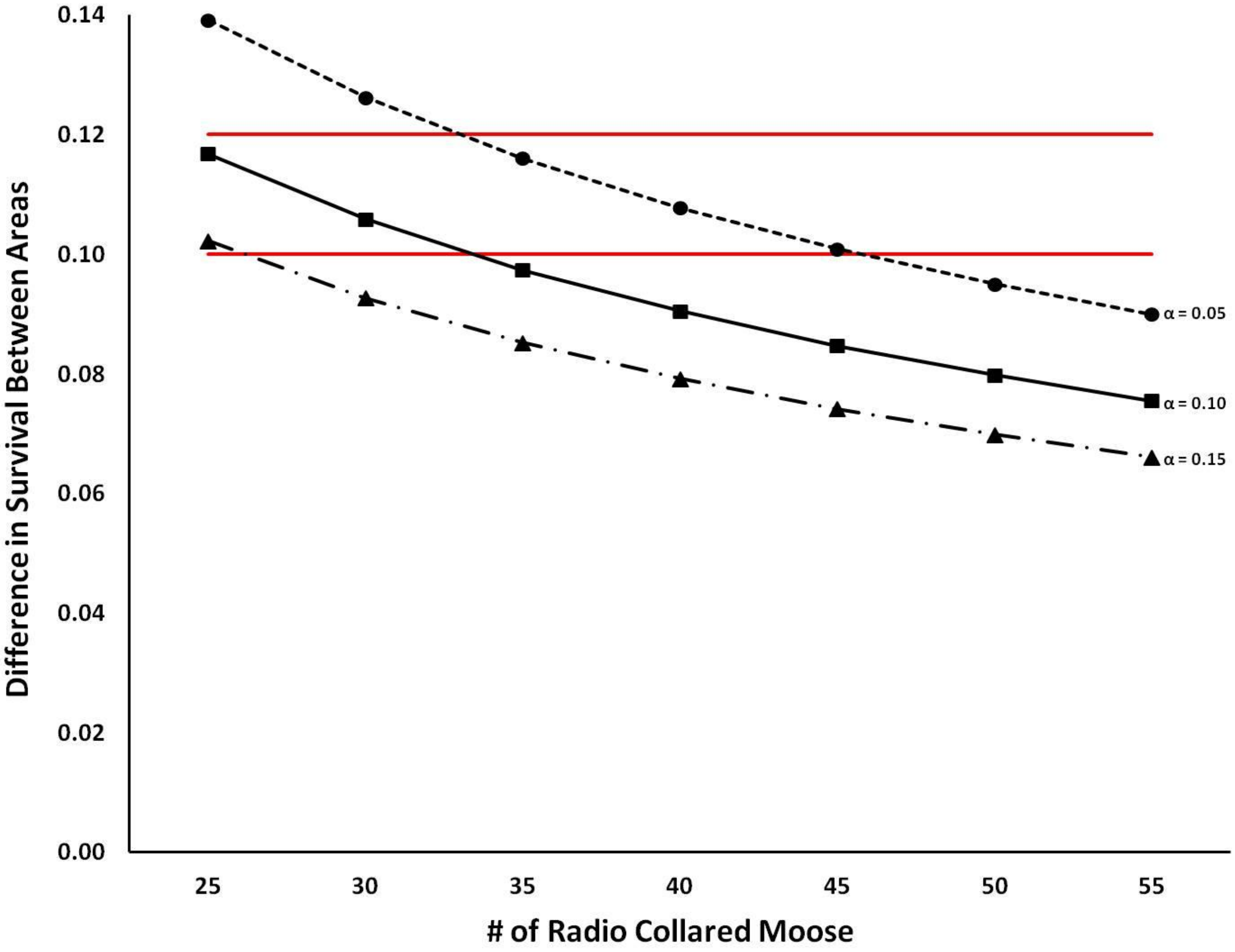


Figure 4. Sample size estimates, with different probabilities of making a Type I error, for detecting geographic differences in adult female moose survival in Colorado. Existing data suggest that as much as a 12% difference in survival is feasible. Red lines encompass the likely range of differences in survival rates that would be encountered as part of this research. Desired sample size is 40 moose per study area.

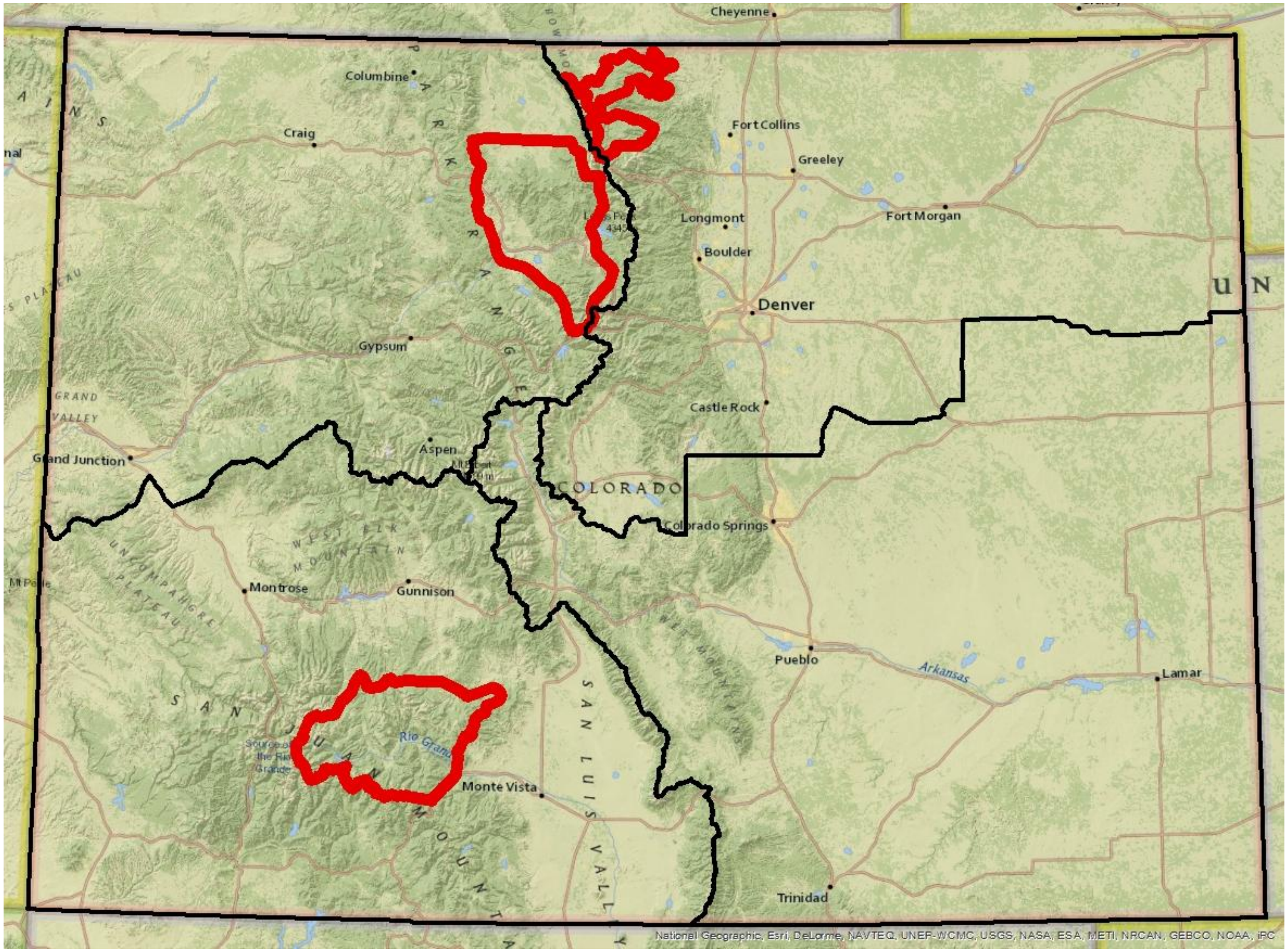


Figure 5. Map of Colorado moose study area locations (red polygon). Colorado Parks and Wildlife regions, and state boundaries, are depicted by heavy black lines.

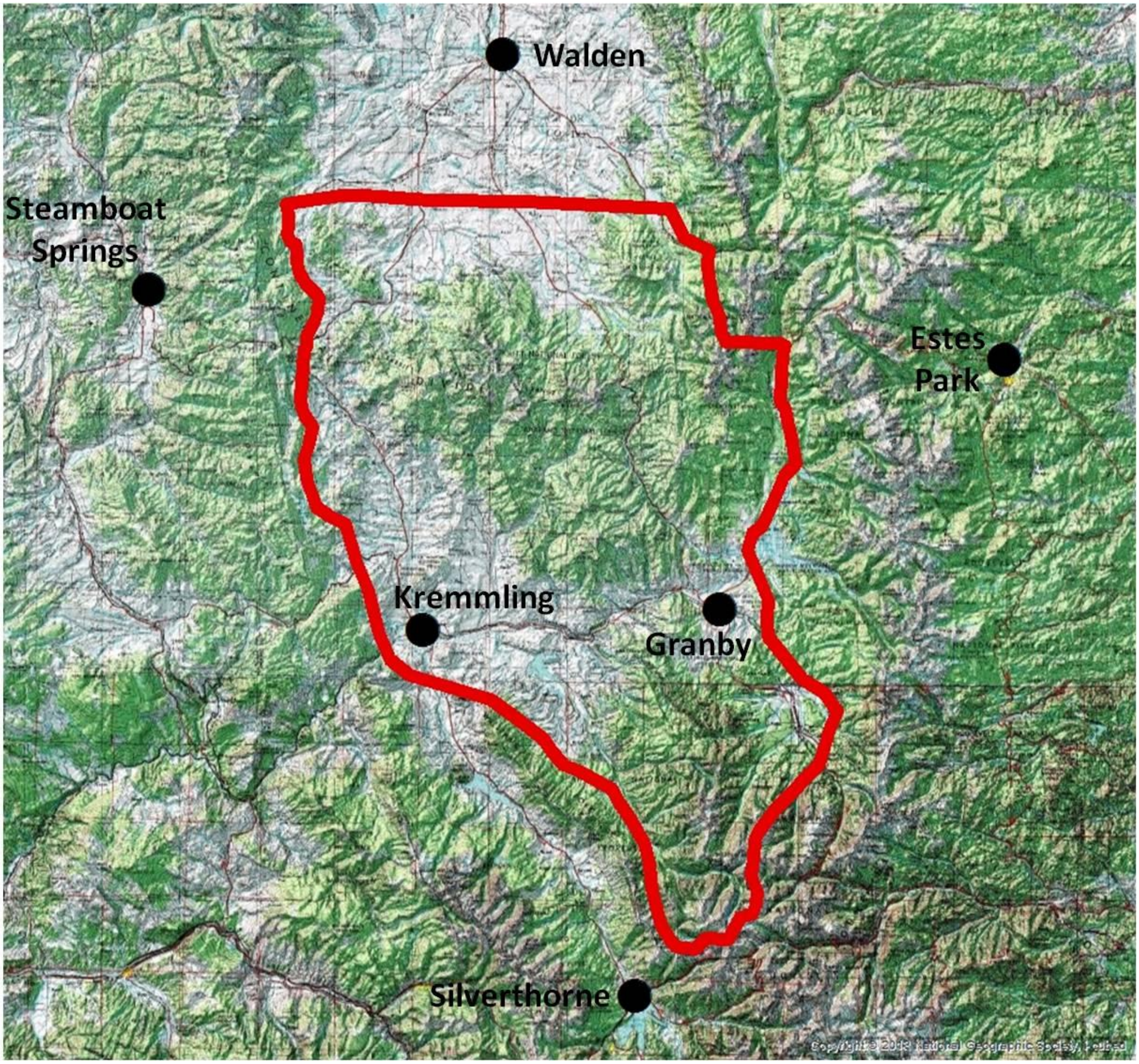


Figure 6. Northwest Colorado moose study area (red polygon), in relation to local communities and centered on the Rabbit Ears Mountains. The majority of moose capture will be located in the central portion of the study area, although capture locations may also expand into the southern portion of North Park, as well as the central portions of Middle Park, include the Williams Fork River drainage, as well as the valley including Tabernash and Fraser, Colorado.

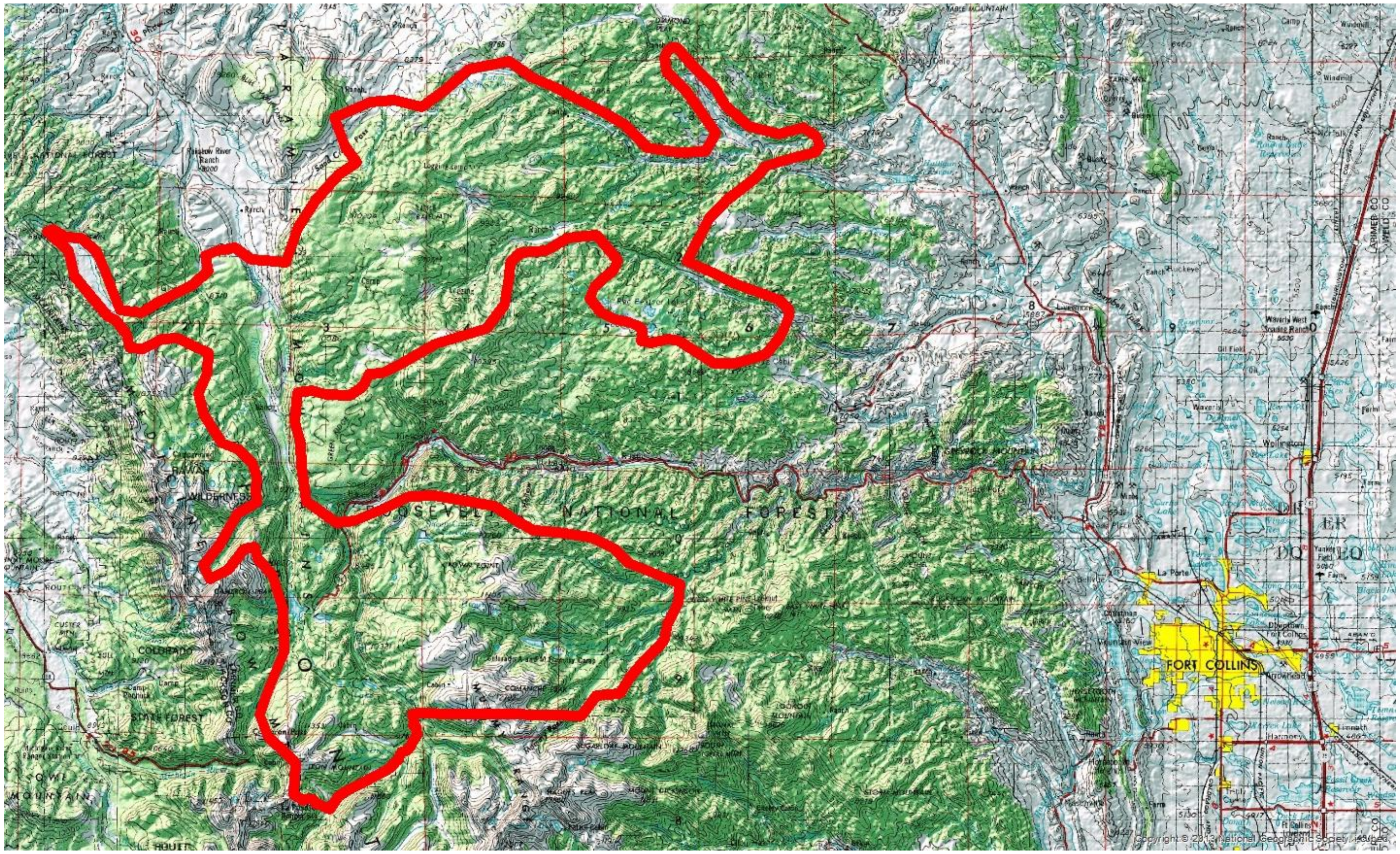


Figure 7. Northeast Colorado moose study area (red polygon), in relation to local communities. The study area is centered on the Laramie River, the upper portions of the Cache la Poudre River, and the Dead Man and Sand Creek areas located to the east of the Laramie River.

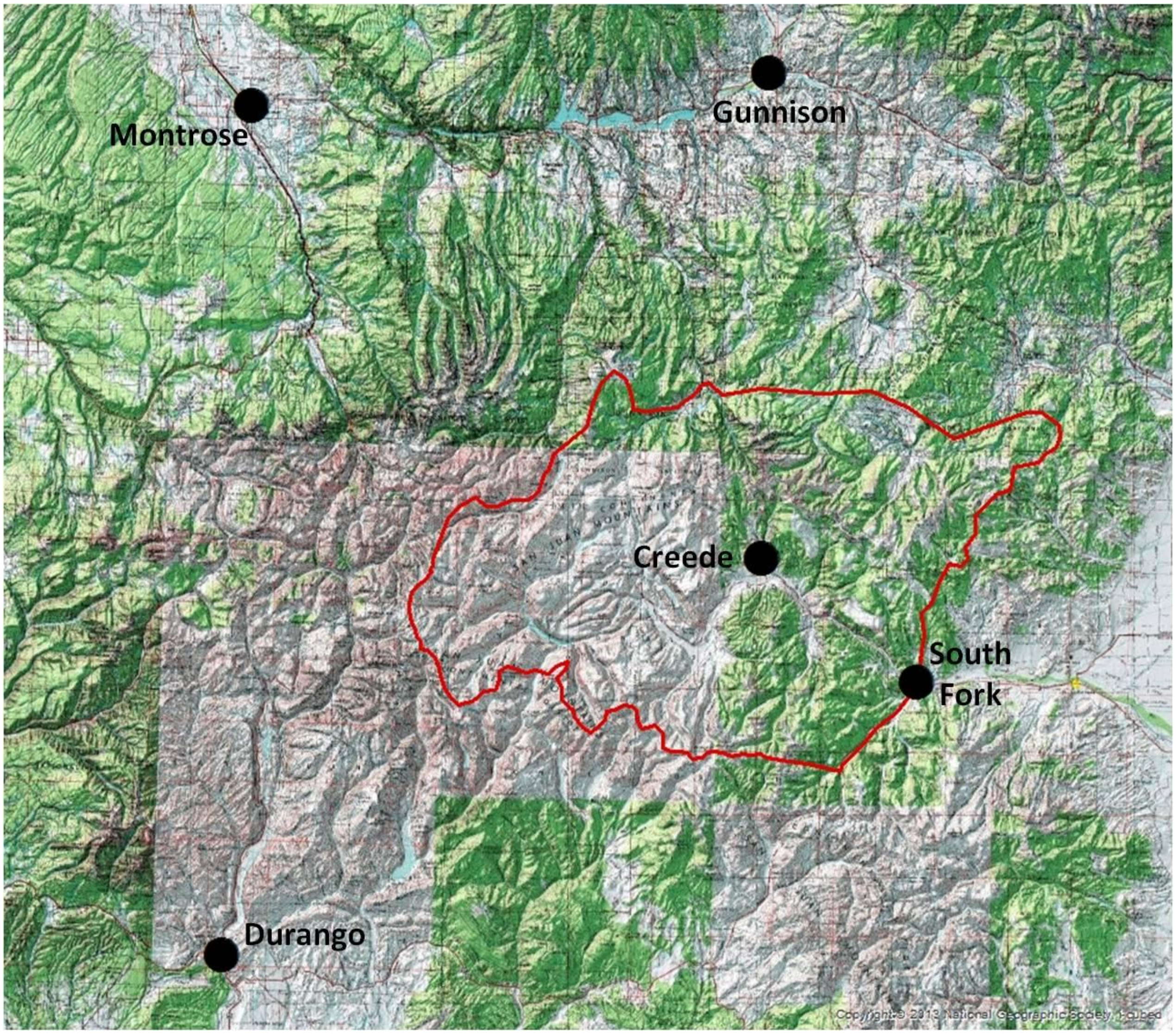


Figure 8. Southwest Colorado moose study area (red polygon), in relation to local communities. The study area is centered on the upper portions of the Rio Grande River, including the Rio Grande Reservoir. As needed, moose will also be captured in the upper portions of Cebolla Creek, and to the east in the vicinity of Carnero Creek. As needed and dependent on approval from the United States Forest Service, moose may also be captured in the Weminuche Wilderness Area to the south of Rio Grande Reservoir and west of the community of South Fork, Colorado.

K. Appendices

Compliance

Endangered Species Act

The project work in this proposal is non-invasive in nature and does not include any ground disturbing activities. The only on-the-ground activity associated with this project will be the capture of moose using a small helicopter during winter. This project does not involve aquatic work therefore there will be no effect to Pallid sturgeon, Greenback Cutthroat trout, Humpback chub, Razorback sucker, Rio Grande Cutthroat trout, Bonytail chub or Colorado pikeminnow. The only other aquatic organism, the Arapahoe snowfly spends the majority of its life in clear, cool streams with a brief terrestrial period in later winter/early spring for mating. Because this species only has a brief terrestrial phase and is restricted to two small tributaries in Larimer County, a chance encounter is highly unlikely. Therefore, we've determined this project may affect but is not likely to adversely affect this species.

This project will not occur in alpine settings and therefore will have no effect on North American wolverine or Uncompahgre Fritillary butterfly. This project will not overlap arid/desert environments and therefore will have no effect on Knowlton's cactus or Colorado hookless cactus. Due to timing of bird migrations and the lack of temporal overlap with the proposed research activities which occur in the winter, there will be no effect to migrating Southwestern willow flycatchers, Yellow-billed cuckoos, Interior least terns, Piping plovers, or Whooping cranes. There will also be no effect for the following plant species because they do not occupy the same habitat as moose: Pagosa skyrocket, Schmoll's milkvetch and Penland Alpine Fen Mustard.

Helicopter darting on moose winter range in Colorado may result in minor disturbance to sage obligate and conifer related species including Greater sage grouse, Gunnison sage grouse and Canada lynx. Capture activities could also occur near or around habitat suitable for Gunnison's prairie dog and Black-footed ferrets. Because all these species and/or their habitat are conspicuous and easily recognized, if any of these species are encountered, researchers will avoid flying in the direction of the animals to limit disturbance. Furthermore, project activities will take place during daylight hours and Black-footed ferrets are mainly nocturnal, so any disturbance to this species would be limited. Helicopter capture has routinely been conducted throughout Colorado, across the range of all these species, and no negative effects have been documented. Therefore, we have determined this project may affect but is not likely to adversely affect the above listed species. Furthermore, because the Gunnison sage grouse is a proposed species for federal listing, we have determined this project will not jeopardize the continued existence of this species.

Due to constraints with tree cover, helicopter related activities may affect but are not likely to adversely affect Mexican spotted owl, New Mexico jumping mouse and Preble's meadow jumping mouse. Mexican spotted owls inhabit Colorado in low numbers, and prefer old growth forests and canyon lands. Since the majority of the work will take place in moose winter range consisting of riparian and shrublands, no negative impacts are anticipated. In the rare event a Mexican spotted owl is seen within the project area, researchers will move to a different location to minimize disturbance.

Helicopter capture poses minimal threat to listed plant species because the only ground contact occurs with helicopter skids and three observers that climb in and out of the helicopter. Helicopter capture may occur in areas that include the following plant species: Skiff milkvetch, osterhout milkvetch, Penland beardtongue, North Park phacelia, Ute's ladie's-tresses, Colorado butterfly plant and Western prairie fringed orchid. Field personnel will be knowledgeable of these species to insure no trampling or crushing of these species will occur in the unlikely event they are encountered. Therefore we have determined this project may affect, but is not likely to adversely affect the above listed plant species.

Animal Welfare Act

Prior to capture, this study will gain capture approval through Colorado Parks and Wildlife's Animal Care and Use Committee. Once gained, project approval numbers will be provided.

NEPA

Pursuant to 516 DM 8.5 Section B1, this action (or these actions) are categorically excluded from further consideration under the National Environmental Policy Act. Additionally, the individual actions do not meet the criteria pursuant to 43 CFR 46.215, Extraordinary Circumstances.

Other Landscape-Oriented Federal Acts

This project will have no negative impact on the landscape, therefore it will not violate provisions of Federal Legislation governing floodplains, wetlands, historical sites, and prime and unique farmlands.

Americans With Disabilities Act

When hiring personnel as part of this project, qualified individuals will not be discriminated against based on disability. No structures or access points will be constructed as part of this research, and thus accessibility is not applicable.

Federally listed, proposed and candidate species considered for: La Plata, Archuleta, San Juan, Hinsdale, Mineral, Saguache, Gunnison, Summit, Grand, Jackson, Routt and Larimer counties.

Greater sage-grouse (*Centrocercus urophasianus*) Population: entire	Candidate
Gunnison sage-grouse (*Centrocercus minimus*) Population: entire	Proposed Endangered
Mexican Spotted owl (*Strix occidentalis lucida*) Population: Entire	Threatened
Southwestern Willow flycatcher (*Empidonax traillii extimus*)	Endangered
Yellow-Billed Cuckoo (*Coccyzus americanus*) Population: Western U.S. DPS	Candidate
Bonytail chub (*Gila elegans*) Population: Entire	Endangered
Colorado pikeminnow (*Ptychocheilus lucius*) Population: except Salt and Verde R. drainages, AZ	Endangered
Greenback Cutthroat trout (*Oncorhynchus clarki ssp. stomias*) Population: Entire	Threatened
Humpback chub (*Gila cypha*) Population: Entire	Endangered
Razorback sucker (*Xyrauchen texanus*) Population: Entire	Endangered
Rio Grande Cutthroat trout (*Oncorhynchus clarki virginalis*)	Candidate

Colorado Butterfly plant (*Gaura neomexicana var. coloradensis*)	Threatened
Colorado hookless Cactus (*Sclerocactus glaucus*)	Threatened
Knowlton's cactus (*Pediocactus knowltonii*)	Endangered
North Park phacelia (*Phacelia formosula*)	Endangered
Osterhout milkvetch (*Astragalus osterhoutii*)	Endangered
Pagosa skyrocket (*Ipomopsis polyantha*)	Endangered
Penland Alpine Fen mustard (*Eutrema penlandii*)	Threatened
Penland beardtongue (*Penstemon penlandii*)	Endangered
Schmoll milk-vetch (*Astragalus schmolliae*)	Candidate
skiff milkvetch (*Astragalus microcymbus*)	Candidate
Ute ladies'-tresses (*Spiranthes diluvialis*)	Threatened
Arapahoe Snowfly (*Capnia arapahoe*)	Candidate
Uncompahgre Fritillary butterfly (*Boloria acrocnema*) Population: Entire	Endangered
Black-Footed ferret (*Mustela nigripes*) Population: entire population, except where EXPN	Endangered
Canada Lynx (*Lynx canadensis*)	Threatened
Gunnison's prairie dog (*Cynomys gunnisoni*) Population: central and south-central Colorado, north-central New Mexico	Candidate
New Mexico meadow jumping mouse (*Zapus hudsonius luteus*)	Candidate
North American wolverine (*Gulo gulo luscus*)	Candidate
Preble's meadow jumping mouse (*Zapus hudsonius ssp. preblei*)	Threatened

Species that may be affected by the project, but only under certain conditions:

Least tern (*Sterna antillarum*) Population: interior pop.	Endangered
Piping Plover (*Charadrius melodus*) Population: except Great Lakes watershed	Threatened
Whooping crane (*Grus americana*) Population: except where EXPN	Endangered
Pallid sturgeon (*Scaphirhynchus albus*) Population: Entire	Endangered
Western Prairie Fringed Orchid (*Platanthera praeclara*)	Threatened

Colorado Division of Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Predatory Mammal Conservation
Task No.	3	:	Black bear exploitation of urban environments: finding management solutions and assessing regional population effects
Federal Aid Project No.	W-204-R1		

Period Covered: July 1, 2012 – June 30, 2013

Author: H.E. Johnson; project cooperators, C. Bishop, J. Broderick, J. Apker, S. Lischke, S. Breck, J. Beckmann, K. Wilson, M. Reynolds-Hogland, and P. Dorsey.

All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the author. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

Across the country conflicts among people and black bears are increasing in frequency and severity, and have become a high priority wildlife management issue. Whether increases in conflicts reflect recent changes in bear population trends or just bear behavioral shifts to anthropogenic food resources, is largely unknown, with key implications for bear management. This issue has generated a pressing need for bear research in Colorado and has resulted in a unique collaboration that builds on the resources and abilities of personnel from 4 entities: Colorado Parks and Wildlife (CPW), the USDA National Wildlife Research Center, Colorado State University, and Wildlife Conservation Society. Collectively, we have designed and implemented a study on black bears that 1) determines the influence of urban environments on bear habitat-use patterns and demography, 2) tests a management strategy for reducing bear-human conflicts, 3) examines public attitudes and behaviors related to bear-human encounters, and 4) develops population and habitat models to support the sustainable monitoring and management of bears in Colorado. This project was initiated in FY10-11; during this past fiscal year we have primarily focused on collecting field data in the vicinity of Durango, Colorado. Specifically, we worked with collaborators and stakeholders on research logistics, trapped and marked black bears, collected GPS collar data on bear locations, monitored demographic rates (adult female survival, adult female fecundity and cub survival) through telemetry and winter den visits, collected data on the availability of late summer/fall mast, tracked human-related bear mortalities and removals from the study area, performed non-invasive genetic mark-recapture surveys, deployed 900 bear-resistant containers for an experiment on the effectiveness of urban-bear-proofing, obtained data on garbage-related bear-human conflicts, and specified a sampling design to assess human compliance with city ordinances. Information from this study will provide solutions for sustainably managing black bears *outside* urban environments, while reducing bear-human conflicts *within* urban environments; knowledge that is critical for wildlife managers in Colorado and across the country.

WILDLIFE RESEARCH REPORT

BLACK BEAR EXPLOITATION OF URBAN ENVIRONMENTS: FINDING MANAGEMENT SOLUTIONS AND ASSESSING REGIONAL POPULATION EFFECTS

HEATHER E. JOHNSON

PROJECT NARRATIVE OBJECTIVES

To conduct a study on black bears in Colorado that 1) determines the influence of urban environments on bear habitat-use patterns and demography, 2) tests a management strategy for reducing bear-human conflicts, 3) examines public attitudes and behaviors related to bear-human encounters, and 4) develops population and habitat models to support the sustainable monitoring and management of bears.

SEGMENT OBJECTIVES

1. Work with personnel from CPW Area 15, CPW Southwest Region, the City of Durango, La Plata County, US Forest Service (Columbine and Pagosa Ranger Districts), Bureau of Land Management (BLM; Tres Rio Field Office), Southern Ute Tribe, and private landowners on field research logistics.
2. Trap and collar adult female black bears in the vicinity of Durango to collect data on bear habitat-use patterns and demography.
3. Monitor bear locations and survival via global position system (GPS) collar locations.
4. Monitor bear fecundity and cub survival through winter den investigations of collared adult female bears.
5. Obtain data on summer/fall natural food availability for bears based on the phenology and abundance of gambel oak, serviceberry, chokecherry, hawthorne, pinyon pine and squaw apple.
6. Track human-related bear mortalities and removals around Durango from lethal conflict managment, vehicle collisions, harvest, and translocations.
7. Perform non-invasive genetic mark-recapture surveys to estimate bear density and population size around Durango (urban site) and in the Piedra watershed (wildland site).
8. Deploy 900 bear-resistant garbage containers for an experiment on the effectiveness of wide-scale urban bear-proofing for reducing bear-human conflicts.
9. Collect data on the frequency of bears accessing human garbage in treatment and control areas for an urban bear-proofing experiment.
10. Specify a sampling design to quantify compliance of human behavior with wildlife ordinances.

INTRODUCTION

In Colorado and across the country, conflicts among people and black bears (*Ursus americanus*) appear to be increasing in number and severity (Hristienko and McDonald 2007, Baruch-Mordo et al. 2008, CPW unpublished data). Bear-human conflicts can result in public safety concerns, property damage, bear mortality (i.e. euthanasia), and high management costs, and thus, have become a critical wildlife management issue. While wildlife agencies have used a variety of tools to try to minimize bear-human conflicts (i.e., education, aversive conditioning of bears, and modifications to harvest), conflict rates have continued to rise. Whether increases in bear-human conflicts reflect recent changes in the bear population or just behavioral shifts to anthropogenic food resources, is largely unknown, as bear population parameters have been exceeding difficult to estimate (Garshelis and Hristienko 2006). Without a thorough understanding of the relationship between conflict rates and bear behavior and population dynamics, it has been difficult for wildlife agencies to successfully reduce conflicts through bear management.

While there is uncertainty about how to reduce bear-human conflicts, two key factors thought to exacerbate this problem are expanding human development and climatic variation. Colorado has had one of the highest rates of exurban development in the nation (Theobald and Romme 2007), and this development has resulted in additional human food on the landscape in the form of garbage, agricultural resources, fruit trees, etc. The availability of human food to bears has been identified as the primary cause of bear-human conflicts (Spencer et al. 2007, Beckmann et al. 2008, Greenleaf et al. 2009), as bears are opportunistic foragers that will readily take advantage of this resource. Bear-use of human food not only increases interactions between bears and people but has been found to alter bear activity patterns, foraging behavior, movement rates, and even survival and reproductive rates (Beckmann and Berger 2003a, Beckmann and Berger 2003b, Hostetler et al. 2009), having the potential to significantly influence both bear behavior and demography. This phenomenon is further complicated by variation in annual weather patterns, as bear-use of human development appears to increase when natural foods are in short supply (Zack et al. 2003, Baruch-Mordo et al. 2010). Because bears predominately consume vegetation, recent patterns of drought in Colorado have caused natural food failures for bears in some years. As a result, bears may be increasing their reliance on human foods, with associated behavioral and demographic impacts. While the effects of urbanization and climate have critical implications for modifying bear-habitat relationships, they also have critical implications for increasing rates of bear-human conflicts. To develop successful strategies to reduce conflicts while maintaining viable bear populations, wildlife agencies must understand how factors such as climate, natural food availability, human food ability, and management influence the behavior and dynamics of bear populations.

To address these questions, Colorado Parks and Wildlife has partnered with the USDA National Wildlife Research Center, Wildlife Conservation Society and Colorado State University. Collectively, we initiated a project in FY10-11 to 1) determine the influence of urban environments on bear habitat-use patterns and demography, 2) test a management strategy for reducing bear-human conflicts, 3) examine public attitudes and behaviors related to bear-human encounters, and 4) develop population and habitat models to support the sustainable monitoring and management of bears in Colorado (Johnson et al. 2011). This information should provide solutions for sustainably managing black bears *outside* urban environments, while reducing bear-human conflicts *within* urban environments; knowledge that is critical for wildlife managers in Colorado and across the west.

During FY12-13, we worked with collaborators and stakeholders on research logistics, trapped and marked black bears, collected GPS collar data on bear locations, monitored demographic rates (adult female survival, adult female fecundity and cub survival) through telemetry and winter den visits, collected data on the availability of late summer/fall mast, tracked human-related bear mortalities and removals from the study area, performed non-invasive genetic mark-recapture surveys, deployed 900 bear-resistant containers for an experiment on the effectiveness of urban-bear-proofing, obtained data on garbage-related bear-human conflicts, and specified a sampling design to assess human compliance with city ordinances. Our efforts focused largely on collecting field data to meet research objectives 1-3, information which will eventually be used to address objective 4. We report general summary information from field activities over the past year; detailed analyses of field data will occur in future years.

STUDY AREA

To meet study objectives, a combination of site-specific field data and statewide data will be required. Site-specific field data is being collected in the vicinity of Durango, and is the focus of this progress report. Regional and statewide analyses will be conducted in future years. The town of Durango contains ~17,000 people (within city limits) and sits at 1,985 m along the Animas river valley. The town is surrounded by mountainous terrain ranging in elevation from ~1,930 to ~3,600 m, and is generally characterized by mild winters and warm summers that experience monsoon rains. Vegetation in the region is dominated by ponderosa pine, oak, pinyon-juniper, aspen, mountain shrub, and agricultural communities. Key forage species for black bears include gambel oak (*Quercus gambelii*), chokecherry (*Padus virginiana*), serviceberry (*Amelanchier alnifolia*), hawthorne (*Crataegus spp*), squaw apple (*Peraphyllum ramosissimum*) and pinyon pine (*Pinus edulis*). Durango is predominately surrounded by public land managed by the San Juan National Forest, BLM, CPW, La Plata County and the City of Durango. The vicinity of Durango is considered high quality bear habitat, and the town has consistently experienced high rates of bear-human conflicts (Baruch-Mordo et al. 2008, CPW unpublished data).

METHODS

Objective 1: Determining the influence of urban environments on bear behavior and demography

To sustainably manage bears in the face of a growing human population and changing landscape conditions, it is critical to elucidate the drivers and dynamics of bear populations. Of those factors that influence bear populations, the expansion of human development is the least understood, most contentious, and has the greatest potential to elicit major population change. To elucidate the influence of human development on bear habitat-use patterns and demography, we are collecting a suite of data types including locations from collared bears on the urban-wildland interface, survival and reproductive rates of those bears in conjunction with their habitat-use patterns, information on annual summer/fall mast production, and genetic data to estimate bear density in urban and wildland habitat types using mark-recapture methods. We briefly describe data collection methods for this portion of the study below; detailed information is available in Johnson et al. (2011).

Collaring and Marking Bears – To assess bear habitat-use patterns and demographic rates with respect to human development, we are capturing and collaring adult female bears. We are specifically targeting adult females as they represent the reproductive segment of the population and allow us to obtain information on multiple key vital rates that drive population growth. For example, in addition to being able to track adult female survival, the vital rate with the highest elasticity (Beston 2011), we can use collared females to track fecundity and cub survival, vital rates that are often associated with variation in bear population trends (Mitchell et al. 2009, Beston 2011).

We have targeted summer trapping efforts within ~10 km of the center of Durango to collar a cohort of bears that experience similar natural food availability, have anthropogenic food resources readily available, and encompass a range of behaviors and habitat-use patterns relative to the urban-wildland interface. Bears are trapped with box traps, which are baited with fish, fruit, human foods (at urban locations) and manufactured scents. Traps are set in the evening and checked the following morning. Adult female bears are fitted with a GPS collar (manufactured by Vectronics), and a tooth (first pre-molar) is pulled for age verification. GPS collars record bear locations every hour, and upload real-time locations to a central database via satellite system every 6 hours. Although trapping efforts are focused on adult females, all bears that are trapped (i.e., males, subadults, yearlings) are uniquely marked with a PIT and ear-tag and are weighed, measured, and sampled for blood and hair.

Evaluating Bear Movement and Habitat-Use Relative to the Urban-Wildland Interface – To examine movement and habitat-use patterns of bears along the urban-wildland interface, we are using GPS collar location data from adult females. Hourly GPS data are downloaded from the collars in the field on a biannual basis (during early fall and winter den checks). We will use those locations to assess the influence of factors such as natural food availability, human food availability, weather, habitat covariates, and individual bear attributes (i.e., age, reproductive status) on bear movement and resource selection patterns (Manly et al. 2002, McLoughlin et al. 2010, Morales et al. 2010). For spatial data, we will use satellite imagery to track annual spring/early summer forage availability, and ground surveys to track late summer/fall mast availability (see details below). We will obtain information on elevation, aspect, slope and terrain ruggedness information from digital elevation models. Weather information will be acquired from PRISM spatial data (www.prism.oregonstate.edu/) which interpolates monthly temperature and precipitation patterns across landscapes, accounting for elevation and topography. We will derive spatial models on distances to perennial water sources and watershed drainages from the National Hydrology Dataset. Vegetation type and cover layers will be generated from the USFS LandFire datasets (http://www.landfire.gov/vegetation.php). Covariates related to human development (e.g., density of human structures and paved roads) will be derived from existing CPW and La Plata County digital data layers on locations of human structures, roads, and census information.

While most habitat and human development information can be extracted from existing spatial data sources, there is no existing data layer that tracks annual variation in late summer/fall hard and soft mast for bears. The abundance of acorn and berry resources for bears is known to be highly variable, depending on annual trends in precipitation and temperature (Noyce and Coy 1989). To account for variation in the availability of natural fall forage for bears around Durango, we conducted bimonthly mast surveys. Surveys were performed from early August through mid-September in 2011 and 2012, when fruits and nuts should reach peak maturation and bears are in their hyperphagia stage prior to hibernation. In the Durango region, key mast species for bears are gambel oak, chokecherry, serviceberry, hawthorne, squaw apple, and pinyon pine (Beck 1991, Tom Beck, personal communication). We randomly selected 16 transects on public lands to evaluate bear mast availability. Each transect was 1 km in length and was situated along an existing trail or stream drainage. For each transect, field technicians recorded the phenological stage and the percentage of plants of each species that exhibited mast in different abundance categories (mast failure, <25% of plants with mast, 25 – 50% of plants with mast, etc).

Estimating Demographic Rates – To assess the influence of human development on bear demographic rates and population trends we are using the following data types: 1) survival and reproduction of collared adult female bears, and cub survival, 2) mortalities and removals of marked and unmarked bears in the vicinity of Durango, and 3) non-invasive genetic surveys to estimate density and abundance of bears around urban and wildland sites.

Collared female bears allow us to track annual survival, fecundity and cub survival (of their offspring); parameters we have monitored since summer 2011 and which we will continue to monitor for the next 3 years. We used real-time GPS collar locations to assess adult female survival, investigating mortalities and slipped collars when GPS locations were stationary for multiple sampling points. Fecundity and cub survival were monitored from den checks of collared females. Numbers of newborn cubs provide information on fucundity, while repeated annual den checks of collared females allow us to estimate cub survival. Yearlings hibernate with their mothers, so we can observe the number of cubs alive in the den in year t that survived their first year of life to $t+1$. Adult female survival, fecundity and cub survival will be used in projection models to assess population performance (Caswell 2001), particularly in relation to habitat selection.

In addition to tracking survival and reproduction of collared bears, we are also tracking survival and cause-specific mortality of marked (i.e., males, subadults) and unmarked bears in the study area. All bears that are trapped are marked with an ear-tag and PIT tag, unique identifiers that we are using to collect data on human-related bear mortalities and removals. Mortalities and removals primarily occur from translocations, vehicle collisions, conflict-related euthanasia and hunter harvest. For all bears removed from the study area we collect a hair and tooth sample and recorded the date, mortality/removal cause, location, bear age, sex, weight, and morphological measurements. We will use mark-recapture and recovery analyses to estimate adult male and subadult survival, while also gaining valuable information on cause-specific bear mortality within the study system.

To better understand the influence of urban environments on bear density and abundance, we are employing non-invasive genetic sampling (Woods et al. 1999, Mowat and Strobeck 2000) to compare these parameters between a bear population around the urban center of Durango and in a nearby "wildland" area. For each area we identified a 36 cell grid (576 km^2) where each cell was 4 x 4 km in size, and within each cell we constructed 1 snare site. Snares consisted of a scented bait hanging high in a tree, surrounded barbed wire around a cluster of trees encircling the bait (wire was strung 50 cm above ground). When bears climb over or under the wire to investigate the bait, they leave a hair sample on the barbed wire. During summers 2011 through 2013, snares were deployed during the first 2 weeks of June, and we conducted 6 weekly sampling occasions thereafter. On each occasion, we randomly re-baited the snare with anise, berry, fish, maple or bacon scent, and collected hair samples from all barbs. Each hair sample was uniquely catalogued according to the site, date, occasion, and barb number.

In summer 2012, we constructed 35 snares in the Durango grid and 34 snares in the wildland grid. The layout of the wildland grid had to be modified to account for closures associated with the Little Sand fire, which began burning on the San Juan National Forest on May 13th 2012. This modification can be easily accounted for in future analyses with spatially-explicit mark recapture statistics (Efford et al. 2009, Gardner et al. 2010) which increase flexibility with sampling designs. In fall 2012, all hair samples were sent to the laboratory at Wildlife Genetics International (Nelson, British Columbia, Canada) for genotyping; genetic results were returned at the end of July 2012. In summer 2013, we constructed 34 snare sites in the Durango grid and 35 sites in the wildland grid (Figure 1). Samples collected in 2013 will be sent to the laboratory this fall and results are expected in summer 2014.

Objective 2: Testing a management strategy to reduce bear-human conflicts

Given that the primary cause of black bear-human conflicts has been attributed to the availability of human foods to bears, it has been suggested that the most effective strategy to reduce conflicts is to reduce the availability of that food source (Peine 2001, Beckmann et al. 2004, Gore et al. 2005, Spencer et al. 2007). This strategy has had some success within national parks (Greenleaf et al. 2009), and anecdotally in some communities (Mammoth Lakes CA, Juneau AK, Whistler BC), but no research has ever scientifically tested the benefits of "cleaning up" a town. Given the high price to operationally "bear-proof" a community, municipalities must have definitive evidence that such an effort would significantly decrease conflict activity before initiating major changes to waste storage and collection practices.

As part of this project, we are implementing the first experimental test of wide-scale urban bear-proofing for reducing bear-human conflicts. As part of the experiment we have designated 2 residential 'treatment' areas and 2 paired 'control' areas, consisting of a total of ~2,000 homes (Figure 2). In spring and early summer 2013 we deployed ~900 bear-resistant garbage containers within the treatment areas (approximately 100 homes already had these containers), such that all residents had a bear-resistant container. We also canvassed homes within the treatment areas, talking with residents about methods to bear-proof their properties, reminding them to lock their garbage containers, and asking that they remove bird feeders, outdoor pet food, and other bear attractants (no action occurred in control areas). Additionally, we increased enforcement of wildlife ordinances within treatment areas, providing official warnings and notifying City Code Enforcement when wildlife ordinances were violated.

To track the effectiveness of these efforts in reducing bear-human conflicts we have planned to collect pre- and post-treatment data. For 2 years pre-treatment (summers 2011 and 2012), field technicians patrolled each street within proposed treatment/control areas on the day waste removal was scheduled to occur (when maximum human food was assumed to be available to bears). Technicians conducted patrols from ~05:30 - 06:30 AM and recorded locations where there was evidence that bears had obtained garbage or other human food sources. Monitoring occurred from early July through mid-Sept, months that experience the highest numbers of bear-human conflicts in Durango (CPW unpublished data). During summer 2013 project personnel have been collecting the first year of post-treatment data (currently ongoing); post-treatment data will be collected for a minimum of 3 years.

Each summer, in addition to collecting information on bears accessing human foods, we have quantified the "availability" of garbage to bears, by documenting the location and container type (wildlife-resistant or regular) of every garbage receptacle in the survey area accessible to bears the night prior to garbage pick-up. These data will allow us to track changes in the number of wildlife-resistant containers in the study area over the course of the experiment, and provide an estimate of the amount of human food available to bears in town. Once the experiment is complete, we will use pre- and post-treatment data collected during morning patrols and from calls received by CPW and the City of Durango to quantify the effectiveness of residential bear-proofing.

Objective 3: Identifying public attitudes and behaviors related to bear-human encounters

Wildlife management agencies must identify the biological factors driving increases in bear-human conflicts, but they also must identify and incorporate human attitudes and perceptions about this issue into management strategies. This is particularly critical for black bears, as increasing bear-human conflicts around urban development have stimulated significant public interest and concern. It is also critical because bear-human conflicts typically arise over bear-use of human foods, prompting investigators to suggest that a critical component of reducing conflicts is managing human behavior (Beckmann et al. 2004, Gore et al. 2008, Baruch-Mordo et al. 2011). Thus, in conjunction with Stacy Lischka, Human Dimensions Specialist for CPW, we have initiated efforts to better understand human attitudes and behaviors in the context of our ecological data on bears.

To assess data on human attitudes we are using public surveys to 1) quantify perceptions about bears, bear management, and bear-human encounters, and 2) explore motivations for compliance and non-compliance with wildlife ordinances designed to reduce bear-human conflicts. To meet those objectives, we developed a three part public mail survey to be conducted in conjunction with our urban bear-proofing experiment. Residents will be surveyed pre-, during, and post-implementation of the experiment, in treatment and control areas, as well as across a larger portion of the community. Surveys will be mailed to all residents within Durango city limits, and a subset of La Plata county residents within the study area. Survey responses will allow us to quantify current attitudes and perceptions about bear-human interactions, and how those perceptions change over time in association with a management effort such as wide-scale urban bear-proofing. The survey will also determine the number of residents that have had interactions with bears, the acceptability of management actions by CPW, and factors that promote or inhibit residents from complying with wildlife ordinances. The first (pre-treatment) public survey was implemented during winter 2012 (see Johnson et al. 2012 for details). The second survey will be conducted during fall 2013 or winter 2014.

In addition to collecting data on human attitudes, we will also collect data on human behavior as part of an effort that was initiated this past year. Data collection will occur in conjunction with the treatment and control areas of the bear-proofing experiment starting summer 2013 (mid-July through mid-Sept). Using a random stratified sampling design we will monitor human compliance with wildlife ordinances at residences throughout the conflict season. Houses will be surveyed on the morning of garbage pick-up (5:30 – 7:00 AM) to record whether those residences have secured their garbage the night prior (locked wildlife-resistant container or in a garage or shed that is not visible from the street) or have garbage available to bears. Compliance data will be analyzed in conjunction with survey information, spatial covariates, and bear activity to better understand how factors such as management actions and rates of wildlife-human interactions influence human behavior. The first year of data collected on human compliance will be summarized in the annual report for FY2013-14.

RESULTS AND DISCUSSION

Objective 1: Determining the influence of urban environments on bear behavior and demography

Between May 20th 2012 and August 26th 2013, an additional 140 unique bears were marked during 327 bear captures; on the project to date there have been 232 different individuals marked during 435 captures. Information about these captures is described below for each discrete capture season: summer 2012, winter 2013, and summer 2013 (ongoing; Table 1).

During summer 2012 we conducted 179 total bear captures; 86 captures were unique individuals and 93 were recaptures. Of the unique individuals captured, there were 37 females and 49 males (Table 1). We placed collars on 25 new adult females, and with those that had been previously collared in 2011, had 40 collars deployed by the end of August. The mean estimated age of bears ≥1 year-old on their initial capture date was 4.8 (5.7 for females and 4.2 for males), and mean weight was 73.2 kg (61.4 kg for females and 82.4 kg for males). The mean age of females that were newly collared in 2012, based on tooth cementum, was 8.6 years, with ages ranging from 3 to 24 years. In total, we placed traps at 90 different locations and conducted 1,114 trap nights. Capture success generally climbed each week until the second week of July, and remained high except for the second week of August (Figure 3). High trapping rates in 2012 were likely due to a combination of extra effort (we increased weekly trap nights from 5 nights/week to 7 nights/week and had a higher number of traps that were baited and set on a consistent basis) and a poor natural food year that brought additional bears into the urban-wildland interface around Durango.

We visited the winter dens of 27 collared females between January and March 2013. Although we had 40 adult female bears collared at the end of summer 2012 there were 4 mortalities in fall: 1 female was legally harvested (B173), 1 was killed in a vehicle collision (B35), one was illegally shot (B134) and 1 died of unknown causes (B174). Additionally, in fall 2012, 9 GPS collars on collared females prematurely failed (B14, B18, B21, B24, B42, B55, B121, B122, and B144) and we could not locate their dens via VHF or GPS signals. Of the 27 adult females that we processed last winter, 13 did not have any cubs or yearlings, 6 had yearlings (6 yearlings in total, all bears had only one surviving yearling), and 8 had newborn cubs (14 cubs in total; 5 females and 9 males). Of those females with newborn cubs, 2 bears had only 1 cub and 6 bears had twins. We PIT and ear-tagged yearlings in the den, recorded information on weight, body size, body condition, and collected hair and blood samples. We also PIT tagged newborn cubs, and recorded their sex and weight. We found that reproductive success, measured as the number of cubs/adult female/year was 0.52 (SE = 0.16) for winter 2013, almost half of the reproductive rate observed in 2012 (0.95, SE = 0.24). Cub survival for 2013 (survival from newborn to 1 year) was ~40% (we do not have these data for 2012 as 2 sequential years are required for estimation).

Between June 1st and August 26th 2012, we conducted summer captures with the goal of obtaining a sample of 40 GPS collared adult females (captures are currently ongoing). During that time there were 114 total captures; 37 were unique individuals and 77 were recaptures (Table 1). Of the unique individuals captures, 17 bears were females and 20 were males (there were also 9 cubs caught of unidentified sex; cubs were not immobilized or processed). The mean estimated age of bears ≥1 year-old on their initial capture date was 5.0 (4.9 for females and 5.0 for males) and the mean weight was 77.5 kg (56.9 kg for females and 92.1 kg for males). This summer, to date, 7 new adult females have been collared, and 5 females were recaptured that had previously slipped collars or had a malfunctioning collar. Given malfunctioning collars and 1 mortality (B65, vehicle collision), 35 females were collared as of August 26th, and trapping will continue through mid-September or until working GPS collars have been deployed. To date, traps have been placed in 93 different trap locations (30 on public land and 63 on private land) for 1,124 trap nights. Thus far, capture success has been fairly steady throughout the summer (Figure 3).

To date, we have obtained >183,000 locations from GPS collars on 56 different female bears; 44 different bears collected location data in 2012 (Figure 4). We will start analyzing habitat-use data in the coming year and have generated spatial covariate data for elevation, slope, aspect, terrain ruggedness, distance to perennial water, distance to drainage, vegetation type, vegetation cover, distance to human structure, density of human structures, distance to paved road, and density of paved roads.

The availability of natural mast foods was extremely limited in 2012, likely due to late freezes in June that destroyed berry and acorn flowers, and due to extreme summer drought. Of the few berries and acorns observed that summer, most were shriveled and dried up during the peak period of hyperphagia for bears (late summer/early fall). For example, gambel oak can be observed along all vegetation transects, but acorns were only observed on 5 of 15 transects, with limited production. Those acorns that did reach maturation were at their peak in mid-Sept. Chokecherry and serviceberry plants were observed on 13 of 15 transects, but no chokecherry fruits were seen (complete mast failure), and only a few shriveled serviceberries were seen. Pinyon pine nuts were fairly abundant on 2 transects, with mast production peaking in mid-Sept. Squaw apple fruits were only seen on 2 transects, and there were limited fruits that were mostly dried up. Hawthorne fruits were not found on any transect (complete mast failure).

Between May 1st 2011 and November 1st 2012, a total of 59 bears were removed from the vicinity of Durango. Of those bears, 21 were killed in vehicle collisions, 18 were legally harvested, 10 were lethally removed due to nuisance behavior (breaking into houses, killing livestock, etc.), 3 died from non-harvest related gunshots, 2 were translocated due to conflicts with people, 1 was electrocuted, and 4 died from unknown causes. Of those mortalities and removals there were 17 adult females, 14 adult males, 11 subadult females, 9 subadult males, 6 cubs, and 2 bears of unknown sex/age class. Forty-one bears were unmarked and 17 were marked or collared for the research project. Additionally, 5 marked bears were reported killed outside the study area; 3 died from lethal conflict management and 2 died from vehicle collisions.

In summer 2012, we collected 1,367 hair samples from the Durango and wildland grids; 586 samples from Durango and 781 samples from the wildland site. Over the 6 sampling occasions from 35 snares around Durango, we collected 92, 136, 59, 55, 142, and 102 samples, respectively. Over the 6 sampling occasions from 34 sites in the wildland grid, we collected 73, 135, 142, 118, 144, and 169 samples, respectively. We received the genetic results back from Wildlife Genetics International at the end of July 2013. Of the 1,367 hair samples submitted to the laboratory, good genotypes were obtained for 707 samples (52%). Of the remaining samples that did not produce a valid genotype, 363 (27%) did not contain enough genetic material, 274 (20%) failed during analyses for other reasons, and 23 (2%) samples were not black bear. Across the 707 valid samples there were 303 genotypes generated from the Durango grid and 404 generated from the wildland grid. In the Durango grid, 97 different individuals were detected during 138 "captures" (multiple hair samples from a single bear during 1 sampling occasion were considered 1 "capture"). Of those individuals, 71 were only detected in 1 sampling occasion and 26 were detected in >1 occasion (recaptures). The probability of detecting a bear within any single sampling occasion was 0.14, and across all sampling occasions was 0.58. In the wildland grid, 55 different individuals were detected during 71 "captures." Of those individuals, 44 were only detected in 1 sampling occasion and 11 were detected in >1 occasion (recaptures). The probability of detecting a bear within any single sampling occasion was 0.09, and across all sampling occasions was 0.42. Detailed mark-recapture analyses of these data will be conducted in the future to estimate annual density and abundance at each site.

In summer 2013, we collected 1,365 hair samples from the Durango and wildland grids; 680 samples from Durango and 685 samples from the wildland site. Over the 6 sampling occasions from 34 snares around Durango we collected 106, 151, 131, 62, 106, and 124 samples, respectively. Over the 6 sampling occasions from 35 sites in the wildland grid we collected 112, 83, 141, 100, 126, and 123 samples, respectively. The number of samples/snare ranged from 0 to 121 in the Durango grid and from 1 to 78 in the wildland grid. Samples will be sent to Wildlife Genetics International this fall for genetic analysis.

Objective 2: Testing management strategies to reduce bear-human conflicts

During summer 2012 (July through mid-August) we collected a second year of pre-treatment data for the bear-proofing experiment. Within proposed treatment and control areas we observed 177 instances of bears accessing residential garbage during our morning patrols (Figure 2); observations peaked in early September. Of those garbage containers accessed by bears, 94% were regular containers or unsecured trash bags and 6% were wildlife-resistant containers. Bears accessed human food from wildlife-resistant containers when they were not properly latched. In quantifying the availability of garbage to bears, we recorded the location and container type of 1,530 garbage cans in proposed treatment and control areas. Of those containers, 86% were regular (non-wildlife resistant) and 14% were wildlife-resistant. This demonstrates the limited residential bear-proofing that currently exists in Durango, and the relevance of conducting an experimental test of wide-scale urban bear-proofing in this community.

This past year, we worked on the logistics of implementing the urban bear-proofing experiment. Final funds were secured through CPW, the Summerlee Foundation, and the International Bear Association to purchase the remaining containers needed for the study. Wildlife-resistant containers were acquired through Solid Waste Systems (Parker, CO), a company that manufactures containers certified by the Living with Wildlife Foundation. Containers were delivered to Durango, entered into the City of Durango's Solid Waste Program database, and distributed by the City in spring and early summer 2013 to residences within treatment areas.

Starting in mid-July 2013, we initiated the first year of post-treatment conflict monitoring. Data collection is currently ongoing, but as of August 26th we had recorded 153 incidences of bears accessing residential garbage; 75 conflicts in the treatment areas and 78 conflicts in control areas. Of those conflicts, 71% occurred with regular garbage containers or unsecured trash, and 29% occurred with wildlife-resistant containers. In quantifying the availability of garbage to bears, we recorded the location and container type of 1,678 garbage cans in treatment and control areas. Within the northern control area 72% of containers were regular and 28% were wildlife-resistant, in the southern control area 91% were regular and 9% were wildlife-resistant, in the northern treatment area 11% of containers were regular (residents that refused a bear-resistant container or have kept additional regular containers on their property) and 89% were wildlife-resistant, and in the southern treatment area 27% were regular and 73% were wildlife-resistant.

SUMMARY AND FUTURE PLANS

During FY12-13 we successfully coordinated field logistics and conducted several aspects of data collection (trapping and collaring bears, tracking human-related bear mortalities, assessing summer/fall forage availability, implementing DNA hair-snare surveys, and monitoring garbage-related bear-human conflicts). We will continue these field activities through 2015, and begin data analyses as field data are completed. In addressing the objectives of this project we hope to better understand the influence of urban environments on bear populations, elucidate the relationship between bear-human conflicts and bear behavior and population trends, develop tools to promote the sustainable management of bears in Colorado, and ultimately, identify solutions for reducing bear-human conflicts in urban environments.

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Prepared by ____
Heather E. Johnson, Wildlife Researcher

Table 1. Capture information for black bears that have been marked in the vicinity of Durango, CO since May 2012 (collared adult females are identified with an "*"). Only information from the initial capture of each individual is shown (no recaptures).

Bear ID	Capture Date	UTM Easting	UTM Northing	Sex	Age	Kg
B120	5/27/2012	254732	4133249	F	1	20.9
B121*	5/29/2012	251670	4132767	F	4	76.2
B122*	5/30/2012	249059	4132998	F	5	66.2
B123	6/5/2012	240102	4128939	M	2	48.1
B124*	6/6/2012	249158	4127065	F	7	80.7
B125*	6/8/2012	244618	4132132	F	8	98.9
B126	6/8/2012	251670	4132767	F	1	15.9
B127*	6/10/2012	239005	4134459	F	10	58.1
B128*	6/11/2012	239005	4134159	F	8	56.2
B129*	6/14/2012	254576	4135043	F	6	54.4
B130	6/22/2012	250152	4127691	M	1	12.7
B131	6/23/2012	765047	4131635	M	6	111.6
B132	6/28/2012	765047	4131635	M	1	20.4
B133*	6/29/2012	765932	4127651	F	3	49.0
B134*	6/30/2012	765932	4127651	F	8	90.7
B135	6/30/2012	252014	4133509	M	1	20.9
B136	7/1/2012	765047	4131635	F	2	46.3
B137	7/5/2012	249059	4132998	M	2	26.8
B138	7/5/2012	254997	4135825	F	2	30.8
B139	7/5/2012	238245	4131204	M	1	30.4
B140	7/5/2012	763921	4132873	M	3	67.1
B141*	7/5/2012	765132	4132506	F	3	55.3
B142	7/6/2012	254997	4135825	M	3	37.2
B143*	7/6/2012	241210	4137115	F	3	45.4
B144*	7/7/2012	238245	4131204	F	9	72.6
B145*	7/7/2012	763921	4132873	F	6	70.3
B146	7/7/2012	254739	4133234	M	5	110.2
B147	7/10/2012	241334	4138018	M	1	43.5
B148	7/11/2012	255983	4135921	M	3	73.9
B149	7/15/2012	244618	4132132	M	1	45.4
B150	7/16/2012	241334	4138018	M	2	53.5
B151	7/26/2012	243888	4129546	M	3	60.3
B152*	7/17/2012	241210	4137114	F	8	99.8
B153	7/17/2012	249059	4132998	M	2	49.9
B154	7/17/2012	253439	4134693	M	3	63.5
B155	7/19/2012	241334	4138018	F	2	30.8
B156	7/19/2012	252621	4130532	F	1	26.3
B157	7/19/2012	248417	4144294	M	6	136.1
B158	7/20/2012	252546	4134789	M	3	50.8

B159	7/21/2012	242236	4127920	F	2	39.9
B160	7/24/2012	249059	4132998	M	2	64.0
B161*	7/25/2012	242546	4134789	F	5	76.2
B162	7/25/2012	249059	4132998	M	10	108.0
B163	7/26/2012	243954	4134875	F	1	37.6
B164	7/28/2012	242611	4133863	M	6	117.0
B165*	7/29/2012	251815	4133706	F	12	85.3
B166	7/29/2012	252621	4130532	M	8	121.6
B167*	7/31/2012	248578	4139143	F	18	58.1
B168	7/31/2012	253439	4134693	M	4	87.5
B169	7/31/2012	249059	4132998	F	2	44.5
B170	8/1/2012	249059	4132998	M	4	119.3
B171	8/2/2012	248192	4137051	M	2	26.8
B172	8/2/2012	248578	4139143	F	2	28.1
B173*	8/3/2012	248578	4139143	F	5	73.9
B174*	8/3/2012	253341	4128740	F	3	43.5
B175*	8/3/2012	254916	4128609	F	10	76.2
B176	8/3/2012	252621	4130532	M	2	54.4
B177	8/4/2012	248578	4139143	M	7	93.9
B178	8/4/2012	249059	4132988	M	2	35.4
B179	8/5/2012	248578	4139143	M	1	35.4
B180*	8/5/2012	248939	4141533	F	3	71.7
B181*	8/5/2012	247127	4138557	F	3	58.1
B182	8/8/2012	259049	4132998	M	2	70.8
B190	8/9/2012	245293	4128959	M	12	153.3
B191	8/11/2012	249059	4132998	M	4	60.3
B192	8/11/2012	245293	4128959	M	9	148.8
B193	8/12/2012	243652	4129360	M	5	87.5
B194	8/12/2012	243218	4128712	M	5	137.0
B195	8/13/2012	259049	4132998	M	6	151.0
B196	8/14/2012	249059	4132998	F	2	42.2
B197	8/16/2012	242772	4129388	M	1	34.0
B198*	8/16/2012	247295	4132138	F	10	75.3
B199	8/17/2012	244208	4129996	M	5	140.6
B200	8/17/2012	245293	4128959	M	5	91.6
B201	8/18/2012	244600	4132218	M	5	99.8
B202	8/19/2012	249059	4132998	M	3	47.6
B203	8/21/2012	244174	4130027	M	1	24.5
B204	8/21/2012	243652	4129360	M	3	71.7
B205*	8/22/2012	243652	4129360	F	4	49.9
B206	8/22/2012	247295	4132138	M	2	46.3
B207	8/23/2012	249059	4132998	M	3	59.0
B212	8/24/2012	243274	4129124	M	2	45.4
B213*	8/24/2012	244174	4130027	F	6	61.2
B214	8/24/2012	249059	4132998	M	2	63.5

B215	8/24/2012	247295	4132138	M	5	127.0
B216	8/28/2012	249059	4132998	M	3	59.9
B244	1/25/2013	240578	4137131	F	1	15.0
B245*	2/14/2013	243288	4123754	F	15	83.0
B246	2/14/2013	243288	4123754	F	1	26.3
B259	6/3/2013	251514	4137313	M	1	32.7
B247	3/10/2013	243920	4135766	M	Cub	2.4
B248	3/11/2013	247275	4126961	M	Cub	2.6
B249	3/11/2013	247275	4126961	M	Cub	4.3
B250	3/14/2013	245069	4137542	F	Cub	2.4
B251	3/15/2013	255660	4131489	M	Cub	1.9
B252	3/15/2013	255660	4131489	M	Cub	2.2
B253	3/16/2013	240747	4132514	F	Cub	2.0
B254	3/16/2013	240747	4132514	F	Cub	2.0
B255	3/19/2013	255951	4141487	M	Cub	1.5
B256	3/19/2013	255951	4141487	M	Cub	1.4
B257	3/27/2013	240819	4154867	M	Cub	2.7
B258	3/27/2013	240819	4154867	F	Cub	2.7
B294	4/19/2013	268453	4207298	F	Cub	2.4
B295	4/19/2013	268453	4207298	M	Cub	2.4
B260	6/4/2013	253231	4138879	M	6	102.1
B261*	6/7/2013	253231	4138879	F	8	78.0
B262	6/10/2013	251343	4134446	M	1	30.8
B263	6/11/2013	254584	4134994	M	6	83.9
B265	6/14/2013	251343	4134446	F	1	38.6
B266	6/17/2013	251933	4137246	M	8	125.6
B267	6/19/2013	249872	4130099	F	2	30.8
B268	6/21/2013	251817	4131555	F	2	31.3
B269	6/21/2013	249153	4132855	M	4	54.4
B274	6/26/2013	256824	4134340	M	6	116.6
B275	6/27/2013	256937	4134617	F	2	34.9
B276	6/29/2013	237708	4130726	F	2	57.2
B277	6/30/2013	238206	4130573	M	10	181.4
B278	7/1/2013	256763	4134317	M	3	79.8
B280	7/8/2013	240340	4131577	F	1	25.9
B281*	7/11/2013	255385	4133334	F	13	63.5
B282	7/16/2013	244631	4132166	M	3	73.0
B283	7/16/2013	242022	4127361	M	2	33.6
B284	7/19/2013	247443	4137388	F	0	10.4
B285*	7/19/2013	254750	4133273	F	8	66.2
B287	7/23/2013	248532	4139266	M	3	75.3
B289	7/25/2013	764348	4132592	M	3	88.5
B290	8/1/2013	246591	4135689	M	4	93.4
B291*	8/2/2013	237566	4124276	F	4	64.4
B292	8/4/2013	246591	4135689	M	3	56.7

B293*	8/6/2013	245913	4139623	F	3	49.4
B296	8/10/2013	245913	4139623	M	2	45.8
B297	8/10/2013	246383	4142011	M	4	99.3
B298*	8/14/2013	245848	4141980	F	5	51.7
B299*	8/16/2013	245848	4141980	F	3	61.7
B300	8/17/2013	243934	4134857	M	10	122.0
B301	8/20/2013	243934	4134793	F	1	33.1
B302	8/23/2013	248263	4136448	M	8	133.8
B303*	8/23/2013	240787	4130376	F	7	93.0
B304	8/23/2013	243934	4134857	M	1	42.2

Figure 1. Locations of the 2013 hair snare sites (red dots) for the Durango and Wildland genetic sampling grids.

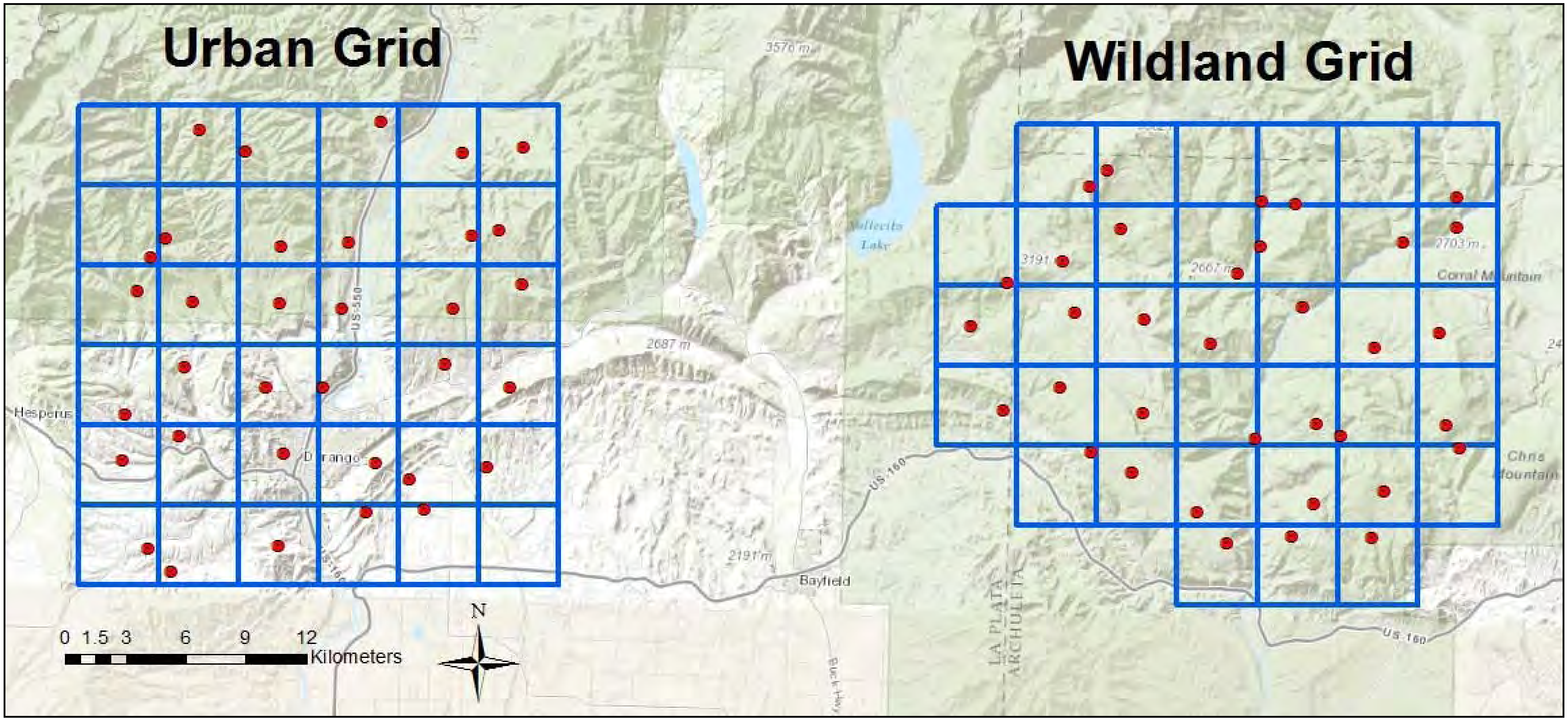

Figure 2. Location of garbage-related conflicts observed during morning patrols and garbage containers (by type) available to bears during summer 2012. Treatment and control areas for the bear-proofing experiment (implemented in summer 2013) are also shown.

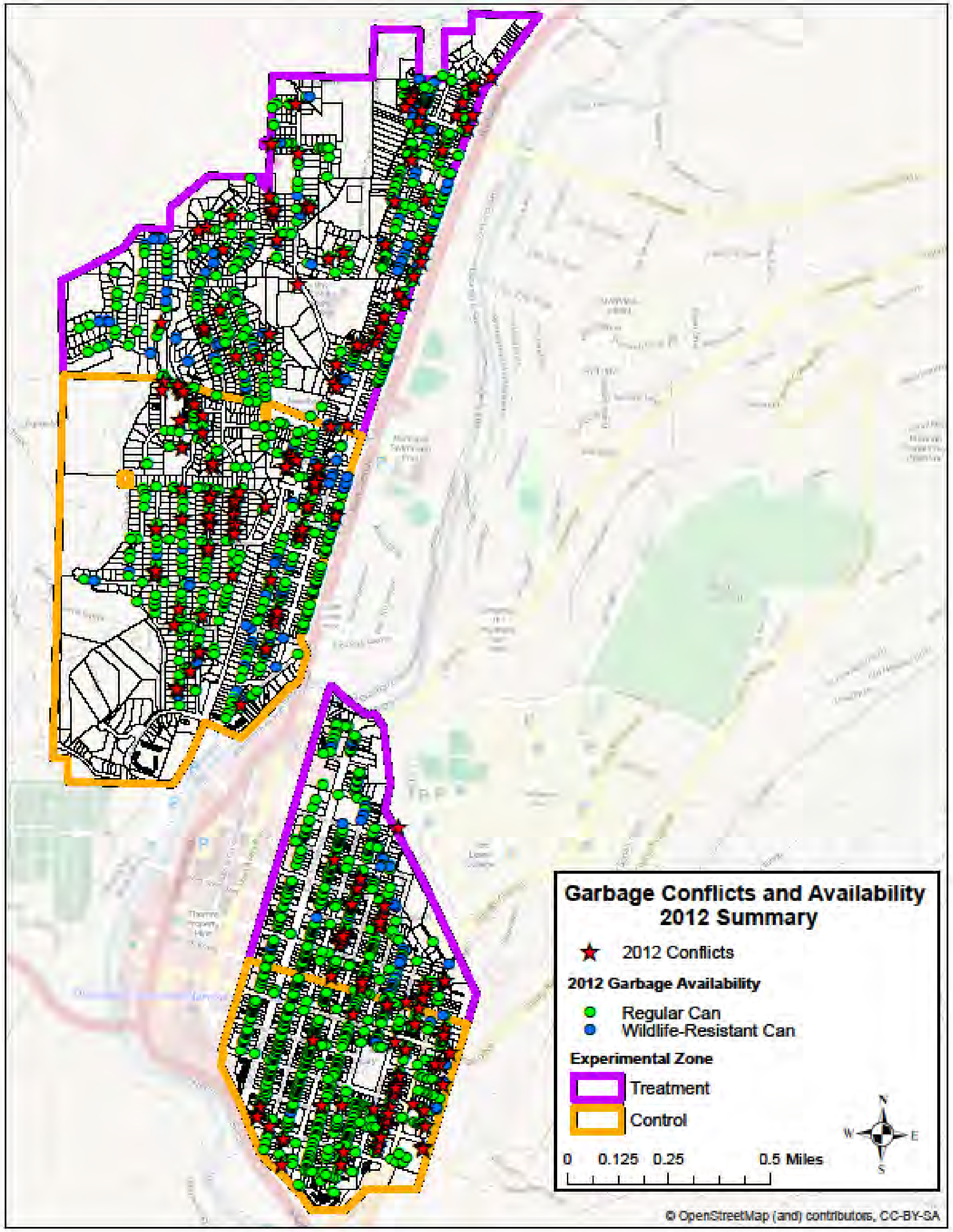

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Figure 3. Number of black bear captures by week from May 15th through September 15th for bear captures during the 2011 through 2013 summer trapping seasons (2013 is currently ongoing).

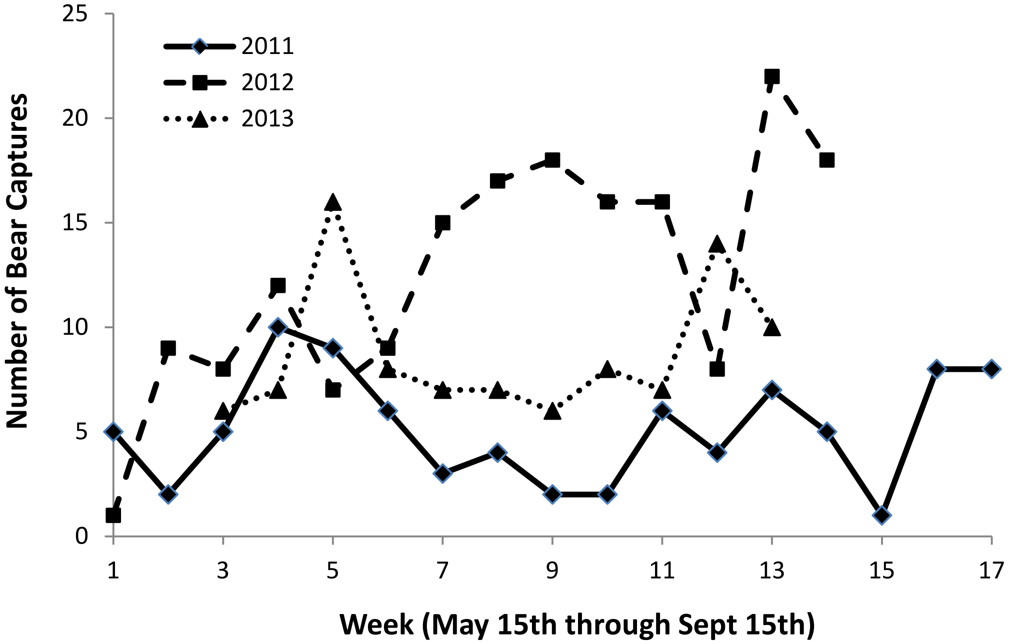
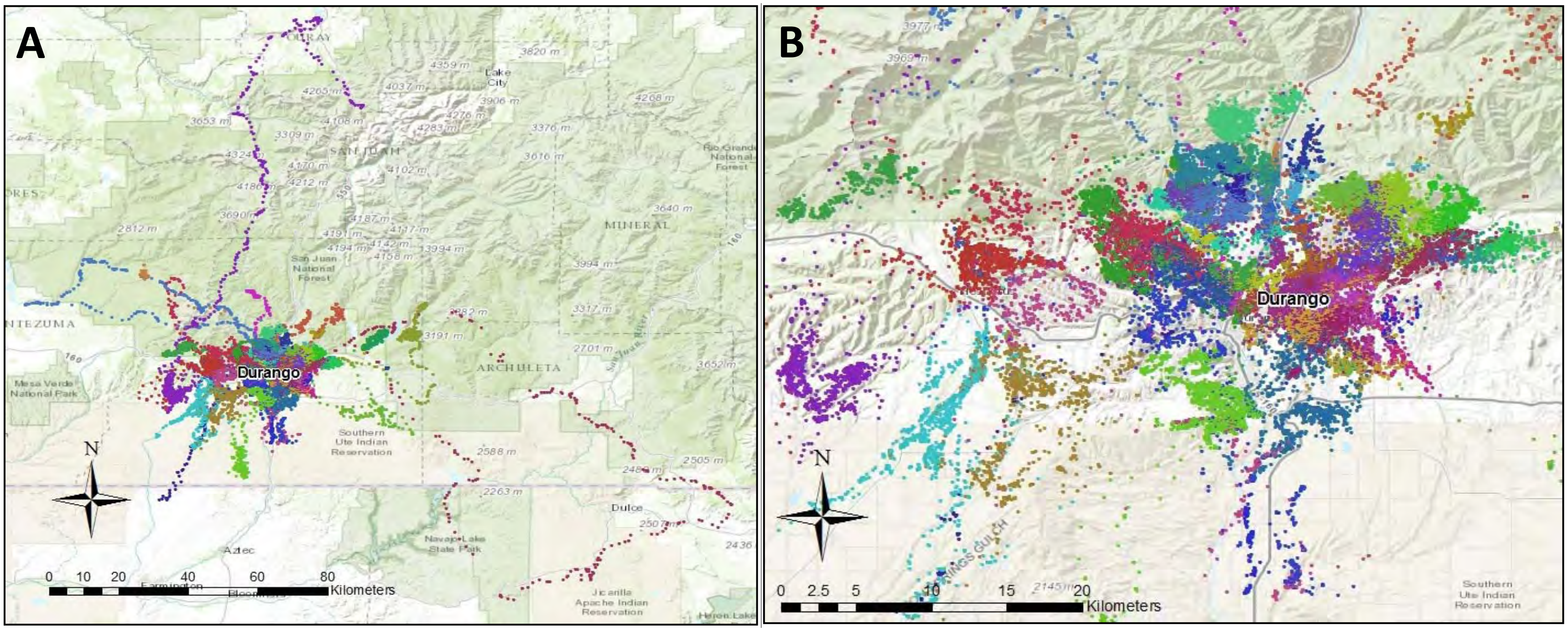


Figure 4. GPS collar locations from 44 adult female black bears from April 2012 through December 2012 in the vicinity of Durango, CO (different colored clusters of points represent different individual bears): A) an overview of all locations and B) locations around the town of Durango.



Colorado Division of Parks and Wildlife
July 2012 –June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Carnivore Conservation
Task No.:	1	:	Puma Population Structure and Vital Rates on the Uncompahgre Plateau
Federal Aid Project: W-204-R1		:	

Period covered: July 31, 2012−June 30, 2013

Author: Kenneth A. Logan.

Personnel: K. Logan, R. Alonso, C. Anton, S. Bard, B. Dunne, W. Hollerman, W. Jesson, R. Navarrete, B. Nay, H. Taylor, S. Waters, B. Banulis, T. Bonacquista, K. Crane, J. Koch, E. Phillips, and G. Watson of CPW; volunteers and cooperators including: private landowners, Bureau of Land Management, Ridgway State Park, Colorado State University, and U.S. Forest Service. Supplemental financial support received in previous years from The Howard G. Buffett Foundation, Safari Club International Foundation, and The Summerlee Foundation.

All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the author. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

The Colorado Parks and Wildlife (CPW) initiated a 10-year study on the Uncompahgre Plateau in 2004 to quantify puma population characteristics in the absence (*reference period*, years 1-5) and presence (*treatment period*, years 6-10) of sport-hunting. The purpose of the study is to evaluate assumptions underlying the CPW model-based approach to managing pumas with sport-hunting in Colorado. The *reference period* began December 2004 and ended July 2009, during which we captured, sampled, and marked 109 pumas for population research purposes on the Uncompahgre Plateau (Logan 2009). This report provides information on the fourth year of the *treatment period* (TY4), August 2012 through July 2013, on puma population characteristics and dynamics with hunting as a mortality factor.

Puma sport-hunting opened November 19 and closed December 29, 2012 after a quota of 5 independent pumas was harvested. The harvest was designed to test the management assumption that an 8-15% harvest of independent pumas results in a stable-to-increasing population. The decline in the puma population on the study area during TY1 to TY3 necessitated a reduction in the harvest quota from 8 to 5 to continue to test the harvest assumption for a stable-to-increasing puma population. A total of 5 pumas were killed: 2 adult females, 2 adult males, and 1 subadult male. The harvest of 5 independent pumas represented 11.9% of the 42 independent pumas in our *minimum count* during November 2012 to April 2013. Independent females and males comprised 40.0% and 60.0% of the harvest, respectively. Four other radio-collared independent pumas (3 adult females, 1 adult male) in the study area population died during the Colorado puma hunting season. Of those, 1 adult female died of natural cause and the remainder was killed by puma hunters in GMUs adjacent to the study area. The total mortality of 9 independent pumas during the TY4 hunting season represented 21.4% of the 42 *minimum count* of independent pumas on the study area.

Seventy hunters requested mandatory permits with an attached voluntary hunter survey in TY4. Forty-two of the hunters provided written responses on the surveys. An estimated 40 hunters actually hunted on the study area, of which about 12.5% harvested pumas and 15.0% captured pumas (i.e., harvested plus treed and released). Twenty of 24 answering hunters responded that they were selective hunters, and the capture, tracking, and population data indicated that most hunters practiced selection. Puma tracks < 1 day old encountered by hunters and pumas captured by hunters indicated that independent male pumas were detected more frequently than females in TY4.

Researchers captured forty-nine individual pumas captured 62 times from August 2012 to July 2013. Two capture teams with dogs operated over 74 search days from January 1, 2013 through April 18, 2013 to find 229 puma tracks, pursue pumas 82 times, and capture 29 pumas 42 times. Capture efforts with cage traps resulted in the capture of 4 independent pumas and 1 cub for the first time, and the recapture of 2 adult females. Twenty-one new cubs were captured and radio-collared. A total of 55 pumas were monitored by radio-telemetry in TY4. Search efforts also revealed the presence of at least 8 other independent pumas. Our *minimum count* of 42 independent pumas from November 2012 to April 2013 included: 31 females and 11 males. The *minimum count* of 42 independent pumas in TY4 was lower than 48 in TY3, 52 in TY2 and 55 in TY1, indicating a steadily declining population. A preliminary *minimum* estimated density of independent pumas was 2.51/100 km^2. The proportion of radio-collared adult females giving birth in the August 2012 to July 2013 biological year was 0.60 (9/15). Since 2005 a birth peak has occurred from May through August, involving 84.9% of births. We monitored 19 female and 8 male adult radio-collared pumas for survival and agent-specific mortality. Adult puma survival rates in TY4 for adult females and males were 0.819 (*SE*=0.0931) and 0.188 (*SE*=0.0845), respectively. Sport-hunting mortality was the major cause of death. Of 21 cubs monitored with radio-telemetry in TY4, 7 died and 1 orphaned cub was removed from the wild. Six died of infanticide and cannibalism by male pumas and 1 was killed by puma hunting dogs. One subadult male was killed by a hunter, and 1 subadult male was struck and killed by a vehicle on state highway 62.

Puma harvest, capture, and radio-telemetry data from the beginning of this study to the present provided information on dispersals of 38 pumas initially marked on the study area. Those pumas moved from about 18 to 370 km from initial capture sites. Since the start of this study 45 adult pumas have been monitored with GPS collars and have yielded over 70,000 locations.

Efforts to develop and test puma population survey methods continued with a collaborative effort with M.S. student K. Yeager and Mammals Researcher Dr. Mat Alldredge. This involved 54 sites in randomly selected cells in a grid system with predator call boxes, digital cameras, and hair gathering devices from December 2012 to March 2013. Pumas were photographed at the sites 18 times with all the photos depicting GPS/VHF-collared pumas. Seven of 11 collared pumas that used the grid were detected by photographs ($p = 0.64$). Six hair samples were acquired from 4 to 5 individual pumas. The quality of the hair samples for accurate genotypes has yet to be analyzed.

WILDLIFE RESEARCH REPORT

PUMA POPULATION STRUCTURE AND VITAL RATES ON THE UNCOMPAHGRE PLATEAU, COLORADO

KENNETH A. LOGAN

PROJECT NARRATIVE OBJECTIVE

Quantify puma population sex and age structure; estimate puma population vital rates, including: reproduction of females, stage-specific survival, and immigration and emigration; quantify agent-specific mortality rates; model puma population dynamics; develop and execute the puma harvest manipulation to begin the population-wide test of Colorado Parks and Wildlife (CPW) puma management assumptions in the third year of a five-year *Treatment Period* of the Uncompahgre Plateau Puma Project— all to improve the CPW model-based approach to managing pumas in Colorado.

SEGMENT OBJECTIVES

1. Execute the fourth year of the five-year *treatment period* by working with CPW biologists and managers to manipulate the puma population with sport-hunting and to survey hunters.
2. Continue gathering data on puma population sex and age structure.
3. Continue gathering data for estimates of puma reproduction rates.
4. Continue gathering data to estimate puma sex and stage-specific survival rates.
5. Continue gathering data on agent-specific mortality.
6. Explore non-invasive methods for sampling pumas to estimate abundance in collaboration with Dr. Mat Alldredge (Mammals Researcher, CPW) and Master of Science graduate student Kirstie Yeager, Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University.

INTRODUCTION

Colorado Parks and Wildlife managers need reliable information on puma biology and ecology in Colorado to develop sound management strategies that address diverse public values and the CPW objective of "achieving healthy, self-sustaining populations" through management (Colorado Division Of Wildlife 2002-2007 Strategic Plan:9). Although 4 puma research efforts have been made in Colorado since the early 1970s and puma harvest data is compiled annually, reliable information on certain aspects of puma biology and ecology, and management tools that may guide managers toward effective puma management is lacking.

Mammals Research staff held scoping sessions with a number of the CPW's wildlife managers and biologists prior to initiating the project. In addition, we consulted with other agencies, organizations, and interested publics either directly or through other CPW employees. In general, CPW staff in western Colorado highlighted concern about puma population dynamics, especially as they relate to their abilities to manage puma populations through regulated sport-hunting. Secondarily, they expressed interest in puma–prey interactions. Staff on the Front Range placed greater emphasis on puma–human interactions. Staff in both eastern and western Colorado cited information needs regarding effects of puma harvest, puma population monitoring methods, and identifying puma habitat and landscape linkages. Management needs identified by CPW staff and public stakeholders form the basis of Colorado's puma research program, with multiple lines of inquiry (i.e., projects):

Improve our ability to manage puma hunting with enhanced scientific bases, strategies, and tools—

- Puma population characteristics (i.e., density, sex and age structure).

- Puma population dynamics and vital rates (i.e., birth rates, survival rates, emigration rates, immigration rates, population growth rates).
- Field methods and models for assessing and tracking changes in puma populations.
- Relative vulnerability of puma sex and age classes to hunter harvest.

Improve our understanding of puma habitat needs and interrelationships of puma management units—

- Puma habitat use, movements, and use of landscape linkages.
- Puma recruitment patterns (i.e., progeny, immigration, emigration).
- Models for identifying puma habitat and landscape linkages.

Improve our understanding of the puma's role in the ecology of other species

- Relationships of puma to mule deer, elk, and other natural prey.
- Relationships of puma to species of special concern, e.g., desert bighorn sheep.

Improve our understanding of puma-human interactions and abilities to manage them

- Behavior of puma in relation to people and human facilities.
- Puma predation on domestic animals.
- Effects of translocating nuisance pumas.
- Effects of aversive conditioning on pumas.

While all projects cannot be addressed concurrently, understanding their relationships to one another is expected to help individual projects maximize their benefits to other projects that will assist the CPW to achieve its strategic goal in puma management (Fig.1). This project has been addressing all of the gray-shaded components on the left side of the conceptual model in Figure 1.

Management issues identified by managers translate into researchable objectives, requiring descriptive studies and field manipulations. Our goal is to provide managers with reliable information on puma population biology and to develop useful tools for their efforts to *adaptively manage* puma in Colorado to maintain healthy, self-sustaining populations.

The highest-priority management needs are being addressed with this intensive population study that focuses on puma population dynamics using sampled, tagged, and GPS/VHF-radio-collared pumas to investigate the effects of sport-hunting and other causes of mortality on puma population dynamics. Those objectives include:

1. Describe and quantify puma population sex and age structure.
2. Estimate puma population vital rates, including: reproduction rates, age-stage survival rates, emigration rates, immigration rates.
3. Estimate agent-specific mortality rates.
4. Improve the CPW's puma model-based management and attendant assumptions with Colorado-specific data from objectives 1–3. Consider other useful models.
5. Conduct a pilot study to develop methods that yield reliable estimates of puma population abundance.
6. Investigate diseases in pumas.

A descriptive and manipulative study will estimate population parameters in an area that appears typical of puma habitat in western Colorado and will yield defensible population parameters based upon contemporary Colorado data. This study will be conducted in two 5-year periods. A completed 5-year *reference period*, 2004-09, (i.e., absence of recreational hunting) allowed puma life history traits to interact with the main habitat factors that influenced puma population growth (e.g., prey availability and vulnerability, Pierce et al. 2000, Logan and Sweanor 2001, Logan 2009). A subsequent 5-year *treatment period* started in 2009-10 which involves the use of controlled recreational hunting to manipulate the puma population.

TESTING ASSUMPTIONS AND HYPOTHESES

Hypotheses associated with main objectives 1–5 of this puma population research are structured to test assumptions guiding puma management in Colorado.

1. Considering limitations (i.e., methods, number of years, assumption violations) to the previous Colorado-specific studies on puma populations (Currier et al. 1977, Anderson et al. 1992, Koloski 2002), managers assume that puma population densities in Colorado are within the range of those quantified in more intensively studied populations in Wyoming (Logan et al. 1986), Idaho (Seidensticker et al. 1973), Alberta (Ross and Jalkotzy 1992), and New Mexico (Logan and Sweanor 2001). The CPW assumes density ranges of 2.0–4.6 puma/100 km^2 (i.e., includes pumas of all stage classes - adults, subadults, and cubs, J. Apker, CPW Carnivore Biologist, person. commun. Nov. 19, 2003) to extrapolate to Data Analysis Units (DAUs) to guide the model-based quota-setting process. Likewise, managers assume that the population sex and age structure is similar to puma populations described in the intensive studies. Using intensive efforts to capture, mark, and estimate non-marked animals developed and refined during the study to estimate the puma population, the following will be tested:

   H_1: Puma densities during the 5-year *reference period* (absence of recreational puma hunting) in conifer and oak communities with deer, elk and other prey populations typical of those communities in Colorado will vary within the range of 2.0 to 4.6 puma/100 km^2 and will exhibit a sex and age structure similar to puma populations in Wyoming, Idaho, Alberta, and New Mexico.

2. Recreational puma hunting management in Colorado DAUs is guided by a model to provide allowable harvest quotas in an effort to achieve one of two puma population objectives: 1) maintain puma population stability or growth, or 2) cause puma population decline (CDOW, Draft L-DAU Plans, 2004, CDOW 2007). These objectives are expected to provide both the capacity for puma population resiliency to achieve a state-wide goal of a healthy, self-sustaining puma population while managing the puma population to provide sport-hunting opportunity and population control in some DAUs (even though puma population dynamics in any DAUs are not known). Basic model parameters assigned to the model are: puma population density, sex and age structure, annual population growth rate, and relative puma habitat quality and quantity. Parameter quantities are currently chosen from literature on studies in western states that are judged to provide reliable information. Background material used in the model assumes a moderate annual rate of growth of 15% (*i.e.,* $\lambda = 1.15$) for the adult and subadult puma population (CDOW 2007). This assumption is based upon information with variable levels of uncertainty (e.g., small sample sizes, data from habitats dissimilar to Colorado). Parameters influencing λ include population density, sex and age structure, female age-at-first-breeding, reproduction rates, sex- and age-specific survival, immigration and emigration.

   H_2: Population parameters estimated during a 5-year *reference period* (in absence of recreational puma hunting) in conifer and oak communities with deer, elk and other prey populations typical of those communities in Colorado will yield an estimated annual adult plus subadult population growth rate that will match or exceed $\lambda = 1.15$.

3. An assumption is that the CPW can manage puma population growth through recreational hunting on the basis that for a stable puma population hunting removes the annual increment of population growth (i.e., from current judgments on population density, structure, and λ). Puma harvest rate formulations for DAUs assume that total mortality (i.e., harvest plus other detected deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus

subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (CDOW 2007). This assumption is vital to providing the capacity for resiliency in the state-wide puma population which is hunted by applying this assumption to about three-quarters of the puma GMUs in the state.

> **H_3:** Total mortality of an estimated 15% of the adults and subadults with no more than 45% of the total mortality comprised of females will not result in a declining trend of the harvest-age segment of the population.

4. To reduce a puma population, hunting must remove more than the annual increment of population growth. For DAUs with the objective to suppress the puma population, the total mortality guide of *greater than* 15 to 28% of the harvest-age population with greater than 45% comprised of females is suggested (CDOW 2007). This assumption is applied to about one-quarter of the GMUs in the state.

> **H_4:** Total mortality of an estimated 16% or greater of the harvestable population with greater than 45% females will cause a declining trend in the abundance of harvest-age pumas (i.e., adults and subadults).

5. The increase and decline phases of the puma population make it possible to test hypotheses related to shifts in the age structure of the population which have been linked to harvest intensity in Wyoming and Utah.

> **H_5:** The puma population on the Uncompahgre Plateau study area will exhibit a young age structure after hunting prohibition at the beginning of the *reference period*. During the 5 years of hunting prohibition, greater survival of independent pumas will cause an older age structure in harvest-age pumas (i.e., adults and subadults) as suggested by the work of Anderson and Lindzey (2005) in Wyoming and Stoner (2004) in Utah. As hunting is re-instated in the *treatment period*, the age structure of harvested pumas and the harvest-age pumas in the population will decline as observed by Anderson and Lindzey (2005) in Wyoming and Stoner (2004) in Utah.

6. Researchers in Wyoming (Anderson and Lindzey 2005) concluded that sex and age composition of the harvest varies predictably with puma population size because the likelihood of a specific sex or age class of puma being harvested with the use of hounds is a product of the relative abundance of particular sex and age classes in the population and their relative vulnerability to harvest. Results of that study suggest that managers could use sex and age composition of the harvest to infer puma population changes (Anderson and Lindzey 2005). The CPW currently uses this approach as one tool to infer potential DAU puma population dynamics (CDOW 2007). This assumes no purposeful selection by hunters for any particular sex or age-stage other than the puma must be legal (i.e., independent subadult or adult, not a lactating female or a female in association with spotted cubs) and that changes in the sex and age structure of the harvested pumas is due solely to changes in the relative abundance of particular sex and age classes in the population and their relative vulnerability to harvest. Theoretically, pumas that travel longer distances with movements that intercept access routes used by hunters (i.e., roads, trails) should be more exposed to detection by hunters and thus more vulnerable to harvest. A key assumption to this method is that pumas are killed as they are encountered and the harvest sex and age composition will reliably indicate whether a population is stable, increasing, or declining even if harvest intensity does not vary. Thus, an alternate view is that a population segment, such as independent females, may be more abundant and have shorter movement lengths, yet be detected more frequently by hunters. However, because the same intensively studied Wyoming puma population was manipulated over 6 years with varying intensities of harvest (Anderson and Lindzey 2005), variations in harvest structure using the same harvest level over a period of years could not be examined. This is a property we will investigate

during the *treatment period* on the Uncompahgre Plateau puma study. Moreover, we will directly evaluate to what extent puma harvest might be influenced by hunter selection. A hunter survey is intended to reveal puma hunter behavior, detection of different classes of pumas, and lack of or presence of hunter selection. These data should allow us to examine the credibility of the assumption of non-selection by hunters and the robustness of this technique in gauging puma population dynamics relative to harvest.

We want to examine the usefulness of this approach in Colorado. CPW managers attempt to weight sport-harvest toward male pumas in GMUs with the stable-to-increasing population objective with an active educational program (i.e., mandatory hunter exam, brochure, workshops). Thus, there is a need to test assumptions associated with the Anderson and Lindzey (2005) method.

> **H_6:** No hunter selection is practiced so that the sex and age structure of pumas harvested by hunters in this population protected from hunting during a 5-year *reference period* and subsequently managed for stability or increase with conservative harvest levels will reflect the relative vulnerabilities to detection and capture with dogs during each year in the 5-year *treatment period* in this order from high to low vulnerabilities: subadult males, adult males, subadult females, adult females without cubs or with cubs >6 months old, and adult females with cubs ≤6 months old (Barnhurst 1986, Anderson and Lindzey 2005). In each of the 5 years of the *treatment period*, subadults and adult males should comprise the majority of the harvest and reflect the assumed sex and age structure (Anderson and Lindzey 2005) of a puma population managed for a stable to increasing phase and not hunted for 5 previous years (i.e., a puma population source).

Desired outcomes and management applications of this research include:

1. Quantification of variations in puma population density, sex and age structure, growth rates, vital rates, and an understanding of factors affecting them will aid adaptive puma management by yielding population parameters and tools useful for assessing puma population dynamics, evaluation of management alternatives, and effects of management prescriptions.
2. Testing assumptions about puma populations, currently used by CPW managers, will help managers to biologically support and adapt puma management based on Colorado-specific estimated puma population characteristics, parameters, and dynamics.
3. Methods for assessing puma population dynamics will allow managers to evaluate modeled populations and estimate effects of management prescriptions designed to achieve specified puma population objectives in targeted areas of Colorado. Ascertaining puma numbers and densities during the project will allow assessment of monitoring techniques. Potential methods include use of harvest sex and age structure and photographic and DNA genotype capture-recapture. Study plans to develop and test feasible field and analytical methods will be developed as we learn the logistics of performing those methods, after we have preliminary data on puma demographics and movements which will inform suitable sampling designs, and if we have adequate funding.
4. Information which will be disseminated to citizen stakeholders interested in pumas in Colorado, and thus contribute to informed public participation in puma management.

STUDY AREA

The study area for the puma population research is on the Uncompahgre Plateau (in Mesa, Montrose, Ouray, and San Miguel Counties; Fig. 2). The study area includes about 2,253 km^2 (870 $mi.^2$) of the southern halves of Game Management Units (GMUs) 61 and 62, and about 155 km^2 (60 $mi.^2$) of the northern edge of GMU 70 (between state highway 145 and San Miguel River). The area is bounded by state highway 348 at Delta, 25 Mesa road and Forest Service road FS503 to Nucla, state highway 97 to state highway 141 to state highway 145 to Placerville, state highway 62 to Ridgeway, U.S. highway 550 to Montrose, and U.S. highway 50 to Delta.

The study area seems typical of puma habitat in Colorado that has vegetation cover that varies from the pinion-juniper covered foothills starting from about 1,700 m elevation to the spruce-fir and aspen forests growing to the highest elevations of about 3,000 m. Mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) are the most abundant wild ungulates available for puma prey. Cattle and domestic sheep are raised on summer ranges on the study area. People reside year-round along the eastern and western fringe of the area, and there is a growing residential presence especially on the southern end of the plateau. A highly developed road system makes the study area easily accessible for puma research efforts. A detailed description of the Uncompahgre Plateau is in Pojar and Bowden (2004).

METHODS

Reference and Treatment Periods

This research was structured in two 5-year periods: a *reference period* (years 1—5) and a *treatment period* (years 6—10). The *reference period* was closed to puma hunting on the study area and was expected to cause a population increase phase. The *treatment period* (starting in November 2009) involves manipulation of the puma population with sport-hunting structured to achieve a management objective for a stable to increasing population. In both phases, puma population structure, and vital rates are being quantified, and management assumptions and hypotheses regarding population dynamics and effects of harvest are being tested. Contingent upon results of pilot studies, we will also assess enumeration methods for estimating puma population abundance.

The *reference period*, without recreational puma hunting as a major limiting factor, was consistent with the natural history of the current puma species in North America which evolved life history traits during the past 10,000 to 12,000 years (Culver et al. 2000) that enable pumas to survive and reproduce (Logan and Sweanor 2001). In contrast, puma hunting, with its modern intensity and ingenuity, might have influenced puma populations in western North America for at least the past 100 years. Hence, the *reference period*, years 1 to 5, provided conditions where individual pumas in this population expressed life history traits interacting with the environment without recreational hunting as a limiting factor. Theoretically, the main limiting factor was vulnerable prey abundance (Pierce et al. 2000, Logan and Sweanor 2001). This allowed researchers to understand basic system dynamics *before* manipulating the population with controlled recreational hunting. In the *reference period*, all pumas in the study area were protected, except for individual pumas involved in depredation on livestock or human safety incidents. In addition, all radio-collared and ear-tagged pumas that ranged in a buffer zone in the northern halves of GMUs 61 and 62 were protected from recreational hunting mortality.

The *reference period* allowed researchers to quantify baseline demographic data on the puma population to estimate parameters useful for assessing the CPW's assumptions for its model-based approach to puma management. The *reference period* also facilitated other operational needs (because hunters did not kill the animals) including the marking of a large proportion of the puma population for parameter estimates and gathering movement data from GPS-collared pumas.

During the *treatment period*, years 6 to10, recreational puma hunting is occurring on the same study area using management prescriptions structured from information learned during previous years. Using recreational hunting for the treatment is consistent with the CPW's objectives of manipulating natural tendencies of puma populations, particularly survival, to maintain either population stability or increase or suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, survival of independent pumas is being influenced mainly by recreational hunting, which is being quantified by agent-specific mortality rates of radio-collared pumas. Dynamics of the puma population are being manipulated to evaluate hypotheses that are related to effects of hunting (i.e., effects of harvest rates, relative vulnerability of puma sex and age classes to hunting, variations in puma population structure due to hunting). The killing of tagged and collared pumas during the *treatment period* is not hampering operational needs (as it would have during the start-up years), because a majority of independent pumas in the population have already been marked, and sampling methods formalized.

Pumas on the study area that may be involved in depredation of livestock or human safety incidences may be lethally controlled. Researchers that find that GPS-collared pumas have killed domestic livestock will record such incidents to facilitate reimbursement to the property owner for loss of the animal(s). In addition, researchers will notify the Area Manager of the CPW if they perceive that an individual puma may be a threat to public safety.

Field Methods

Puma Capture: Realizing that pumas live at low densities and capturing pumas is difficult, as a starting point, our logistical aim was to have a *minimum* of 6 puma in each of 6 categories (36 total) radio-tagged in any year of the study if those or greater numbers are present. The 6 categories are: adult female, adult male, subadult female, subadult male, female cub, male cub. Our aim was to provide more quantitative and precise estimates of puma demographics than were achieved in earlier Colorado puma studies. This relatively large number of pumas might represent the majority of the puma population on the study area, and would provide the basic data for age- and sex-specific reproductive rates, survival rates, agent-specific mortality rates, emigration, and other movement data.

Puma capture and handling procedures were approved by the CPW Animal Care and Use Committee (file #08-2004). All captured pumas were examined thoroughly to ascertain sex and describe physical condition and diagnostic markings. Ages of adult pumas were estimated initially by the gum-line recession method (Laundre et al. 2000) and dental characteristics of known-age puma (Logan and Sweanor, unpubl. data). Ages of subadult and cub pumas were estimated initially based on dental and physical characteristics of known-age pumas (Logan and Sweanor unpubl. data). Body measurements recorded for each puma included at a minimum: mass, pinna length, hind foot length, plantar pad dimensions. Tissue collections included: skin biopsy (from the pinna receiving the 6 mm biopsy punch for the ear-tags), and blood (30 ml from the saphenous or cephalic veins) for genotyping individuals, parentage and relatedness analyses, and disease screening; hair (from various body regions) for genotyping tests of field gathered samples. Universal Transverse Mercator Grid Coordinates on each captured puma were recorded via Global Positioning System (GPS, North American Datum 27).

Pumas were captured year-round using 4 methods: trained dogs, cage traps, foot-hold snares, and by hand (for small cubs). Capture efforts with dogs were conducted mainly during the winter when snow facilitated thorough searches for puma tracks and enabled dogs to follow puma scent. The study area was searched systematically multiple times per winter by four-wheel-drive trucks, all-terrain vehicles, snow-mobiles, and on foot. When puma tracks ≤1 day old were detected, trained dogs were released to pursue pumas for capture.

Pumas usually climbed trees to take refuge from the dogs. Adult and subadult pumas captured for the first time or requiring a change in telemetry collar were immobilized with Telazol (tiletamine hydrochloride/zolazepam hydrochloride) dosed at 5 mg/kg based on estimated body mass (Lisa Wolfe, DVM, CPW, attending veterinarian, pers. comm.). The immobilizing agent was delivered into the caudal thigh muscles via a Pneu-Dart® shot from a CO_2-powered pistol. Immediately, a 3m-by-3m square nylon net was deployed beneath the puma to catch it in case it fell from the tree. A researcher climbed the tree, fixed a Y-rope to two legs of the puma and lowered the cat to the ground with an attached climbing rope. Once the puma was on the ground, its head was covered, its legs tethered, and vital signs monitored (Logan et al. 1986). Normal signs include: pulse ~70 to 80 bpm, respiration ~20 bpm, capillary refill time ≤2 sec., rectal temperature ~101^{o}F average, range = 95 to 104^{o}F (Kreeger 1996). Pumas that climbed trees too dangerous for the pumas or researchers for capture were released without handling, or we encourage the animals to leave the tree by heaving snowballs toward them. If the pumas climbed a safe tree, then we handled them as described above.

A cage trap was used to capture adults, subadults, and large cubs when pumas were lured into the trap using road-killed or puma-killed ungulates (Sweanor et al. 2008). A cage trap was set only if a target puma scavenged on the lure (i.e., an unmarked puma, or a puma requiring a collar change). Researchers continuously monitored the set cage trap from about 1 km distance by using VHF beacons on the cage and door. Researchers handled captured pumas within 30 minutes of capture. Puma were immobilized with Telazol injected into the caudal thigh muscles with a pole syringe. Immobilized pumas were restrained and monitored as described previously. If non-target animals were caught in the cage trap, we opened the door and allowed the animal to leave the trap.

Small cubs (≤10 weeks old) were captured using our hands (covered with clean leather gloves) or with a capture pole. Cubs were restrained inside new burlap bags during the handling process and were not administered immobilizing drugs. Cubs at nurseries were approached when mothers were away from nurseries (as determined by radio-telemetry). Cubs captured at nurseries were removed from the nursery a distance of 30 to 100 m to minimize disturbance and human scent at nurseries. Immediately after handling processes were completed, cubs were returned to the exact nurseries where they were found (Logan and Sweanor 2001).

Marking, Global Positioning System- and Radio-telemetry: Pumas do not possess easily identifiable natural marking, such as tigers (see Karanth and Nichols 2002), therefore, the capture, marking, and GPS- or VHF- collaring of individual pumas was essential to a number of project objectives, including estimating numbers, vital rates, and gathering movement data relevant to population dynamics (i.e., emigration and movement across Data Analysis Unit boundaries). Adults, subadults, and cubs were marked 3 ways: GPS/VHF- or VHF-collar, ear-tag, and tattoo. The identification number tattooed in the pinna was permanent and could not be lost unless the pinna was severed. A colored (bright yellow or orange), numbered rectangular (5 cm x 1.5 cm) ear-tag (Allflex USA, Inc., DFW Airport, TX) was inserted into each pinna to facilitate individual identification during direct recaptures. Cubs ≤10 weeks old were ear-tagged in only one pinna.

Adult and subadult female pumas were fitted with GPS collars (approximately 400 g each, Lotek Wireless, Canada) if available. Initially, GPS-collars were programmed to fix and store puma locations at 4 times per day to sample daytime, nighttime, and crepuscular locations (i.e., 0:00, 06:00, 12:00, 19:00). GPS locations for pumas provided precise, quantitative data on movements to assess the relevance of puma DAU boundaries, our search efforts, and to evaluate puma behavior and social structure. The GPS-collars also provided basic information on puma movements and locations to design other pilot studies in this program on vulnerability of puma to sport-harvest, habitat use, and enumeration methods (e.g., photographic or DNA mark-recapture).

Subadult male pumas were fitted initially with conventional VHF collars (Lotek, LMRT-3, ~400 g each) with expansion joints fastened to the collars, which allowed the collar to expand to the average adult male neck circumference (~46 cm). If subadult male pumas reached adulthood on the study area, we would recapture them and fit them with GPS collars. In addition, other adult and female subadult pumas were fitted with VHF collars when GPS collars were not available.

VHF radio transmitters on GPS collars enabled researchers to find those pumas on the ground in real time to acquire remote GPS data reports, facilitate recaptures for re-collaring, and to determine their reproductive and survival status. VHF transmitters on GPS- and VHF-collars had a mortality mode set to alert researchers when pumas were immobile for 3 to 24 hours so that dead pumas could be found to quantify survival rates and agent-specific mortality rates by gender and age. Locations of GPS- and VHF-collared pumas were identified about once per week (as flight schedules and weather allowed) from light fixed-wing aircraft (e.g., Cessna 185) fitted with radio signal receiving equipment (Logan and Sweanor 2001). GPS- and VHF-collared pumas were located from the ground opportunistically using a hand-held yagi antenna. At least 3 bearings on peak aural signals were mapped to fix locations and estimate location error around those locations (Logan and Sweanor 2001). Aerial and ground locations were plotted on 7.5 minute USGS maps (NAD 27) and UTMs along with location attributes were recorded on standard forms. GPS and aerial locations were mapped using GIS software.

We attempted to collar all cubs in observed litters. Cubs were fit with small VHF transmitters mounted on expandable collars that expand to adult neck size (Wildlife Materials, Murphysboro, Illinois, HLPM-2160, 47g, Telonics, Inc., Mesa, Arizona MOD 080, 62g, or Telonics MOD 205, 90g,) when cubs weighed 2.3–11 kg (5–25 lb). Cubs could wear these small expandable collars until they were over 12 months old. Cubs were recaptured to replace collars as opportunities allowed. Monitoring radio-collared cubs allowed quantification of survival rates and agent-specific mortality rates (Logan and Sweanor 2001).

Analytical Methods

Population characteristics each year were tabulated with the number of individuals in each sex and age category. Age categories, as mentioned, include: adult (puma ≥24 months old, or younger breeders), subadults (young puma independent of mothers, <24 months old that do not breed), cubs (young dependent on mothers, also called kittens) (Logan and Sweanor 2001). When data allowed, age categories were further partitioned into months or years.

Reproductive Rates: Reproductive rates were estimated for GPS- and VHF-collared female pumas directly (Logan and Sweanor 2001). Genetic paternity analysis will be used to ascertain paternity for adult male pumas (Murphy et al. 1998).

Survival and Agent-specific Mortality Rates: Radio-collared pumas provided known fate data used to estimate survival rates for each age stage using the Kaplan-Meier procedure to staggered entry (Pollock et al. 1989). A binomial survival model was also used for crude estimates of survival during the subadult age stage (Williams et al. 2001:343-344). In addition, when data collection is complete, survival rates will be modeled in program MARK (White and Burnham 1999, Cooch and White 2004) where effects of individual (e.g., sex, age stage, reproductive stage) and temporal (i.e., *reference period*, *treatment period*) covariates to survival can be examined. Agent-specific mortality rates can also be analyzed using proportions and Trent and Rongstad procedures (Micromort software, Heisey and Fuller 1985).

Population Inventory: The population of interest was independent pumas (i.e., adults and subadults) mainly during November to March which corresponds with the Colorado puma hunting season. Independent pumas were those that could be legally killed by recreational hunters. Initially, we estimated the *minimum* number of independent pumas and puma density (i.e., number of independent puma/100 km^2) each winter. The *minimum* number of independent pumas included all marked pumas known to be present on the study area during the period, plus individuals thought to be non-marked and detected by visual observation or tracks that were separated from locations of radio-collared pumas. Furthermore, adults comprised the breeding segment of the population and subadults were non-breeders that are potential recruits into the adult population in ≤1 year.The sampling unit was the individual independent puma (~≥1 yr. old).

Puma Population Dynamics: A deterministic, discrete time model parameterized with population characteristics and vital rates from this research was used to assess puma population dynamics (Logan 2008).

<u>Functional Relationships</u>: Once data collection is complete, a variety of analyses will be conducted to estimate parameters and examine functional relationships. Graphical methods will be used to initially examine functional relationships among puma population parameters. Linear regression procedures and coefficients of determination will be used to assess functional relationships if data for the response variable are normally distributed and the variance is the same at each level. If the relationship is not linear, data is non-normal, and variances are unequal, we will consider appropriate transformations of the data for regression procedures (Ott 1993). Non-parametric correlation methods, such as Spearman's rank correlation coefficient, will also be used where appropriate to test for monotonic relationships between puma abundance and other parameters of interest (Conover 1999). Relationships of explanatory variables to survival parameters will be modeled in MARK. Statistical analyses can be performed in a variety of software (e.g., SYSTAT, R, and MARK).

RESULTS AND DISCUSSION

<u>Segment Objective 1</u>

<u>*Puma harvest:*</u> This biological year, August 2012 to July 2013, was the fourth year of the *treatment period* (TY4) in this study of puma population dynamics on the Uncompahgre Plateau. The hunting season on the study area began on November 19, 2012 and was scheduled to extend to January 31, 2013, unless the harvest quota was taken before then. The harvest design quota was 5 pumas. This represented an 11.1% harvest of the projected minimum number of 45 independent pumas expected on the study area during November through March in TY4 (Logan 2012). The expected number of 45 was derived with a simple linear model that regressed the number of independent pumas observed in TY1 (55), TY2 (52, and TY3 (48) on year and projected to TY4 (i.e., 45 expected). We reduced the harvest rate because the population of independent pumas was declining during TY1 to TY3, contrary to the expected population trend in this research project and the realization that the population would probably continue to decline with a 15% harvest rate. This harvest design still tests the CPW's current assumption that total mortality (i.e., harvest plus other natural deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (Assumption and Hypothesis 3 p.5-6 this report). The 11% harvest in TY4 is in the middle of the 8 to 15% harvest range we are testing. The initial quota of 8 pumas for TY1, TY2, and TY3 was based on the projected minimum number of 53 independent pumas expected on the study area in winter 2009-10, modeled from a *minimum count* of pumas during winter 2007-08 (Table 1; Logan 2010). The quota of 8 pumas for TY3 was based on the observed *minimum count* of 52 independent pumas during November 2010 to April 2011 in TY2 and that approximately the same number of independent pumas was expected during the puma hunting season for TY3.

The hunting structure in TY4 was the same as in TY1 to TY3, except for the reduction in quota (see above). The number of puma hunters on the study area was not limited. Each hunter on the study area was required to obtain a hunting permit from the CPW Montrose Service Center. Permits were free and unlimited. Each permit allowed the individual hunter with a legal puma hunting license in Colorado to hunt in the puma study area for up to 14 days from the issue date. Unsuccessful hunters that wanted to continue hunting past the permit expiration date requested a new permit for another 14 days, or until the hunter killed a puma within the season, or the season on the study area closed due to the quota being reached, or the end of the hunting season. This permit system allowed the CPW to monitor the number of hunters on the study area and to contact each hunter for survey information (see later in this section).

All pumas harvested on the study area were examined by principal investigator K. Logan or a wildlife research technician and sealed as mandated by Colorado statute. All successful hunters reported their puma kill and presented the puma carcass for inspection by CPW within 48 hours of harvest. Upon inspection, the following data were recorded: sex, age, and location of harvest. In addition, an upper premolar tooth was collected for aging (i.e., mandatory) and a tissue sample was collected for DNA genotyping. Each successful hunter was also asked at that time to complete a one-page hunter survey form. All other hunters that did not report a puma kill on the study area were asked to complete the survey form and return it in a stamped envelope that was provided.

The puma hunting season occurred on the study area from November 19 to December 29, 2012, taking 41 days to fill the quota of 5 pumas; the longest hunting season yet on the study area during this *treatment period*. This was 8 more days than it took to harvest 8 pumas in TY3 (i.e., 33 days, Nov. 21 to Dec. 23, 2011), 20 days more than it took to harvest 8 pumas in TY2 (i.e., 21 days, Nov. 22 to Dec. 12, 2010) and 15 more days than it took to harvest 8 pumas in TY1 (i.e., 26 days, Nov. 16 to Dec. 11, 2009).

Five pumas were killed on the study area, including: 2 adult females, 2 adult males, and 1 subadult male (Table 2). Of the 5 harvested pumas, 3 were marked: F152, M156 and M179. In addition to the pumas killed on the study area during the Colorado puma hunting season, 4 other marked independent pumas died (Table 3): adult female F93 was killed by another puma on the study area, and 3 pumas were killed by hunters on adjacent GMUs, including subadult female F149 (GMU 70), adult female F177 (GMU 65) and adult male M178 (GMU 65). All these pumas were included in the *minimum count* of pumas for TY4 because they were initially captured on the study area and were present in the population during the TY4 survey period (Nov.–Apr.).

The harvest of 5 independent pumas on the study area was 11.9% (5/42*100) of the *minimum count* of 42 independent pumas counted on the study area, including 31 females and 11 males, determined by the research team during November 2012 to April 2013 (Table 4). Independent females and males comprised 40.0% (2/5*100) and 60.0% (3/5*100) of the harvest, respectively. This harvest structure was 6.4% (2/31*100) of the independent females and 27.3% (3/11*100) of the independent males.

Considering the mortality of 4 other radio-collared independent pumas (F93, F149, F177, M178; Table 3), the mortality of 9 independent pumas was 21.4% (9/42*100) of the *minimum* number of 42 independent pumas. The mortality composition of 5 females and 4 males was comprised of 55.6% (5/9*100) females and 44.4% (4/9*100) males. This harvest structure was 16.1% (5/31*100) of the independent females and 36.4% (4/11*100) of the independent males in the *minimum count*.

The *minimum count* of 42 independent pumas in TY4 was lower than the minimum count of 48 independent pumas in TY3, 52 independent pumas in TY2, and 55 in TY1 (Table 4) and indicates a consistently declining population (Fig.3.). The population decline is explained mainly by the declining number of independent male pumas (Table 4) and the relatively low adult male survival rates (see Table 15, later). The number of adult females have also declined, but to a lesser extent (Table 4).

<u>Hunter permits and survey:</u> In TY4 mandatory permits with the voluntary survey attached were requested by 70 individual puma hunters. This number is slightly down from 74 in TY3, up from 64 hunters in TY2, and down from 79 hunters in TY1. Twenty-three of the hunters requested a second permit, 7 hunters requested a third permit, and zero hunters requested a fourth permit after a previous permit expired after 14 days. Forty-two hunters (60.0%; 42/70*100) provided responses to the voluntary survey by turning in the printed survey. Of the respondents, 18 hunters indicated that they did not hunt on the study area. The proportion of the 42 respondents that hunted extrapolated to the total of 70 hunters (24/42 = 0.571) indicated that about 40 hunters took to the field for pumas on the study area during the 41-day TY4 hunting season. This was down from 49 hunters in TY3, 42 hunters in TY2 and 67 hunters in TY1 (Logan 2010, 2011). Considering that 40 hunters were estimated to be afield, then 12.5% of the hunters harvested pumas (5/40*100) and 15.0% of hunters captured pumas (6/40*100; see captured and released pumas below and in Table 5).

The 42 puma hunters that turned in the written volunteer survey were asked to answer, “Do you consider yourself a *selective* or *non-selective* hunter?” A *selective* hunter is one that purposely is hunting for a specific type of legal puma, such as a male, large male or large female. A *non-selective* hunter is one that intends to take whatever legal puma is first encountered or caught, with no desire for sex or size. *Selective* hunter was indicated by 20 respondents that answered the question (83.3%; 20/24 = 0.833). Of the remaining hunters, 4 indicated they were non-selective (16.7%). Eighteen hunters that returned surveys did not answer the question. The voluntary hunter survey also revealed that one hunter treed a puma on the study area, but chose not to kill it (Table 5). The hunter reported he treed a puma he believed to be a female. But his description of a yellow ear-tag in the puma indicated that it was instead a subadult male. The hunter’s reason for not wanting to kill the puma was he did not want to kill a female puma.

In an effort to better ascertain the vulnerability of sexes and age-stages (i.e., adult, subadult) of independent pumas to detection by puma hunters and hunter selection to address assumption 6 and hypothesis 6 (previously), the survey was changed in TY2 to ask hunters, “What was the sex of the lion that made the first set of tracks you encountered that were less than one day old?”. This question pertained to pumas that could be pursued by dogs and captured with a relatively high probability to allow the hunter an opportunity to harvest the puma. Associated with the question, we asked, “Did you pursue the lion to harvest it?” Hunters’ responses in TY4 showed they encountered 19 puma tracks less than one day old. Of those, 8 tracks were of females, and 11 tracks were of males, indicating that during the TY4 hunting season males were more detectable than females even though independent females outnumbered independent males by 31 females and 11 males based on the *minimum count* (Table 4). In comparison with the previous 2 treatment years (these data were not gathered in the survey for TY1) tracks < 1 day old reported by puma hunters consistently favored females (TY2: 20 female, 10 male; TY3: 15 female, 6 male).

Of the 8 female tracks less than one day old, 7 hunters that encountered them said they had no intent to harvest the puma and one hunter did not indicate his intent. Of the 11 male tracks less than one day old, 10 of the hunters that encountered them indicated intent to harvest the pumas and in fact did harvest 3 of them. One hunter did not pursue the male puma with intent to harvest it.

These preliminary survey and harvest data for TY4 indicate that hunters detected independent male pumas more frequently than females and males were captured by hunters more frequently than females by 2 to 1 (i.e., males = 3 harvested + 1 captured and released; females = 2 harvested). Moreover, hunters were choosing to kill males more frequently than females. Results in TY4 indicated selection for male pumas by hunters was consistent with TY1, TY2, and TY3 results, except in those 3 previous treatment years hunters caught females slightly more frequently than males, and males were selected for harvest. This preliminary assessment from years TY1, TY2, TY3, and TY4 puma harvest and hunter survey data suggests that female pumas were detected by hunters more frequently than male pumas, except for TY4, the large majority of puma hunters were selective, and hunter choices influenced harvest sex and age composition.

Segment Objective 2

After the harvest quota was filled, puma research teams immediately initiated capture operations with trained dogs. Two fully-staffed capture teams, one each detailed on the east and west slopes of the study area, systematically and thoroughly searched the study area to capture, sample, and GPS/VHF radio-collar pumas the remainder of winter and early spring 2012-13. These efforts along with cage trap efforts and hand-capturing cubs at nurseries maintained samples to quantify population sex and age structure, survival, and agent-specific mortality, and allowed determination of *minimum* population size on the study area during November to April.

We made 62 puma captures of 49 individuals from August 2012 to July 2013 (Tables 6-11); 29 individual pumas were captured with dogs 42 times. Seven pumas were captured in cage traps. Thirteen cubs were captured at nurseries by hand. A total of 55 individual pumas were monitored with radio-telemetry from August 2012 to July 2013 (some of these had been collared in previous years), representing sex and age classes including: 19 adult females, 8 adult males, 5 subadult females, 2 subadult males, and 21 cubs (i.e., the 2 subadult males survived to adult age during the biological year).

Trained dogs were used as our main method to capture, sample, and mark pumas from January 1, 2013 to April 18, 2013. Those efforts resulted in 74 search days, 229 total puma tracks detected of which 125 were ≤1 day old, 82 pursuits, and a total of 42 puma captures of 29 individual pumas (Table 6). Search days with dogs in TY4 (74) were slightly lower than TY3 (79 days) and lower than TY1 (86 days) and TY2 (81 days)(Table 12). The frequency of tracks (tracks/day) encountered in TY4 was equivalent to TY1 and lower than TY2 and TY3. The number of pursuits in TY4 was 7 less than TY3 was 17 less than in TY2 and 11 less than in TY1. The capture rate in TY4 was substantially higher than TY1 and TY3 but somewhat less than TY2. The number of new pumas captured for the first time in TY4 was 3 higher than TY1, 3 lower than TY2 and 1 more than TY3 (Table 12).

Researchers in the two hound capture teams also recorded instances when the *first* tracks ≤1 day old of independent pumas were encountered on each search route each day to represent encounters with puma tracks that could be detected and pursued by puma hunters. The count was: 46 tracks of females, including 9 associated with cubs; 23 tracks of males; and 1 track of unspecified sex. These tracks ≤ 1 day old were found after the TY4 puma hunting season when 4 independent females and 4 independent males were harvested (Tables 2 and 3). Therefore, the harvested pumas were not present to make tracks for our researchers to observe. By comparison, the number of *first* tracks <1 day hunters reported by puma hunters in TY4 was 8 females and 11 males (Segment Objective 1 above).

Puma capture efforts using ungulate carcasses and cage traps occurred from September 18, 2012 to May 22, 2013 with the main efforts in the fall and spring (Table 10). We used 50 road-killed mule deer and one road-killed elk at 28 different sites. Two adult females (F176, F177), 2 adult males (M178, M179, 1 subadult female (F186), and 1 cub (F186 were captured for the first time. Two adult females (F93, F95) were recaptured and re-collared. Pumas scavenged at 12 of 51 (23.53%) of the ungulate carcasses used for bait. Pumas sometimes walked past the ungulate baits but did not feed (Table 10).

We sampled 23 new cubs, including 12 females and 11 males (Table 11). All except 2 were radio-collared to monitor survival and agent-specific mortality (Appendix A). One non-marked female cub (PF1062) climbed an electrical utility pole and was electrocuted on 12/18/2012. A previously non-marked cub (PM1068) was found dead, killed and partially consumed by a male puma; the same fate that befell his sibling M191.

Besides our direct puma captures with dogs January through April, we detected 10 radio-collared pumas that we were able to identify with GPS or VHF telemetry 12 times, thus, negating the need to capture those pumas directly with dogs (Table 6). Upon detecting puma tracks that were aged at ≤1 day old, we followed the tracks with a radio receiver in an effort to detect if the tracks might be of a puma wearing a functional collar. We assigned tracks to a collared individual if we received radio signals from a puma that we judged to be <1 km from the tracks and in direction of travel of the tracks. This approach allowed us to more efficiently allocate our capture efforts toward pumas of unknown identity on the study area, particularly unmarked pumas or pumas with non-functioning GPS- or VHF- radiocollars.

In addition to the harvest and capture data (previously), our search efforts revealed the presence of at least 22 other pumas which we included in our *minimum count* November 2012 through April 2013 (Table 4). We classified those pumas as: 7 adult females, 2 adult males, 1 subadult female, and 12 cubs.

Three adult females, 1 adult male and 1 cub were treed by our hounds, but we could not handle the pumas because they climbed dangerous trees (Table 8). Four of those were bio-darted for genotyping. Also, 1 cub jumped from a tree and was briefly caught by dogs (P1073). We collected a hair sample from it. We collected tissue samples from 1 cub that was electrocuted (previously), 1 cub killed and partially eaten by a male puma, and 1 subadult female shot by a bobcat hunter (Table 8). We could separate the activity of the other pumas from the GPS- and VHF- collared pumas in time, space, and track size differences between females, males, and numbers of cubs with females. Also, 1 non-marked adult male was photographed by a digital trail camera while consorting with 2 adult GPS-collared females (F136, F182) at the same time.

Our search and capture efforts during January through April 2013 and information from the puma hunting season in TY4 enabled us to quantify a *minimum count* of 42 independent pumas detected on the Uncompahgre Plateau study area, including 31 independent females and 11 independent males (Table 4). This count was based on the number of known radio-collared pumas, non-marked pumas killed by hunters on the study area, observations of marked and non-marked pumas observed by researchers or pursued, treed and released by hunters on the study area, and puma tracks observed by researchers that could not be attributed to pumas with functioning radiocollars. Of the 42 independent pumas, 29 (69.0%) were marked and 13 (31.0%) were assumed to be non-marked animals (i.e., some may have ear-tags and tattoos). Our observed *minimum count* of 42 independent pumas for TY4 was close to the expected model projected 45 independent pumas that we used to reset the harvest quota for TY4 (see Segment Objective 1, *Puma harvest*).

The abundance was higher on the east slope of the study area compared to the west slope. But the sex structure of independent pumas on the east and west slopes was similar. The east slope count included 24 independent pumas (18 females, 6 males). The west slope count included 18 independent pumas (13 females, 5 males). A decline in the study area puma population was most evident on the west slope. Considering the *minimum count* of 42 independent pumas in TY4, a preliminary *minimum* density for the winter puma habitat area estimated at 1,671 km^2 on the Uncompahgre Plateau study area was 2.51 independent pumas/100 km^2.

The TY4 *minimum count* of 42 independent pumas is lower than the 3 previous treatment years TY1, TY2, and TY3, which indicated a steadily declining trend in the puma population on the Uncompahgre Plateau study area (Fig. 3). The declining trend was further reflected by declining survival rates of adult pumas on the study area (see Segment Objective 4&5 below). The major cause of death in the independent pumas was sport-hunting mortality (Logan 2010, 2011, 2012, this report).

The estimated age structure of independent pumas in November 2012 at the beginning of the puma hunting season in TY4 on the Uncompahgre Plateau study area is depicted in Figure 4. The male age structure has declined when compared with TY1, TY2, and TY3 (Logan 2010, 2011, 2012) with the oldest males about 4 years old. The female age structure is also distributed to the younger ages with a few reaching 9 or 10 years (Logan 2010, 2011). In addition to the independent pumas, we counted a minimum of 24 cubs in TY4 (Table 4).

Segment Objective 3

During the past 8.7 years of this work we compiled data on puma reproduction that was not previously available on pumas in Colorado (Table 13). Puma reproduction data (i.e., litter size, sex structure, gestation, birth interval, proportion of females giving birth per year) were summarized for the *reference period* in Logan (2009). In TY4 we directly observed 6 litters in nurseries of which 1 was born in May, 2 in June, 2 in July, and 1 in August (Table 11), each with 1 to 3 cubs born to radio-collared females. Data on reproduction we observed in TY1, TY2, TY3, and TY4 were added to Table 13 which gives the reproductive chronology and information on mates (if known) of reproducing females. Those data will not be summarized again until the end of the *treatment period*. The proportion of radio-collared adult females giving birth from August 2012 to July 2013 biological year (TY4) was 0.53 (8/15). For the previous 3 treatment years the proportion was TY1=0.53 (8/15), TY2=0.53 (9/17), and TY3=0.29 (5/17).

Considering our 53 total litters from 27 females, including 51 observed with cubs 26 to 42 days old and 2 other litters confirmed by nurseries and nursling cub tracks with GPS-collared females (the latter include F111's cubs caught later when 8.5 months old) (Table 13), the distribution of puma births by month from 2005 to 2013 indicate births extending from March into September (Fig. 5). Births are high in May and June, peak in July, high in August and decline in September. Births during late spring to late summer (May to August) involve 84.9% (45/53*100) of the births (Fig. 5). The data indicate that the large majority of puma breeding activity occurred February through May (i.e., gestation averages about 90-92 days, Logan 2009). In comparison, Anderson et al. (1992:47-48) found on the Uncompahgre Plateau during 1982-1987 that of 10 puma birth dates 7 were during July, August, and September, 2 in October, and 1 in December, with most breeding occurring April through June. The 2 data sets indicated puma births on the Uncompahgre Plateau have occurred in every month except January and November (so far). As we gather more data on the puma births during the *treatment period*, we will examine the distributions of births in the *reference* and *treatment periods* separately for a treatment effect on timing of breeding and births.

Segment Objectives 4 & 5

From December 8, 2004 (capture and collaring of the first adult puma M1) to July 31, 2013, we radio-monitored 28 adult male and 42 adult female pumas to quantify survival and agent-specific mortality rates (Table 14). Survival and agent-specific mortality of adult pumas were summarized for the *reference period* in Logan (2009). Preliminary estimates of adult puma survival rates in the absence of sport-hunting during the *reference period* indicated high survival, with adult male survival generally higher than adult female survival (Table 15).

We monitored 19 adult females and 8 adult males for annual survival and agent-specific mortality in TY4. Annual survival rate for adult females was 0.819 (*SE*=0.0931) and for males was 0.188 (*SE*=0.0845). Preliminary adult puma survival for TY1, TY2, and TY3 are also shown in Table 15. So far, adult male survival is substantially lower in the *treatment period* than in the *reference period.* Adult female survival is lower in TY1 and TY3, with marked decline in TY3. Yet, female survival is generally higher than male survival. These characteristics are indicative of hunter selection for male pumas (previously in Segment Objective 1). The lower adult puma survival rates, particularly of males, were consistent with an observed decline in the puma population on the study area (see Segment Objective 2, previously).

Human-related factors caused 4 deaths of radio-marked adult pumas in TY4, including: sport-hunting harvest (2 males- M178, M179; 2 females- F152, F177) (Tables 2, 3, 14). In addition, 1 adult female puma died of natural causes: F93 was killed by another puma (Table 14).

We have information on 35 subadult pumas (i.e., independent pumas <24 months old), including 14 females and 21 males (Table 16). We lost radio contact with 2 male and 2 females that probably dispersed from the study area unknown distances. Of the remaining 31 subadults (females and males combined), 8 (3 females, 5 males) died before reaching adulthood, indicating a rough preliminary binomial survival rate of 0.74 (i.e., 23/31) for subadults surviving to the adult age stage (i.e., 24 mo. old). Of the 8 subadults that died, 4 deaths were from natural causes, 3 were from sport-hunting, and 1 was from a vehicle strike (Table 16).We need to increase our efforts to acquire larger samples of male and female radio-monitored subadult pumas to acquire more reliable estimates of their survival.

Harvest data along with our capture and radiotelemetry data provided dispersal and fate information on 38 marked pumas, 29 males and 9 females. Of those, 28 (4 females, 24 males) were initially captured and marked as cubs, and 10 (5 females, 5 males) were captured and marked in the subadult life-stage on the Uncompahgre Plateau puma study area (Table 17). Twenty-three males were killed by hunters away from the study area at linear distances (i.e., from initial capture sites to kill sites) ranging from about 20 to 370 km. Two males with extreme moves were killed in the Snowy Range of southeastern Wyoming (369.6 km) and the Cimarron Range of north-central New Mexico (329.8 km). One male was killed by a hunter on the study area 12.9 km from his original capture site. Four females were killed by puma hunters off the study area ranging from 20.7 to 74.5 km from initial capture sites. One female was killed by a hunter on the study area 18.2 km from her initial capture site. Female F52 was treed and released by hunters in December 2008 and 2009 south of Powderhorn, Colorado, indicating that she established an adult home range there before she was killed by a puma hunter in that area on Jan. 9, 2012. Three males (M67, M87, M92) that were marked initially as cubs born on the east slope of the study area, dispersed from their natal ranges and were recaptured as adults on the west slope of the study area. Two of those (M67, M87) were killed on their adult territories by hunters. One (M92) is of unknown fate as of July 2013.

A preliminary estimate of cub survival during the *reference period* was summarized in Logan 2009 using 36 radio-collared cubs (16 males, 20 females) marked at nurseries when they were 26 to 42 days old. In that summary, estimated survival of cubs to one year of age was 0.53. [The estimated minimum survival rate using the Kaplan-Meier procedure was 0.5285 (SE = 0.1623). The maximum estimated cub survival was practically the same, 0.5328 (SE = 0.1629).] The major natural cause of death in cubs, where cause could be determined, was infanticide and cannibalism by other, especially male, pumas.

In TY4 we monitored the fates of 21 radio-collared cubs (Table 11, Appendix A). We lost contact with 2 (F185, F195) after they shed their expandable radio-collars prematurely. Of the remaining 19 collared cubs, 7 died and 1 was orphaned and removed from the wild to be rehabilitated to the subadult stage. One non-marked cub in association with a radio-collared cub was also found dead. Eight cubs from 3 litters (1 of those litters with the radio-collared and a non-collared cub) died from infanticide and cannibalism by male pumas. One cub (M175) died when it was apparently mauled by puma-hunting dogs. Later his mother (F152) was killed by a puma hunter. Her death orphaned the remaining cub (M174) and he was recaptured and removed from the wild to be rehabilitated at the CPW Wildlife Rehabilitation Center in Del Norte, Colorado. Of the 11 remaining live radio-collared cubs 4 survived to the subadult stage and 7 were being monitored in association with their mothers as of July 31, 2013. A greater number of cubs over a longer period of time must be sampled before estimating cub survival and agent-specific mortality rates in the *treatment period*.

Subadult male puma M161 was struck and killed by a vehicle on state highway 62 at Dallas Divide on the south boundary of the study area in October 2012 (Tables 17, 18, Appendix A). This mortality made the fifteenth puma death recorded due to vehicle collision on the study area since 2004 (Table 18). Six of the 15 pumas were marked, including 3 adults with GPS/VHF collars. Those 3 adults died during the first year of the *treatment period*.

Forty-five adult pumas (33 females, 12 males) have worn GPS collars since this project began in 2004 (Table 19). Over 70 thousand GPS locations have been obtained and will be used for studies on puma behavior, social organization, population dynamics, population genetics, movements, population survey methods, habitat use and puma-human relations in collaboration with colleagues in Mammals Research, Colorado State University, and Arizona State University.

Segment Objective 6

We continued to explore non-invasive methods for sampling pumas to estimate abundance by collaborating with Dr. Mat Alldredge (Mammals Researcher, CPW) and Master of Science graduate student Kirstie Yeager, Colorado Cooperative Fish and Wildlife Research Unit and Colorado State University. Here only a brief summary will be presented. M.S. student Kirstie Yeager is currently in the process of analyzing data. For a detailed report refer to Yeager (2013).

A grid of 2 km x 2 km (4 sq. km) cells was established on the east slope of the Uncompahgre Plateau study area (Fig. 6). Eighteen cells were identified randomly for each of 3 survey periods each lasting about 28 days. A total of 54 random cells were surveyed during December 2012 to March 2013. Within each random cell M.S. student Kirstie Yeager subjectively chose the "best" site to attract pumas by using vocal baits each consisting of a Fur-Finder ® (Magna, UT) electronic predator call of a distressed deer fawn. Each site also had a Reconyx ® (Holmen, WI) PC900 Hyperfire camera to record animal activity and hair-sampling devices (i.e., barbed-wire strands, sticky rollers) to attempt to acquire hair. This was an effort to evaluate these methods for a non-invasive survey of puma abundance by using tissue to genetically identify individuals in a mark-recapture structure.

During the survey spanning December 2012 to March 2013 eleven GPS and VHF collared pumas were known to use the survey grid for varying amounts of time, including 7 adult females, 1 subadult female, 2 adult males, and 1 subadult male. During the survey a total of 18 photographs of pumas visiting the sites were acquired, and all 18 of the photographs depicted GPS or VHF collared pumas. No non-collared pumas were photographed. Of the 11 collared pumas known to use the grid, at least 7 of them were photographed 1 to 4 times each, including 5 adult females, 1 subadult female, and 1 subadult male. Probability of detecting the 11 collared pumas available during the entire survey time was 0.64 (p = 7/11). Six hair samples were acquired from 4 to 5 individual pumas. The quality of the tissues for accurate genotypes of the individual will be determined by K. Yeager later by comparing with genotypes derived from skin and hair samples acquired from the individual pumas at capture and handling events.

SUMMARY

Manipulative, long-term research on puma population dynamics, effects of sport-hunting, and development and testing of puma enumeration methods began in December 2004. After 8.7 years of effort 202 unique pumas have been captured, sampled, marked, and released. Using these animals, we monitored fates of pumas in all sexes and age stages, including: 42 adult females, 28 adult males, 14 subadult females, 21 subadult males, 56 female cubs, 82 male cubs, and 1 cub of undetermined sex (some individuals occur in more than one stage class). Data from marked animals were used to quantify puma population characteristics and vital rates in a *reference period* without sport-hunting off-take as a mortality factor from December 2004 to July 2009. Puma population characteristics and vital rates in a reference condition allowed us to develop a puma population model, and to use population data and modeling scenarios to conduct a preliminary assessment of CPW puma management assumptions and guide directions for the remainder of the puma research on the Uncompahgre Plateau. Moreover, our data and model provide tools currently useful to CPW wildlife biologists and managers for assessing puma harvest strategies. The 5-year *treatment period* began August 2009 in which sport-hunting is a mortality factor. The *treatment period* will be a population-wide test of CPW puma management assumptions. Now 4 years of the *treatment period* are complete (TY1, TY2, TY3, TY4). Although data support some CPW puma management assumptions (e.g., population structure, density, how sport-harvest can cause population decline), it is still too early in this research to adequately test all the assumptions and attendant hypotheses. Although the assumption and hypothesis on harvest structure and hunter selection is not supported with the first 4 years of data in the *treatment period*, this could change with a substantial change in abundance and sex structure of independent pumas available for hunting in TY5. The puma harvest quota for TY5 is recommended to be 5 independent pumas to align with the research design and harvest objective, and the hunters will be surveyed again. Since the beginning of this study 2 efforts have been made to develop and test non-invasive methods for estimating puma abundance. These efforts were in collaboration with Colorado State University in a Ph.D. program (Jesse Lewis) and a M.S. program (Kirstie Yeager). To improve data on puma population vital rates, attention will be given to increasing radio-collared sample sizes across the various life stages and sexes. Furthermore, we will continue collaboration with colleagues on investigations of puma population parameter estimation, population genetics, puma movements, puma habitat modeling and mapping, puma-human relations, and disease prevalence. All of these efforts should enhance the Colorado puma research and management programs.

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Table 1. Projected puma population growth modeled from a *minimum count* of independent pumas during winter 2007-08 *reference period* year 4 (RY4). *Treatment period* year 1 (TY1), shaded in gray, indicates the results used to derive a quota of 8 independent pumas, representing 15% of the independent pumas (from Logan 2009).

		Projected Minimum Puma Population Size					**Independent Pumas**	
		Adult		**Subadult**				
Harvest Level	**Year**	**Female**	**Male**	**Female**	**Male**	**Cub**	**Total**	**Lambda**
No harvest.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	23	14	8	8	42	53	1.17

Table 2. Pumas harvested by sport-hunters in Treatment Year 4 (TY4) on the Uncompahgre Plateau Study Area, Colorado, November 19 to December 29, 2012.

Puma sex	**Age (yr.)**	**Previous M/F I.D. or specimen P no. if not marked**	**Date of kill**	**Location/UTM NAD27 Zone, Easting, Northing**	**Hunter/status**
F	2.5	P1058	12/10/2012	12, 756299, 4250598	Mark Rackay/resident
M	1.5	M156	12/10/2012	12, 753851, 4249709	Dustin Gleason/resident
M	2.5	P1066	12/21/2012	12, 741039, 4236392	Mia Enstrom/resident
F	2.5	F152	12/23/2012	13, 239123, 4248299	Jared Roberts/resident
M	2.5	M179	12/29/2012	12, 759988, 4250158	Gary Gleason/resident

Table 3. Four other independent VHF/GPS-collared pumas in the *minimum count* November 2012 to April 2013 (TY4) for the Uncompahgre Plateau Study Area that also died during November to April 2012-2013 period coinciding with the Colorado puma hunting season.

Puma sex (M or F)	**Age (yr.)**	**Date of kill/death**	**Place of kill/UTM NAD27 Zone, Easting, Northing**	**Hunter/status/other cause**
F93	11	11/11/2012	Linscott Canyon on study area 12, 761904, 4253939	Killed by another puma
F149	1.7	12/31/2012	GMU 70W, Dry Creek, south of Naturita, CO 12, 713658, 4229703	Duane Pool/non-resident/Bobby Starks Outfitter
F177	2.5	12/10/2012	GMU 65, Tommy Creek fork of Cow Creek, 13, 263944, 4233691	Scott Hill/resident/Matt Iverson Outfitter
M178	3	12/11/2012	GMU 65, Uncompahgre River, trailed off of study area at McKenzie Buttes, 13, 258413, 4239129	Michael Delfino/non-resident/Ben Harris-Needle Rock Outfitter

Table 4. *Minimum count* of pumas based on numbers of known radio-collared pumas, visual observations of non-marked pumas, harvested non-marked pumas, and track counts of suspected non-marked pumas on the study area during September 2009 to April 2010 of Treatment Year 1 (TY1), November 2010 to April 2011 (TY2), November 2011 to April 2012 (TY3), and November 2012 to April 2013 (TY4), Uncompahgre Plateau study area, Colorado.

Treatment Year (TY)	**Study Area region**	**Adults**		**Subadults**		**Cubs**		
		Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Unknown sex**
TY1	East slope	16	10	1	1	1	4	4-8*
	West slope	14	10	0	3	3	3	5-6
	subtotals	30	20	1	4	4	7	9-14
	Total Independent Pumas = 55, including 31 females, 24 males. Cubs = 20-25							
TY2	East slope	15	5	3	2	7	9	7
	West slope	15	7	2	3	2	5	9
	subtotals	30	12	5	5	9	14	16
	Total Independent Pumas = 52, including 35 females, 17 males. Cubs = 39							
TY3	East slope	13	4	1	3	4	2	4
	West slope	14	5	3	5	1	2	6
	subtotals	27	9	4	8	5	4	10
	Total Independent Pumas = 48, including 31 females, 17 males. Cubs = 19							
TY4	East slope	15	4	3	2	4	4	3
	West slope	10	5	3	0	2	5	6
	subtotals	25	9	6	2	6	9	9
	Total Independent Pumas = 42, including 31 females, 11 males. Cubs = 24							

*One adult non-marked female puma was killed by a hunter in Roubideau Canyon. The female puma was lactating, indicating she had nurslings. Up to 4 cubs were assumed to be in the litter.

Table 5. Pumas captured and released by sport-hunters in Treatment Year 4 (TY4) on the Uncompahgre Plateau Study Area, Colorado, November 19 to December 29, 2012. Data are from puma hunter responses in 42 original voluntary surveys on printed permits. Total response rate from 70 individual permitted hunters was 60% (42/70 = 0.60*100).

Puma sex/age stage/mark	**Date of capture**	**Capture location**	**Hunter name**	**Reason for releasing the puma given by hunter**
M/subadult/ eartags	12/23/2012	Sim's Mesa	Jeremiah Wheeler	Hunter thought the puma was a female. Yellow ear-tag indicated male puma. Number on ear-tag not noted by hunter.

Table 6. Summary of puma capture efforts with dogs from January 1, 2013 to April 18, 2013, Uncompahgre Plateau, Colorado.

Month	No. Search Days	No. & type of puma tracks found[a,b]	No. & type of pumas pursued	No. & I.D. or type of pumas captured, observed, or identified
January	23	93 tracks: 13 male, 50 female, 19 cub, 11 undetermined independent pumas <u>Tracks ≤1 day old:</u> 5 male, 22 female, 10 cub	32 pursuits: 5 male, 18 female, 9 cub	12 pumas captured 19 times: M180, M190 (twice), F129, F181, F136 (twice), F137 (4 times), F194, F74 (twice), PM1067 (twice; cub of F171; bio-darted; not handled in dangerous trees), M191 (probably cub of F28), M192 and M193 (cubs of F118). In addition, adult females F74 , F136, F137, F171 and subadult female F194 were associated with tracks by VHF telemetry.
February	23	69 tracks: 15 male, 34 female, 14 cub, 6 undetermined independent puma <u>Tracks ≤1 day old:</u> 12 male, 27 female, 14 cub, 2 undetermined independent puma	29 pursuits: 9 male, 11 female, 7 cub, 2 undetermined independent puma	13 pumas captured 13 times: M183, M196, PM1072 (bio-darted; not handled in dangerous trees), F182, PF1070 (bio-darted; not handled in dangerous trees), PF1071 (bio-darted; not handled in dangerous trees), cub unknown sex of PF1071 bayed on dangerous ledge but could not be handled safely, F136, F171, F197, F28 (non-functional collar; bio-darted; not handled in dangerous trees), F195 (cub of F118), M192 (cub of F118). In addition, adult females F140 (2 times), F74, F111 and subadult female F181 were associated with tracks by VHF telemetry.
March	21	48 tracks: 12 male, 24 female, 11 cub, 1 undetermined independent puma <u>Tracks ≤1 day old:</u> 5 male, 7 female, 3 cub	11 pursuits: 4 male, 4 female, 3 cub	4 pumas captured 4 times: PM1072 (not handled in dangerous trees), F137, F28 (non-functional collar; not handled in dangerous trees) F184 (cub of F111), P1073 (sex undetermined; hair collected, escaped). In addition, adult male M190 was associated with tracks by VHF telemetry.
April	7	19 tracks: 1 male, 8 female, 10 cub <u>Tracks ≤1 day old:</u> 0 male, 8 female, 10 cub	10 pursuits: 4 female, 6 cub	4 pumas captured 5 times: F111, PF1074 (bio-darted; not handled in dangerous trees), M198 (twice; cub of PF1074), F199 (cub of PF1074). In addition, subadult female F186 was associated with tracks by VHF telemetry.
TOTALS	74	229 tracks: 41 male, 116 female, 54 cub, 18 undetermined <u>Tracks ≤1 day old:</u> 23 male 64 female 37 cub 2 undetermined	82 pursuits: 18 male, 37 female, 25 cub 2 undetermined	29 individual pumas were captured 42 times with aid of dogs. In addition, 10 radio-collared pumas were detected 12 times by tracks and identified with VHF telemetry ≤1 km from the tracks. 12 independent pumas (adults, subadults) were captured with dogs for the first time (refer to Tables 7 and 8).

[a] Puma hind-foot tracks with plantar pad widths >50 mm wide are assumed to be male; ≤50 mm are assumed to be female (Logan and Sweanor 2001:399-412).

[b] Each capture season researchers also recorded instances when the *first* puma tracks ≤1 day old were encountered on each search route each day to gather data on vulnerability to detection using methods similar to puma hunters. For 2012-2013 (TY4) the count was: 46 tracks of females, including 9 of those associated with cubs; 23 tracks of males; and 1 track of undetermined sex.

Table 7. Adult and subadult pumas captured for the first time, sampled, tagged, and released from October 2012 to April 2013, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
F176	F	27	42	10/17/2012	Cage trap	North of Norwood Hill, San Miguel Canyon
F177	F	28	44	10/27/2012	Cage trap	North McKenzie Mesa
M178	M	29	65	11/13/2012	Cage trap	North McKenzie Mesa
M179	M	25	54	11/18/2012	Cage trap	East rim Dry Creek Basin
M180	M	18	45	1/1/2013	Dogs	Dolores Creek
F181	F	21	36	1/15/2013	Dogs	Happy Creek
F182	F	48	55	2/4/2013	Dogs	Fisher Canyon
M183	M	54	72	2/14/2013	Dogs	Roubideau Canyon
F186	F	29	38	3/30/2013	Cage trap	7N Mesa, Roubideau Canyon
M190	M	36	57	1/1/2013	Dogs	San Miguel Canyon
F194	F	26	40	1/29/2013	Dogs	San Miguel Canyon
M196	M	45	78	2/5/2013	Dogs	San Miguel Canyon
F197	F	18	49	2/14/2013	Dogs	San Miguel Canyon

Table 8. Pumas that were captured and observed with aid of dogs, some of which were biopsy-darted or hair was collected and given specimen numbers (e.g., PM1067, M for male, F for female), but were not handled at that time for safety reasons, and a puma killed by a bobcat hunter, January 2013 to March 2013, Uncompahgre Plateau, Colorado.

Puma sex & I.D.	Age stage or months	Capture date	Location	Comments
PM1067	17	1/25/2013	Horsefly Creek	Cub of F171, sibling of M170.
PF1069	18	1/11/2013	Lower Maverick Draw	Puma shot by a bobcat hunter that thought the cat was a bobcat. Puma not previously marked.
PF1070	Adult	2/11/2013	North Fork Cottonwood Creek	Mother of 3 cubs ~5-6 mo. old; one of which was bayed on a ledge but not handled.
PF1071	Adult	2/25/2013	Potter Creek, Roubideau Canyon	Mother of 1 male cub ~18 mo. old (not handled).
PM1072	Adult	2/27/2013	North Fork Cottonwood Creek	Puma naturally marked with abbreviated right pinna with 2 notches and left nostril pad removed.
P1073	6	3/15/2013	Monitor Creek, Roubideau Canyon	Puma cub was mauled by dogs and escaped. Hair left at scene was collected.
PF1074	Adult	4/12/2013	Craig Draw	Mother of cubs M198, F199.

Table 9. Pumas recaptured October 2012 to April 2013, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture Date	Mass (kg)	Estimated Age (mo.)	Capture Method/ Location	Process
F93	10/3/2012	39	132	Cage trap/Happy Canyon	Replaced VHF collar with GPS collar.
F129	1/2/2013	43	28	Dogs/Horsefly Creek	Fit with GPS collar.
F136	1/17/2013	Observed	53	Dogs/McKenzie Creek	F136 climbed dangerous trees; not handled.
	1/18/2013	Observed	53	Dogs/Caterwauler Canyon, SE Loghill Mesa	F136 climbed dangerous trees; not handled.
	2/7/2013	50	54	Dogs/south rim Loghill Mesa	Replaced non-functional GPS collar with a new one.
F137	1/4/2013	Observed	48	Dogs/West Fork Dry Creek	F137 climbed dangerous tree; not handled.
	1/9/2013	Observed	48	Dogs/Piney Creek	F137 climbed dangerous tree; not handled.
	1/13/2013	Observed	48	Dogs/Dry Creek Forks	F137 climbed dangerous tree; not handled.
	1/31/2013	Observed	48	Dogs/Dry Creek	F137 climbed dangerous tree; not handled.
	3/6/2013	Observed	48	Dogs/Lower Dry Creek	F137 climbed dangerous tree; bio-darted for tissue sample, but not handled.
F74	1/15/2013	34	65	Dogs/Lower Clay Creek	F74 fit with new radiocollar.
	1/30/2013	Observed	65	Dogs/Lower Cottonwood Creek	None.
F171	2/5/2013	Observed	43	Dogs/Horsefly Creek	None.
F28	2/21/2013	Observed	120	Dogs/East Fork Big Bucktail Canyon	F28 climbed dangerous tree; not handled to replace non-functional GPS collar.
	3/1/2013	Observed	121	Dogs/North Fork Cottonwood Creek	F28 climbed dangerous tree; bio-darted for tissue sample, but not handled to replace non-functional GPS collar.
F95	3/14/2013	40	67	Cage trap/Roubideau Canyon	Replaced VHF collar with GPS collar.
F111	4/12/2013	35	60	Dogs/Piney Creek	Replaced GPS collar.
M190	1/1/2013	Observed	36	Dogs/San Miguel Canyon	M190 took refuge in dangerous ledges; not handled.
PM1067	1/29/2013	Observed	17	Dogs/Horsefly Creek	PM1067 climbed dangerous tree; not handled.
M192	2/1/2013	Observed	7	Dogs/Mailbox Park	None.
PM1072	3/12/2013	Observed	Adult	Dogs/Big Bucktail Canyon	PM1072 climbed dangerous tree; not handled.
M198	4/18/2013	Observed	9	Dogs/upper Horsefly Creek	None.

Table 10. Summary of puma capture efforts with cage traps from September 18, 2012 to May 22, 2013, Uncompahgre Plateau, Colorado.*

Month	No. of Sites	Carnivore activity & capture effort results
September	4	Female puma walked ~5-10 m from mule deer bait 6 days old, but did not feed, East McKenzie Mesa bait site. Black bears, bobcats, coyotes scavenged some mule deer carcasses.
October	13	Adult puma F93 recaptured in cage trap baited with mule deer 10/3/2012. Adult puma F176 captured for the first time in cage trap baited with mule deer 10/17/2012. Adult puma F177 captured for first time in cage trap baited with mule deer 10/27/2012. Non-marked female puma scavenged mule deer bait at SE Loghill Mesa rim 10/30/2012; set cage trap; but, puma did not return. Adult puma F136 walked past same mule deer bait, 8 days old, at SE Loghill Mesa Rim on 10/31/2012, but did not feed. Unknown puma walked past mule deer bait in mouth of Clay Creek, but did not feed. Bobcats and gray foxes scavenged from some of the mule deer carcasses.
November	7	Adult puma M178 captured for first time in cage trap baited with mule deer 11/13/2012. Adult puma M179 captured for first time in cage trap baited with mule deer 11/18/2012. Non-marked female puma scavenged mule deer bait at SE Loghill Mesa rim 11/5/2012; set cage trap; but, puma did not return (probably same as in October). Puma M178 walked by mule deer bait 5 days old on SE Loghill Mesa 11/10/2012, but did not feed.
March	14	Adult puma F95 recaptured in cage trap baited with mule deer 3/14/2013. Puma cub F185 captured for the first time in cage trap baited with mule deer 3/23/2013. Subadult puma F186 captured for the first time in a cage trap baited with mule deer 3/30/2013. Puma, probably F95, fed on mule deer bait on east Roubideau Canyon rim, cage trap set; puma did not return. Adult puma M183 visited mule deer bait on 7N Mesa, but did not feed. Female puma, probably F118, walked ~3 m from mule deer bait on N Norwood Hill, but did not feed. Coyotes, bobcats and black bear scavenged some of the mule deer carcasses.
April	3	Adult F171 fed on elk bait at Horsefly Canyon on 4/23/2013; no capture effort needed. Black bears and coyotes scavenged on elk bait.
May	2	Black bears scavenged mule deer baits.

* We used 50 road-killed mule deer and 1 road-killed elk at 28 different sites. Of the road-killed baits, 12 of 51 (23.53%) were scavenged by pumas.

Table 11. Puma cubs sampled August 2012 to July 2013 on the Uncompahgre Plateau Puma Study area, Colorado.

Cub I.D.	Sex	Estimated birth date[a]	Estimated age at capture (days)	Mass (kg)	Mother	Estimated age of mother at birth of this litter (mo)
PF1062	F	6/2012	183	13.5	Nonmarked	Adult
M166	M	7/5/2012	33	2.2	F136	51
M167	M	7/5/2012	33	2.1		
M168	M	7/27/2012	37	2.3	F96	78
F169	F	7/27/2012	37	2.2		
F173	F	7/27/2012	37	2.5		
M174	M	8/8/2012	32	1.9	F152	25.7
M175	M	8/8/2012	32	1.8		
F184	F	8/25/2012	208	13.0	F111	58
F185	F	9/2012	183	12.0	Nonmarked	Adult
F187	F	5/14/2013	31	2.3	F96	88
F188	F	5/14/2013	31	2.5		
M191	M	7/2012	183	14.0	F28 probably[b]	112
PM1068	M	7/2012	183	Unknown		
M192	M	6/20/2012	199	21.0	F118	50
M193	M	6/20/2012	199	20.0		
F195	F	6/20/2012	227	20.0		
M198	M	6/2012	274	30	PF1074	Adult
F199	F	6/2012	282	25		
F189	F	6/18/2013	38	2.6	F136	62
F200	F	6/18/2013	38	2.6		
M201	M	6/18/2013	38	2.8		
F202	F	6/25/2013	35	2.5	F172	48

[a] Estimated age of cubs sampled at nurseries is based on the starting date for GPS location and radio-telemetry foci for mothers at nurseries, and development characteristics of cubs caught with mothers without radiocollars or mothers with non-functioning radiocollars.

[b] F28 had a non-functional GPS collar, but recapture sites and tracked travel routes were consistent with associations with cubs M191 and PM1068. Another non-marked cub was in association, making the total number of cubs = 3.

Table 12. Summary of puma capture efforts with dogs, December 2004 to April 2013, Uncompahgre Plateau, Colorado.

Period	Track detection effort	Pursuit effort	Puma capture effort	Effort to capture an independent puma for the first time
Dec. 2, 2004 to May 12, 2005	109/78 = 1.40 tracks/day	35/78 = 0.45 pursuit/day 78/35 = 2.23 day/pursuit	14/78 = 0.18 capture/day 78/14 = 5.57 day/capture	11 pumas captured for first time 11/78 = 0.14 capture/day 78/11 = 7.09 day/capture
Nov. 21, 2005 to May 26, 2006	149/82 = 1.82 tracks/day	43/82 = 0.52 pursuit/day 82/43 = 1.91 day/pursuit	14/82 = 0.17 capture/day 82/14 = 5.86 day/capture	7 pumas captured for first time 7/82 = 0.08 capture/day 82/7 = 11.71 day/capture
Nov. 13, 2006 to May 11, 2007	177/78 to 182/78 = 2.27-2.33 tracks/day	45/78 to 47/78 = 0.58-0.60 pursuit/day 78/47 to 78/45 = 1.66-1.73 day/pursuit	22/78 = 0.28 capture/day 78/22 = 3.54 day/capture	7 pumas captured for first time 7/78 = 0.09 capture/day 78/7 = 11.14 day/capture
Nov. 19, 2007 to April 24, 2008	217/77 to 218/77 = 2.82-2.83 tracks/day	49/77 = 0.64 pursuit/day 77/49 = 1.57 day/pursuit	20/77 = 0.26 capture/day 77/20 = 3.85 day/capture	7 pumas captured for first time 7/77 = 0.09 capture/day 77/7 = 11.00 day/capture
Dec. 9, 2008 to April 30, 2009	198/71 to 202/71 = 2.79-2.84 tracks/day	75/71 to 78/71 = 1.06-1.10 pursuit/day 71/75 to 71/78 = 0.91-0.95 day/pursuit	24/71 = 0.34 capture/day 71/24 = 2.96 day/capture	9 pumas captured for first time 9/71 = 0.13 capture/day 71/9 = 7.89 day/capture
Dec. 15, 2009 to April 30, 2010	266/86 = 3.09 tracks/day	93/86 = 1.08 pursuit/day 86/93 = 0.92 day/pursuit	26/86 = 0.30 capture/day 86/26 = 3.31 day/capture	9 pumas captured for first time 9/86 = 0.11 capture/day 86/9 = 9.56 day/capture
Nov. 16 and Dec. 14, 2010 to April 22, 2011	300/81 = 3.70 tracks/day	99/81 = 1.22 pursuit/day 81/99 = 0.82 day/pursuit	52/81 = 0.64 capture/day 81/52 = 1.56 day/capture	15 pumas captured for first time 15/81 = 0.18 capture/day 81/15 = 5.40 day/capture
Dec. 27, 2011 to April 12, 2012	268/79 = 3.39 tracks/day	89/79 = 1.13 pursuit/day 79/89 = 0.89 day/pursuit	26/79 = 0.28 capture/day 79/26 = 3.04 day/capture	11 pumas captured for first time 11/79 = 0.14 capture/day 79/11 = 7.18 day/capture
Jan. 1, 2013 to April 18, 2013	229/74 = 3.09 tracks/day	82/74 = 1.11 pursuit/day 74/82 = 0.90 day/pursuit	42/74 = 0.57 capture/day 74/42 = 1.76 day/capture	12 pumas captured for the first time 12/74 = 0.16 capture/day 74/12 = 6.17 day/capture

Table 13. Individual puma reproduction histories, Uncompahgre Plateau, Colorado, 2005-2013.

Consort pairs and estimated ages[a]				**Dates pairs consorted[b]**	**Estimated birth date[c]**	**Estimated birth interval (mo.)**	**Estimated gestation (days)**	**Observed number of cubs[d]**
Female	**Age (mo.)**	**Male**	**Age (mo.)**					
F2	53				05/28/05			3
F2	67				07/29/06	14.0		2
F2	89				05/19/08	22.0		4
F3	36				08/01/04			1
F3	50	M6	37	06/22-24/05	09/26/05	13.8	93-95	2
F3	62				09/17/06	11.7		3
F3	84	M51	60	03/31/08	07/03/08	21.5	94	3
F3	107	M55	69	03/28-31/10	06/28/10	23.8	89-92	2
F7	67				05/19/05			2
F7	82				08/13/06	14.9		4
F7	106				07/10/08	23.9		3
F8*[e]	24				06/26/05			2
F8	37				08/13/06	13.4		4
F8	60	M73	49	02/28-29/08	05/29/08	22.5	90-91	2
F8	95				04/18/11	34.7		2
F16	32				09/22/05			4
F16	52				05/24/07	19.9		4
F16	75	M6	80	01/13-14/09	04/15/09	22.7	91-92	3
F23*	21				05/30/06			3
F23	45	M27 or M29[f]	78 107	02/19-25/08	05/23/08	23.8	87-93	3
F23	80	M67	53	01/28-31/11	04/22/11	Non-funct.GPS	84-86	2
F24	75	M29	92	04/12-15/07	06/14/07		90-93	4
F24	114				09/10	Non-funct.GPS		3
F25	74				08/01/05			1
F25	94				04/16/07	20.5		1
F25	110				08/19/08	16.1		2
F25	129				3/10	Non-funct.GPS		3
F28*	36				06/09/06			2
F28	48	M29	88	12/27-29/06	03/30/07	11.7	92-93	≥2 tracks
F28	68				11/08			1
F28	112				07/12			3
F30*	48	M55	34	04/16-20/07	07/17/07		88-92	3
F50	21				07/01/06			1
F54	24				07/01/06			1
F70*	38	M51	60	03/10/08	06/05/08		87	3
F70	52				08/31/09	14.8		3
F70	76				08/18/11	23.6		3
F72*	28				07/09/08			1
F72	51				06/12/10	23.1		2
F72	64				07/15/11	13		3 photographed
F75	32				08/07			1
F75	55	M73	61	02/11/09	05/07/09	23.2	93	2
F93	56				08/07			2
F93	90				06/16/10			2
F94*	46				05/27/09			3
F94	60	M55	70	04/15/10	07/15/10	13.3	91	3
F96	55	M55	71	05/21/10	08/21/10			4
F96	78				07/27/12	23.2		3
F96	88				05/14/13	9.6		2

Table 13 continued.

Consort pairs and estimated ages[a]				Dates pairs consorted[b]	Estimated birth date[c]	Estimated birth interval (mo.)	Estimated gestation (days)	Observed number of cubs[d]
Female	Age (mo.)	Male	Age (mo.)					
F104	110				07/08/10			3
F111*	32				06/16/10			2
F111	58				08/25/12	26.3		2[k]
F116[g]	36				2009			2
F118	27				08/08/10			3
F118[h]	50				06/20/2012	22.4		3
F119	66				08/09			2
F119[i]	96 expected				02/12 expected	29 expected		1 plus 1-2 uterine scars
F135	33				07/06/11			2
F136[j]	39				07/10/11			≥1 remains
F136	51				07/05/12	12		2
F136	62	Non-marked[l]	Unk.	03/19/13	06/18/13	11	92	3
F137	30				07/08/11			≥1
F137	54				07/12/2013			3
F152*	25.7				08/08/2012			2
F171	22				08/11			2
F171	45				07/31/2013			4
F172	48				06/25/2013			1

[a] Ages of females were estimated at litter birth dates. Ages of males were estimated around the dates the pairs consorted.

[b] Consort pairs indicate pumas that were observed together based on GPS data or VHF location data.

[c] Estimated birth dates were indicated by GPS data of mothers at nurseries or by back-aging cubs to approximate birth date.

[d] Observed number of cubs do not represent litter sizes as some cubs were observed when they were 5 to 16 months old after postnatal mortality could have occurred in siblings. Only cub tracks were observed with F28.

[e] Asterisk (*) indicates first probable litter of the female, based on known history or nipple characteristics noted at first capture of the female.

[f] A radio-collared, ear-tagged male puma was visually observed with F23 on 2/25/08. Both M27 and M29 wore non-functional GPS collars in that area at the time.

[g] When captured on 1/20/10, puma F116 was in association with 2 large cubs which were not captured.

[h] Two cubs observed with F118 south of Norwood 9/24/2012.

[i] F119 died of a ruptured uterus and internal bleeding on 1/28/12. Cub in uterus in third trimester; 1-2 uterine scars indicated expulsion of 1-2 fetuses.

[j] Remains of F136's cubs found 8/9/11. Cause of death predation by puma or black bear.

[k] Tracks evidence of one other cub in association with F111 and cub F184, but not captured and marked.

[l] A non-marked adult male puma was photographed consorting with adult female pumas F136 and F182 at the same time on the NE rim of Loghill Mesa on 03/19-20/13.

Table 14. Summary for individual adult puma survival and mortality, December 8, 2004 to July 31, 2013, Uncompahgre Plateau, Colorado.

Puma I.D.	**Monitoring span**	**Status: Alive/Lost contact/Dead; Cause of death**
M1	12-08-04 to 08-16-06	Dead. Lost contact− failed GPS/VHF collar. M1 ranged principally north of the study area as far as Unaweep Canyon. M1 was killed by a puma hunter on 01-02-10 west of Bang's Canyon, north of Unaweep Canyon, GMU 40. M1 was about 97 months old at death.
M4	01-28-05 to 12-28-05	Dead; killed by a male puma. Estimated age at death 37−45 months.
M5	08-01-06 to 02-20-09	Dead. Born on study area; offspring of F3. M5 was independent of F3 by 13 months old, and dispersed from his natal area at about 14 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at age 54 months.
M6	02-18-05 to 05-21-10	Dead. M6 was struck and killed by a vehicle on highway 550 south of Colona, CO on 05-21-10. M6 was about 99 months old at death.
M27	03-10-06 to 05-07-09	Dead. Lost contact− failed GPS/VHF collar. Recaptured 12-02-07 & 01-22-08 by puma hunter/outfitter north of the study area. Possibly visually observed on study area with F23 on 02-25-08. Recaptured by a puma hunter/outfitter 12-11-08 & 12-28-08 north of the study area. Photographed by a trail camera on the study area (Big Bucktail Canyon) on 5 occasions: 03-27-09, 04-02-09, 04-15-09, 04-24-09, & 05-07-09. M27 was killed by a puma hunter on 12-09-09 in the North Fork Mesa Creek, Uncompahgre Plateau, GMU 61 North. M27 was about 100 months old at death.
M29	04-14-06 to 02-25-09	Dead. Lost contact− failed GPS/VHF collar. Possibly visually observed on study area with F23 on 02-25-08. Recaptured on study area 02-25-09, but could not be safely handled to change faulty GPS collar. M29 was killed by a puma hunter on 11-16-09 in Beaver Canyon, GMU 70 East. M29 was about 121 months old at death.
M32	04-26-06 to 12-02-10	Dead. Killed by a puma hunter on 12-02-10 in McKenzie Creek on the Uncompahgre Plateau study area. M32 was about 112 months old at death.
M51	01-07-07 to 03-20-09	Dead. Lost contact− failed GPS/VHF collar after 03-20-09. Killed by a puma hunter on 12-11-09 in Shavano Valley, Uncompahgre Plateau study area. M51 was about 77 months old at death.
M55	01-21-07 to 07-31-10	Dead. Killed by a puma hunter on 11-25-10 in Spring Creek Canyon on the Uncompahgre Plateau study area. M55 was about 77 months old at death.
M67	08-23-07 to 12-18-11	Dead. M67 is offspring of F30. Dispersed natal area. Established territory on W side U.P. study area. Killed by a puma hunter in Tabaguache Creek 12-18-2011 at age 52.9 months.
M71	01-29-08 to 11-12-09	Dead. Lost contact– M71 shed his VHF collar with an expansion link on about 11-12-09. He was killed by a puma hunter on 12-09-09 on the west rim of Spring Creek Canyon, Uncompahgre Plateau study area. M71 was about 47 months old at death.
M73	02-21-08 to 10-26-11	Dead. Illegally killed 10-26-2011 in Bear Pen Gulch, upper East Fork Escalante Canyon; shot through abdomen during second rifle season. M73 was about 80 months old at death.
M87	02-09-11 to 12-06-11	Dead. M87 is offspring of F3. Dispersed from natal area. Established territory on W side of U.P. study area. Killed by a puma hunter in 47 Canyon, Tabaguache Canyon 12-06-2011. M87 was 41 months old at death.
M90	11-16-10 to 11-23-10	Dead. M90 was killed by a hunter on 11-23-10 on McKenzie Butte. M90 was offspring of F72, born 07-09-08. He was 28 months old at death.
M100	03-27-09 to 07-31-09	Dead. M100 was killed by a puma hunter on 01-16-10 in Naturita Canyon, GMU 70 East. M100 was about 63 months old at death.
M114	02-27-10 to 03-10-12	Dispersed from U.P. study area after 06-23-10. Killed by a puma hunter in Beaver Creek, NE of Canyon City, GMU59, 03-10-12. M114 was about 55 months old at death.
M133	11-12-10 to 12-01-10	Dead. M133 was killed by a puma hunter on 12-01-10 in Dry Fork Escalante Canyon north of the study area. M133 was about 43 months old at death.

Table 14. Continued.

Puma I.D.	Monitoring span	Status: Alive/Lost contact/Dead; Cause of death
M134	06-01-11 to 06-10-11	Dead. M134 was offspring of unmarked female puma in Roubideau Canyon. Independent by about 03-28-11. Shot dead by USDA, APHIS, WS agent while in the act of attacking domestic sheep on 06-10-11 when he was 24 months old at start of adult life stage.
M138	07-01-11 to 12-23-11	Dead. Killed by a puma hunter in Horsefly Canyon (E) 12/23/11. M138 was about 29 months old at death.
M144	09-01-11 to 02-25-13	Dead. Initially captured as 18 mo. old subadult on W side U.P. study area 03-07-11. Dispersed from study area. Established adult territory on NW U.P. Killed by puma hunter 2-25-2013 in GMU 40, North Fork West Creek, Unaweep Canyon.
M153	09-01-11 to 09-13-11	Dead. Killed for depredation control; killed an alpaca in Pleasant Valley 09-13-11.
M165	07-01-12 to 02-17-12	Alive. Initially captured as 19 mo. old subadult on W side U.P. study area 02-24-12. Moved to Escalante Creek drainage by adult age 07-31-12. Killed by puma hunter 12-17-2012 in GMU 62N, Dry Fork Escalante Canyon.
M178	11-13-12 to 12-11-12	Dead. Originally captured on the study area 11-13-12. Killed by puma hunter 12-11-12 after tracking M178 off the study area and onto adjacent GMU 65.
M179	11-18-12 to 12-29-12	Dead. Killed by puma hunter on study area 12-29-12.
M180	07-01-13 to 07-31-13	Alive.
M183	02-14-13 to 07-31-13	Alive.
M190	01-02-13 to 07-31-13	Alive.
M196	02-05-13 to 07-31-13	Alive.
F2	01-07-05 to 08-14-08	Dead; killed by another puma (sex of puma unknown; male suspected) 08-14-08. F2 was about 92 months old at death.
F3	01-21-05 to 12-11-11	Dead. Killed by a puma hunter in Lindsay Creek 12-11-11. F3 was about 120 months old at death.
F7	02-24-05 to 08-03-08	Dead. Killed by U.S. Wildlife.Services agent 08-03-08 for predator control of depredation on domestic sheep. F7 was about 107 months old at death.
F8	03-21-05 to 12-17-12	Lost radio contact. Last live signal heard 12/17/2012 in Big Bucktail Canyon on study area. Fate unknown; was not recaptured on study area Jan. to April 2013.
F16	10-11-05 to 09-11-09	Dead. F16 was struck and killed by a vehicle on Ouray County Road 1 southwest of Colona, CO on 09-11-09. F16 was about 80 months old at death.
F23	02-05-06 to 06-06-12	Dead. Killed by a male puma about 06-06-12. F23 was about 94 months old at death. F23 may have attempted to defend 2 cubs (F149, M161; 13.5 months old) and/or calf elk kill.
F24	01-17-06 to 07-31-11	Dead. Killed by a male puma in Logging Camp Draw about 09-16-11. F24 was about 126 months old at death. F24 may have attempted to defend ≥2 cubs (F147, non-marked siblings; 12 mo. old).
F25	02-08-06 to 02-03-11	Dead. Lost radio contact after 09-04-09– failed GPS/VHF collar. Photographed alive with three ~9 month old cubs on 12-03-10 on Loghill Mesa. F25 shot dead by a ranch hand on 02-03-11 in Pleasant Valley, Dallas Creek because she was seen among cattle. F25 was about 138 months old at death and in excellent physical condition (49 kg).
F28	03-23-06 to 02-16-12	Lost radio contact after 09-25-07− failed GPS/VHF collar. Recaptured F28 on the study area 02-01-10 and 01-01-11 and 02-16-12, but could not be handled to replace non-functional GPS collar.
F30	04-15-06 to 07-29-08	Dead. Killed by another puma (sex of puma unknown) 07-29-08. F30 was about 60 months old at death.
F50	12-14-06 to 03-26-07	Dead of natural causes 03-26-07; probably injury or illness-related; exact agent unknown. F50 was about 30 months old at death.
F54	01-12-07 to 08-18-07	Dead; killed by a male puma while in direct competition for prey (i.e., mule deer fawn) 08-18-07. F54 was about 49 months old at death.
F70	01-14-08 to 12-22-11	Dead. Killed by a puma hunter Spring Creek 12-22-11. F70 was 80 months old at death. Her death orphaned 2 cubs, F157 and F158, at 4 months old; both starved to death about 01-15-12 at about 5 months old.
F72	02-12-08 to 12-21-11	Lost radio contact after 12-02-10. F72 recaptured in Fisher Creek on 03-18-11, but could not be handled to replace non-functional GPS collar. Photographed on Miller Mesa S of U.P. study area on 12-18 to 21-11 with 3 new cubs born about July 2012.
F74	01-15-13 to 5-16-13	Lost radio contact after 5-16-13; radiocollar fell off after canvas breakaway tab broke; detected 6-10-13.

Table 14 continued.

Puma I.D.	Monitoring span	Status: Alive/Lost contact/Dead; Cause of death
F75	03-26-08 to 12-13-11	Dead. Killed by a puma hunter in North Fork Cottonwood Creek 12-13-11. F75 was about 98 months old at death.
F93	12-05-08 to 11-11-12	Dead. Killed by another puma 11-11-12. Fatal bite wounds to the skull.
F94	12-19-08 to 02-01-11	Dead. Shot dead on 02-01-11 by USDA, APHIS, WS agent for predation on domestic elk in Happy Canyon. F94 was about 74 months old at death.
F95	08-01-09 to 07-31-13	Alive.
F96	01-28-09 to 07-31-13	Alive.
F104	05-21-09 to 01-31-12	Dead. Died probably of starvation associated with senescence in lower Roubideau Creek 01-31-12. F104 was about 132 months old at death.
F110	09-21-09 to 02-25-10	Dead. Killed by a puma hunter on 02-25-10 in GMU 70 East. F110 was about 41 months old at death.
F111	01-01-10 to 07-31-13	Alive.
F113	01-26-10 to 06-06-10	Dead. F113 died 06-06-10 of injuries consistent with being struck by a vehicle. GPS data indicated that F113 had crossed highway 550 and roads on Loghill Mesa north of Ridgway 24-30 hours before she died in McKenzie Creek. F113 was about 42 months old at death.
F116	01-20-10 to 09-20-11	Dead. Died about 09-20-11 of unknown natural cause associated with pregnancy and birth of new litter of cubs. F116 was about 60 months old at death.
F118	02-25-10 to 07-31-13	Alive.
F119	03-25-10 to 01-28-12	Dead. Died of ruptured uterus and internal bleeding associated with pregnancy in Clay Creek Canyon 01-28-12. F119 was about 95 months old at death.
F135	01-01-11 to 09-20-11	Dead. Died of unknown natural cause in E Fork Dry Creek 09-20-11. Her death orphaned cubs M154 and M155 at 76 days old; both died of starvation or disease when 77 (M154) and 81 (M155) days old.
F136	01-20-11 to 07-31-13	Alive.
F137	01-21-11 to 07-31-13	Alive.
F140	08-01-12 to 07-31-13	Alive.
F143	02-15-11 to 07-31-13	Alive.
F152	06-16-12 to 12-23-12	Dead. Killed by puma hunter on study area, Spring Creek Canyon.
F163	07-01-12 to 07-31-13	Alive.
F171	01-20-12 to 07-31-13	Alive.
F172	03-28-12 to 07-31-13	Alive.
F176	10-17-12 to 07-31-13	Alive.
F177	10-27-12 to 12-10-12	Dead. Killed by puma hunter 12-10-12 in GMU 65 adjacent to study area.
F181	04-01-13 to 07-31-13	Alive.
F182	02-04-13 to 07-31-13	Alive.
F186	03-30-13 to 07-31-13	Alive.
F194	01-29-13 to 06-17-13	Dispersed, exhibited subadult behavior. Fate unknown. Censor.

Table 15. Preliminary estimated survival rates *(S)* of adult-age pumas during the 4 years in the *reference period* (i.e., the study area is closed to puma hunting) and 4 years in the *treatment period*, Uncompahgre Plateau, Colorado. Survival rates of pumas estimated with the Kaplan-Meier procedure to staggered entry of animals (Pollock et al. 1989). Survival rates are for an annual survival period defined as the biological year (August 1 to July 31). Survival rates were estimated only for periods when $n \geq 5$ individual pumas were monitored in the interval. Puma survival in the *reference period* pertained only to pumas that died of natural causes. Pumas that were killed by people in the *reference period*, a non-natural cause (i.e., two adult pumas: F7 for depredation control 8/3/2008 and M5 killed by a puma hunter off the protected study area and buffer zone 2/20/2009) were right censored. In the *treatment period* all sources of natural and human-caused mortality are considered in the survival estimates.

Biological Year	**Females**			**Males**		
	S	**SE**	***n***	***S***	**SE**	***n***
Reference Annual 2 8/1/2005 to 7/31/2006	1.000	0.0000	10	0.667[a]	0.2222[a]	6[a]
Reference Annual 3 8/1/2006 to 7/31/2007	0.909	0.0867	11	1.000	0.0000	5
Reference Annual 4 8/1/2007 to 7/31/2008	0.831	0.0986	14	1.000	0.0000	7
Reference Annual 5 8/1/2008 to 7/31/2009	0.875	0.1031	13	1.000	0.0000	8
Treatment Annual 1 8/1/2009 to 7/31/2010	0.784	0.1011	19	0.667	0.1924	8
Treatment Annual 1[b] 8/1/2009 to 7/31/2010 With mortalities of all marked adult males	NA (see rates above)	NA	NA	0.333[b]	0.1361[b]	12[b]
Treatment Annual 2 8/1/2010 to 7/31/2011	0.947[c]	0.0568	19	0.250	0.1082	9
Treatment Annual 3 8/1/2011 to 7/31/2012	0.548[d]	0.1063	20	0.167	0.1076	7[d]
Treatment Annual 4 8/1/2012 to 7/31/2013	0.819	0.0931	19	0.188	0.0845	8[e]

[a] Adult male annual *S* 2005 to 2006 is probably underestimated with poor precision because 3 of the 6 pumas were GPS/VHF-monitored for 4 to 5 months at the end of the interval; 1 of 6 adult males died.

[b] This second estimate of adult male puma survival 8/1/2009 to 7/31/2010 includes 5 males that had non-functional (4) or shed (1) radiocollars. All adult males with non-functional or shed radiocollars in this study survived into *treatment year* 1 (TY1), which was expected considering adult male survival in 3 previous years. All 5 of those adult males were detected and killed by hunters in TY1.

[c] Only 1 of 2 adult female puma mortalities is represented in this survival analysis for 8/1/2010 to 7/31/2011, that of F94 killed for depredation control. One other adult female mortality, F25, is not represented because she wore a non-functional GPS collar making it impossible for us to monitor her survival. F25 was shot by a ranch hand on 2/3/2011 when he saw her among cattle.

[d] Sample included F143, F163, M144, ranged on NW Uncompahgre Plateau N of the study area but not on the U.P. study area, vulnerable to annual hunting.

e Sample includes F143, F163, M144, M165 that ranged on north half of the Uncompahgre Plateau north of the study area (not on the study area) and were at risk to annual sport-hunting mortality.

Table 16. Summary of subadult puma survival and mortality, December 2004 to July 2013, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status
M5	09-16-05 to 06-30-06	308	Survived to adult stage. M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-21-06 to 12-02-07	529	Survived to adult stage. M11 was offspring of F2, born May 2005. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
F23	01-04-06 to 02-04-06	31	Survived to adult stage. Captured on the study area when about 17 months old. Survived to adult stage; gave birth to first litter at about 21 months old. Killed by a male puma about 06-06-12. F23 was about 94 months old at death.
M31	04-19-06 to 04-26-06	7	Survived to adult stage. M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M49	03-26-07 to 10-01-07	189	Survived to adult stage. M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old, a young adult.
F52	01-10-07 to 05-15-07	125	Survived to adult stage. F52 dispersed from study area as a subadult by 01-16-07. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old and could have been in her adult-stage home range. GPS collar nonfunctional. F52 was killed by a puma hunter on 01-09-12 in North Beaver Creek SE of Powederhorn, CO. She was about 79 months old at death.
F66	08-23-07 to 11-05-07 11-25-08 to 06-03-09	74 190	Died in subadult stage. F66 was offspring of F30, born July 2007. Lost contact; her cub collar quit after 11-05-07. Recaptured as an independent subadult on her natal area 11-25-08 when 16 months old. Mother F30 was killed by a puma when F66 was 12 months old, within the age range of normal independence. F66 died of injuries to internal organs that caused massive bleeding attributed to trampling by an elk or mule deer on about 05-28-09 when she was 23 months old. Her range partially overlapped her natal area.
M69	01-11-08 to 04-07-08	87	Survived to adult stage. M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.

Table 16 continued

Puma I.D.	Monitoring span	No. days	Status
F95	12-29-08 to 07-31-12	214	Alive. F95 is the offspring of F93, born about August 2007. She became an independent subadult by about 18 months old (02-11-09 aerial location) and an adult by about 24 month old (Aug. 2009). F95 established an adult home range adjacent to and overlapping the northern portion of her natal area.
M99	02-27-09 to 04-22-09	54	Died in subadult stage. M99 probably killed by another puma (canine punctures in skull including braincase) in Jan. 2010 when he was about 16 months old. His radiocollar quit after 54 days.
M112	02-10-11 to 04-18-11	67	M112 was offspring of F70 born August 2009. M112 associated with F96 and her two radio-collared cubs F129 and M130 during 02-10-11 to 04-18-11. Lost contact of M112 after 04-18-11. Dispersed. M112 was killed by a puma hunter 01-06-2013, GMU 73, SE of Dolores, CO; UTM: 12S, 732863E, 4146772N; age 41 months, adult stage.
M115	01-13-10 to 07-21-10	189	Died in subadult stage. M115 was offspring of F28, born in Nov. 2008. He was about 14 months old when first captured on Jan. 13, 2010. When he was recaptured on 03-18-10, he had previously suffered a broken left ulna. M115 was probably independent by 07-15-10 when he was located outside of his natal area on a probably dispersal move. M115 died on about 07-21-10 apparently from complications of his broken left foreleg; probably not allowing him to kill prey sufficiently for survival. M115 was about 20 months old at death.
M120	12-06-11	1	Died in subadult stage. M120 was offspring of F3. M120 was killed by a puma hunter 12-06-11 in his natal area in Spring Creek. He was 17 months old at death.
M122	08-12-10 to 04-18-11	250	M122 was offspring of F104, born 07-08-10. Lost contact after 04-18-11 when radio-collar malfunctioned. Dispersed. Killed by puma hunter in GMU 62, Tatum Draw, Dry Fork Escalante Creek, N of natal area 01-23-13; UTM: 12S, 735353E, 4283455N; age 30 months, adult stage.
M131	09-25-10 to 04-18-11	206	M131 was offspring of F96, born 08-21-10. Lost contact after 04-18-11 when collar malfunctioned. Dispersed. Killed by puma hunter in GMU 60, Lion Creek, extreme W CO 01-17-13; UTM: 12S, 670829E, 4246980N; age 29 months old, adult stage.
M134	03-28-11 to 06-10-11	74	Survived to adult stage (barely). M134 was offspring of unmarked female puma in Roubideau Canyon. Independent by about 03-28-11. Shot dead by USDA, APHIS, WS agent while in the act of attacking domestic sheep on 06-10-11 when he was 24 months old at start of adult life stage.
M138	01-26-11 to 06-30-11	155	Survived to adult stage. Entered adult life stage 07-01-11. Killed by a puma hunter 12-23-11 in Horsefly Canyon. M138 was about 29 months old at death.
F140	01-13-12 to 07- 31-12	200	Survived to adult stage. Turned adult in Aug. 2012. Probably offspring of F28. Has established a home range adjacent to natal area where she was initially captured at 5 months old on 01-02-11.
M141	12-23-11	1	Died in subadult stage. M141 was killed by a puma hunter on 12-23-11 in Little Bucktail Creek. He was 16 months old at death.
M144	03-07-11 to 09-08-11	185	Survived to adult stage. Emigrated from U.P. study area. Established adult territory on northwest Uncompahgre Plateau. M144 is sibling of F145 below. Killed by puma hunter 2/25/2013 at ~41 mo. old.
F145	03-08-11 to 09-08-11	184	Survived to adult stage. Emigrated from U.P. study area and to Colorado Mesa. Killed by a puma hunter 01-23-12 in West Bangs Canyon. F145 was 28 months old at death.

Table 16 continued

Puma I.D.	Monitoring span	No. days	Status
F146	03-08-11 to 03-23-11	15	Died in subadult stage. F146 was killed and eaten by a male puma while in competition for an adult bull elk carcass that one of the pumas killed in Coal Canyon on the study area. F146 was about 19 months old at death.
F147	09-16-11 to 04-12-12	209	Lost contact; radiocollar quit after 04-12-12. F147 orphaned at about 12 months old when her mother F24 was killed by a male puma on 09-16-11.
F149	06-06-11 to 12-31-12	575	Died in subadult stage. F149 was offspring of F23, born 04-22-11. F149 (sibling of M161 below) was orphaned at 13.5 months old when her mother F23 was killed by a male puma. F149 dispersed from the natal area by 07-16-12 to E side U.P. study area when she was 14.8 months old; onto Bostwick Park, then W to Dry Creek. Killed by a puma hunter 12-31-12 in GMU 70W, Dry Creek; UTM: 12S, 713658E, 4229703N; age 20 months.
M150	03-28-11 to 04-11-11	14	Dispersed. M150 was offspring of F111, born on 08-31-09. He was independent by 03-28-11 when he was 19 months old. Lost contact after 04-11-11 when M150 was in Cow Creek southeast of the study area.
F152	05-04-12 to 06-16-12	44	Survived to adult stage. F152 was independent from her mother F93 by 05-04-12 when about 23 months old. She ranged as a subadult and adult on the natal area (07-31-12).
M153	04-12-11 to 09-06-11	147	Survived to adult stage. Consorted with F137 when 23 months old on 09-07-2011. Killed by Wildlife Services agent for depredation on an alpaca in Dallas Creek on 09-13-11. M153 was 23 months old at death.
M161	06-06-12 to 08-03-12	59	Died in subadult stage. M161 (sibling of F149 above) was orphaned at 13.5 months old when his mother F23 was killed by a male puma. M161 dispersed from the natal area by 06-29-12 to E side U.P. study area when he was 14 months old. He shed his expandable cub collar about 08-03-12. M161 was struck and killed by a vehicle on Dallas Divide, HWY 62 in October 2012 when he was 18 months old.
F163	01-26-12 to 07-01-12	157	Survived to adult stage. F163 was captured at about 18 months old on the study area. She emigrated from the study area and established an adult home range on the NW Uncompahgre Plateau as of July 2012 (07-16-12 location).
M164	02-14-12 to 02-26-12	12	Lost contact after 02-26-12. M164 may have dispersed a long distance. Fate unknown.
M165	02-24-12 to 12-17-12	298	M165 moved from W to E side of the study area. Appeared to establish adult home range on NE Uncompahgre Plateau. Killed by a puma hunter 12-17-12 in GMU 62N, Dry Fork Escalante Creek; UTM: 12S, 730184E, 4272500N; age about 29 months, adult stage.
M180	01-01-13 to 07-01-13	182	M181 moved to NE Uncompahgre Plateau, ranging N of the study area. Turned to adult age (24 mo.) July 2013.
F181	01-15-13 to 07-01-13	168	F181 moved from E to W side of study area. Turned to adult age (24 mo.) April 2013.
F194	01-29-13 to 6-17-13	140	Lost contact after 06-17-13. F194 dispersed S, last location on North Mt., head of Naturita Creek. Estimated age 30 months in June 2013.
F197	02-13-13 to 07-01-13	139	F197 ranges on W side of the study area. Turns to adult age (24 mo.) August 2013.

Table 17. Records of pumas that dispersed from the Uncompahgre Plateau study area, December 2004 to July 2013.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
M5	02-04-05	13S,240577E, 4251037N→ 12S,665853Ex 4277125N	102.2	M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-27-05	13S,248278E, 4239858N→ 12S,741882Ex 4161575N	84.8	M11 was offspring of F2, born May 2005. Shed expandable radiocollar 10-24 to 11-08-05. Recaptured and re-collared 04-02-06. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
M31	04-19-06	12S,746919E, 4225441N→ 13S,500000Ex 4050000N	329.8	M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M38	09-08-06	13S,249200E, 4239703N→ 12S,703371E, 4316856N	104.1	M38 was offspring of F2, born July 29, 2006. Shed his expandable radiocollar by 03-06-07. Photographs by trail camera in McKenzie Cr. of M38 & Unm. F sibling with F2 on 07-16 to 17-07 at 352-353 days old. M38 was killed by a puma hunter in Ladder Creek southwest of Grand Junction, CO on 01-07-11. He was 53.2 months old at death.
M39	09-11-06	12S,724270E, 4243610N→ 12S,709889E, 4313490N	71.3	M39 was offspring of F8, born August 2006. M39 was killed by a puma hunter in Bangs Canyon, GMU 40 on 03-12-10 when he was 42.8 months old.
M43	09-15-06	12S,760177E, 4242995N→ 12S,739859E, 4308557N	68.6	M43 was offspring of F7, born August 2006. He shed the expandable radiocollar 11-7 to 17-06, after which direct contact was lost. M43 was killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO when he was 29.5 months old.
M48	10-18-06	12S,756676E, 4247777N→ 12S,704982E, 4248998N	52.0	M48 was the offspring of F3, born September 2006. M48 was killed by a puma hunter in Tabeguache Creek, GMU 61N on 12-27-09 when he was 38.9 months old.
M49	12-05-06	12S,757241E, 4258259N→ 12S,693350E, 4274559N	66.1	M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek GMU 61N in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old.
M58	06-27-07	13S,258543E, 4238071N→ 13S,274670E, 4309488N	73.2	M58 was offspring of F16, born May 2007. M58 was killed by a puma hunter on 12-27-09 in the North Fork of the Gunnison River north of Paonia, GMU 521; he was 31 months old.

Table 17 continued.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
M63	08-17-07	12S,738144E, 4233628N→ 12S,689111E, 4277908N	66.1	M63 was offspring of F24, born July 14, 2007. He was not radio-collared as a cub. M63 was killed by a puma hunter in Calamity Creek on northwest Uncompahgre Plateau on 01-01-11. M63 was 41.5 months old at death.
M65	08-17-07	12S,738144E, 4233628N→ 12S,684084E, 4314200N	97.0	M65 was offspring of F24, born July 2007. M65 was killed by a USDA, APHIS, WS agent for depredation on llamas in the Little Dolores River on 11-07-09. M65 was 27.8 months old.
M67	08-23-07	13S,257371E, 4235231N→ 12S,725113E, 4242447N	57.7	M67 was offspring of F30, born July 17, 2007 in Fisher Creek on the east slope of the study area. He was not radiocollared as a cub. M67 dispersed from the natal area and was recaptured in Tomcat Creek on the west slope of the study area on 02-24-10 when he was 31 months old. M67 is a resident adult in that area (07-31-11). Killed by puma hunter in GMU61N on 12-18-11 when 52.9 months old.
M68	08-23-07	13S,257371E, 4235231N→ 12S,711262E, 4198681N	80.7	M68 was offspring of F30, born July 2007. He was orphaned at 12 months old when his mother was killed by a puma. He was killed by a puma hunter in the Disappointment Valley in southwest CO on 12-30-08; he was 17 months old.
M69	01-11-08	13S,248191E, 4246810N→ 13T,378900E, 4591990N	369.6	M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.
M82	07-05-08	12S,726901E, 4243463N→ 13S,255316E, 4216768N	60.5	M82 was offspring of F8, born May 29, 2008; sibling of M83 below. He shed his expandable cub radiocollar after 03-20-09. M82 was killed by a puma hunter on 12-10-09 in the Beaver Creek fork of East Dallas Creek, GMU 65. M82 was 19 months old.
M83	07-05-08	12S,726901E, 4243463N→ 12S,670949E, 4314779N	90.7	M83 was offspring of F8, born May 29, 2008; sibling of M82 above. He was not radiocollared as a cub. M82 was killed by a puma hunter on 01-18-11 in Coates Creek west of Glade Park, CO. He was 31.6 months old at death.
M87	07-31-08	13S,239006E, 4248601N→ 12S,724325E, 4244118N	39.2	M87 was offspring of F3, born July 3, 2008 on the east slope of the study area; sibling of M88 below. He was not radiocollared as a cub. M87 dispersed from the natal area. He was recaptured on the west slope of the study area on 02-09-11 when he was 31 months old. M87 is was resident adult on the west slope of the study area. He was killed by a puma hunter on 12-06-11 at 41 months old north of the study area.
M88	07-31-08	13S,239006E, 4248601N→ 12S,704835E, 4197839N	77.6	M88 was offspring of F3, born July 3, 2008 on the east slope of the study area; sibling of M87 above. He was not radiocollared as a cub. M87 dispersed from the natal area. He was killed by a puma hunter in Dawson Creek, Disappointment Valley on 11-30-10 when he was 29 months old.
M92	09-29-08	13S,246359E, 4226949N→ 12S,750871E, 4222921N	21.9	M92 was offspring of F25, born August 19, 2008. He was radiocollared as a cub; last contact on 12-12-08. M92 dispersed from the natal area and was recaptured in McKenzie Creek, west slope of the study area on 04-22-11 when he was 32 months old. He could not be handled to fit a new radiocollar because of a dangerous tree.

Table 17 continued.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
M107	06-28-09	13S,242359E, 4252618N→ 12S,754886E, 4341330N	89.2	M107 was offspring of F94, born May 25, 2009; sibling of F108 below. He was not radiocollared as a cub. M107 dispersed from the nata area. He was killed by a puma hunter in Cottonwood Creek near Molina, CO on 12-09-10 when he was 19 months old.
M112	01-23-10	13S,248567E, 4240108N→ 12S,732863E, 4146772N	102.5	M112 was initially captured 4.7 mo. old in his natal area while dependent on his mother F70 on 01-23-10. He was recaptured 01-24-11 in the natal area at 17 months old, independent of F70. M112 associated with F96 and her two radio-collared cubs F129 and M130 during 02-10-11 to 04-18-11 when he was 18-20 mo. old. Lost contact of M112 after 04-18-11. Dispersed and emigrated from the U.P. study area. M112 was killed by a puma hunter 01-06-2013, GMU 73, SE of Dolores, CO; UTM: 12S, 732863E, 4146772N; age 41 months.
M114	02-27-10	13S,256933E, 4237862N→ 13S,492615E, 4266192N	237.5	M114 was initially captured at about 30 months old. Emigrated from the U.P. study area. He was killed by a puma hunter on 03-10-12 in Beaver Creek, GMU59. He was about 55 months old at death.
M117	02-05-10	12S,731840E, 4232346N→ 12S,743909E, 4216633N	19.7	M117 was offspring of F119. He wore an expandable cub collar, but shed the collar by 07-15-10 on the natal area when about 11 months old. M117 was killed by a puma hunter in Beaver Creek, San Miguel River at the southern extreme of his natal area on 01-01-11. He was 17 months old at death. It is unknown if M117 was independent from his mother F119 at the time of his death.
M126	09-05-10	12S,734503E, 4224636N→ 12S, 710850E, 4239350N	27.7	M126 was offspring of F118, born Aug. 8, 2010. Lost radio contact after 03-17-11; shed his radiocollar at a mule deer cache. Dispersed from natal area. Killed by a puma hunter on 01-08-12 in Tuttle Draw WNW of Nucla, CO as 17-month-old subadult.
M144	03-07-33	12S,727173E, 4242012N→ 12S,696439E, 4276888N	46.6	M144 was initially captured as an independent subadult in association with subadults F145 and F146 on the study area. Mother is unknown. He moved off the study area on 03-15-11. M144 established his adult territory on northwest Uncompahgre Plateau and upper Unaweep Canyon from Sep. 2011 to 02-25-13. M144 was killed by a puma hunter 02-25-13 in GMU 40, North Fork West Creek, Unaweep Canyon.
M161	01-23-12	12S,727932E, 4239430N→ 13S,247567E, 4220129N	49.2	M161 (sibling of F149) was orphaned when his mother F23 was killed by a male puma on 06-06-12; he was 411 days (13.5 mo.) old. M161 dispersed from the natal area by 06-29-12 when he was 14 months old and moved to the east slope of the U.P. study area. M161 shed his expandable cub collar about Aug. 3, 2012 in head of E Fk. Dry Creek. He was struck and killed by a vehicle on highway 62 at Dallas Divide in October 2012; he was 18 mo. old.

Table 17 continued.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
F52	01-10-07	13S,258058E, 4236260N→ 13S,319217E, 4240467N	61.1	F52 was captured on the study area when about 18-20 months old. Dispersed from study area as a subadult by Jan. 16, 2007. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old . F52 was treed again by puma hunters on about 12-16-09 south of Powderhorn: 13S,319480E,4233219N. F52 was about 53-55 months old. This suggests that F52 has an adult home range in that area. F52 was killed by a puma hunter on 01-09-12 in North Beaver Creek SE of Powederhorn, CO. She was about 79 months old at death.
F97	02-04-09	12S,727529E, 4237648N→ 12S,705930E, 4227299N	24.0	F97 was offspring of F23, born May 23, 2008. She was radio-collared at 8.5 month old in San Miguel Canyon; but, lost contact on 05-12-09 after F97 shed the radiocollar at an elk cache. F97 dispersed from the U.P. study area. She was killed by a puma hunter on 01-22-12 in Dry Creek west of the U.P. study area when she was 43.9 months old.
F106	06-14-09	12S,736451E, 4240278N→ 13S,258089E, 4235866N	46.9	F106 was offspring of F75, born May 7, 2009. She wore an expandable cub collar, but shed it about 03-23-10. F106 dispersed from the natal area and moved to the east slope of the study area where she was photographed at one of our scent station cameras at the mouth of Fisher Creek from 02-27-11 to 03-03-11. She was identified by her eartag. F106 was 21 months old.
F108	06-28-09	13S,242359E, 4252618N→ 12S,752013E, 4263883N	18.2	F108 was offspring of F94, born May 25, 2009; sibling of M107 above. She was fitted with an expandable cub collar; but, shed the collar in the original nursery due to failure of the fastener. F108 dispersed from the natal area. She was killed by a puma hunter on the study area on 11-29-10 when she was 17 months old.
M122	08-12-2010	12S,746164E, 4276613N→ 12S,735353E, 4283455N	12.9	M122 was offspring of F104, born July 8, 2010. Fitted with expandable cub collar 08-12-10. Lost contact 04-28-11 due to transmitter malfunction. Killed by puma hunter N of natal area 01-23-13 at 30 mo. old.
M131	09-25-10	12S,760695E, 4243505N→ 12S,670829E, 4246980N	90.1	M131 was offspring of F96, born August 21, 2010. Lost contact after 07-21-11. Shed his radiocollar about 07-27-11. Survived to recapture on 02-02-12 at 17.4 months old, with sibling F129; neither handled due to dangerous trees. Emigrated from U.P. study area. Killed by a puma hunter 01-17-13 at 29 mo. old in GMU 60 in western Colorado near border with Utah.
F143	02-15-11	12S,723748E, 4238579N→ 12S,721795, 4264246	25.7	F143 was captured on the study area when about 24 months old. Dispersed N on the Uncompahgre Plateau and established an adult home range on the NW portion of the Uncompahgre Plateau (most recent location 07-16-12).
F145	03-18-11	12S,727181E, 4241468N→ 12S,705833E, 4312909N	74.5	F145 was originally captured in association of M144 and F146; they may be siblings. Mother unknown. She moved off the study area with M144 on 03-15-11. F145 emigrated to Colorado Mesa. She was killed by a puma hunter 01-23-12 in West Bangs Canyon. F145 was 28 months old at death.

Table 17 continued.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
F149	06-06-11	12S,729993E, 4242329N→ 12S,713658E, 4229703N	20.7	F149 (sibling of M161) was orphaned when her mother F23 was killed by a male puma on 06-06-12; she was 411 days (13.5 mo.) old. F149 dispersed from the natal area by 07-16-12 when she was 14.8 months old and moved to the NE Uncompahgre Plateau, onto Bostwick Park, then back across Uncompahgre Plateau. She emigrated from the U.P. study area and was killed by a puma hunter 12-31-12 at 20 mo. old
F163	01-26-12	12S,732153E, 4232452N→ 12S,695407E, 4280753N	60.7	F163 was initially captured at about 18 months old. She emigrated from the study area and may have established an adult home range on the N portion of the Uncompahgre Plateau as of July 2012 (07-16-12 most recent location).
M165	02-24-12	12S,722816E, 4246926N→ 12S,730814E, 4272500N	26.9	M165 was first captured 02-24-12 at ~19 mo. old. His origin unknown. He moved from the west slope of the U.P. study area to the east slope of the U.P. north of the study area between 05-04-2012 and 06-15-12. He was killed by a puma hunter in GMU 62N on 12-17-12 when he was ~29 mo. old.
F194	01-29-13	12S,742443E, 4225259N→ 12S,729101E, 4201962N	26.9	F194 was first captured at ~24 mo. old on W slope of U.P. study area on 01-29-13. Her origin unknown. She emigrated from the U.P. study area heading S. Her last aerial location was 06-17-13 on North Mt. in the SW head of Naturita Creek.

*Estimated linear dispersal distance (km) from initial capture site on Uncompahgre Plateau study area to hunter kill, or last recapture, radio location, or observation site.

Table 18. Recorded deaths of non-marked and marked pumas struck by vehicles and other unusual causes, in chronological order, on the Uncompahgre Plateau puma study area, Colorado, from 2004 to 2012.

Puma sex & ID if marked	**Estimated age (mo.)**	**Date recorded**	**Cause of death**	**General physical condition**	**Location & UTM NAD27**
M	12	09-24-04	Vehicle collision	Good	Pleasant Valley, County Road 24 13S,252870E,4227520N
F	49	07-28-05	Vehicle collision	Good Not pregnant or lactating	Highway 62 east of Dallas divide 13S,250000E,4222500N
F17[a]	11	08-18-06	Vehicle collision	Good	Highway 550 south of Colona 13S,257602E,4242185N
F	18-24	11-06-06	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843E,4235985N
F	6	01-30-07	Vehicle collision	Good	Highway 62 west of Dallas divide 12S,762286Ex4218992N
F P1005	36	09-16-08	Asphyxia, lodged in fork of tree	Unknown, decomposed	Davis Point, Roubideau Canyon 12S, 743718E,4255277N
M	12-24	08-13-08	Vehicle collision	Good	Highway 145 west of Placerville 13S,756490E,4212336N
F61[a]	18	11-13-08	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843E,4235985N
F	12	08-10-09	Vehicle collision	Good	Highway 145 east of Norwood 12S,745739E,4222548N
F16[b]	80	09-11-09	Vehicle collision	Good	Ouray County Road 1 13S,253733E,4240060N
M6[b]	99	05-21-0	Vehicle collision	Good	Highway 550 south of Colona 13S,258610E,4236805N
F113[b]	42	06-06-10	Vehicle collision	Good Not pregnant or lactating	F113 crossed Highway 550 and roads on Loghill Mesa 24-30 hours before she died in McKenzie Creek 13S,257272E,4238435N
M P1018[c]	24	08-25-10	Vehicle collision	Excellent	Highway 62 Leopard Creek 12S,237747E,4220330N
F P1030[c]	6	02-16-11	Vehicle collision	Good	Highway 62 Leopard Creek 12S,760953E,4216683N
M P1034	4	10-07-11	Vehicle collision	Fair	Highway 62 Leopard Creek 12S,762806E,4219531N
M161	18	06-17-13	Vehicle collision	Unknown, decomposed	Highway 62 Dallas Divide 13S,2475674220129

[a] Subadult marked (i.e., tattoos, eartags), but not radio-collared.
[b] Adult GPS/VHF-collared pumas.
[c] Non-marked puma with P one-thousand number designation.

Table 19. Pumas monitored with GPS collars on the Uncompahgre Plateau, Colorado, December 2004 to July 2013.

Puma I.D.	Sex	Age stage	Dates monitored
M1	M	adult	12-08-04 to 07-20-06
M4	M	adult	01-28-05 to 01-14-06
M6	M	adult	02-18-05 to 05-14-08
M27	M	adult	03-12-06 to 06-21-06
M29	M	adult	04-14-06 to 01-01-08
M51	M	adult	01-07-07 to 07-15-08
M55	M	adult	01-21-07 to 11-25-10
M100	M	adult	03-27-09 to 01-16-10
M133	M	adult	11-12-10 to 12-01-10
M178	M	adult	11-13-12 to 12-11-12
M179	M	adult	11-18-12 to 12-29-12
M183	M	adult	02-14-13 to 07-31-13
F2	F	adult	01-07-05 to 08-14-08
F3	F	adult	01-21-05 to 12-11-11
F7	F	adult	02-24-05 to 08-03-08
F8	F	adult	03-21-05 to 10-10-06
F16	F	adult	10-12-05 to 09-10-09
F23	F	subadult	01-04-06 to 02-04-06
		adult	02-05-06 to 09-04-09
F24	F	adult	01-17-06 to 07-25-07
F25	F	adult	02-09-06 to 09-09-09
F28	F	adult	03-24-06 to 08-15-07
F30	F	adult	03-30-07 to 02-22-08
F50	F	adult	12-14-06 to 03-26-07
F52	F	subadult	01-10-07 to 05-08-07
F54	F	adult	01-12-07 to 08-18-08
F70	F	adult	01-14-08 to 12-22-11
F72	F	adult	02-12-08 to 07-07-10
F75	F	adult	03-26-08 to 06-03-09
F93	F	adult	10-03-12 to 11-11-12
F95	F	adult	03-14-13 to 07-31-13
F96	F	adult	01-28-09 to 07-31-12
F104	F	adult	05-29-09 to 01-31-12
F111	F	adult	01-01-10 to 07-31-13
F113	F	adult	01-27-10 to 06-06-10
F129	F	adult	01-02-13 to 07-31-13
F135	F	adult	01-01-11 to 09-20-11
F136	F	adult	01-20-11 to 07-31-13
F137	F	adult	04-12-11 to 07-31-13
F152	F	subadult	01-18-12 to 06-15-12
		adult	06-16-12 to 12-23-12
F171	F	adult	01-20-12 to 07-31-13
F172	F	adult	03-28-12 to 07-31-13
F177	F	adult	10-27-12 to 12-10-12
F181	F	subadult	01-15-13 to 04-15-13
		adult	04-16-13 to 07-31-13
F182	F	adult	02-04-13 to 07-31-13
F186	F	adult	03-30-13 to 07-31-13

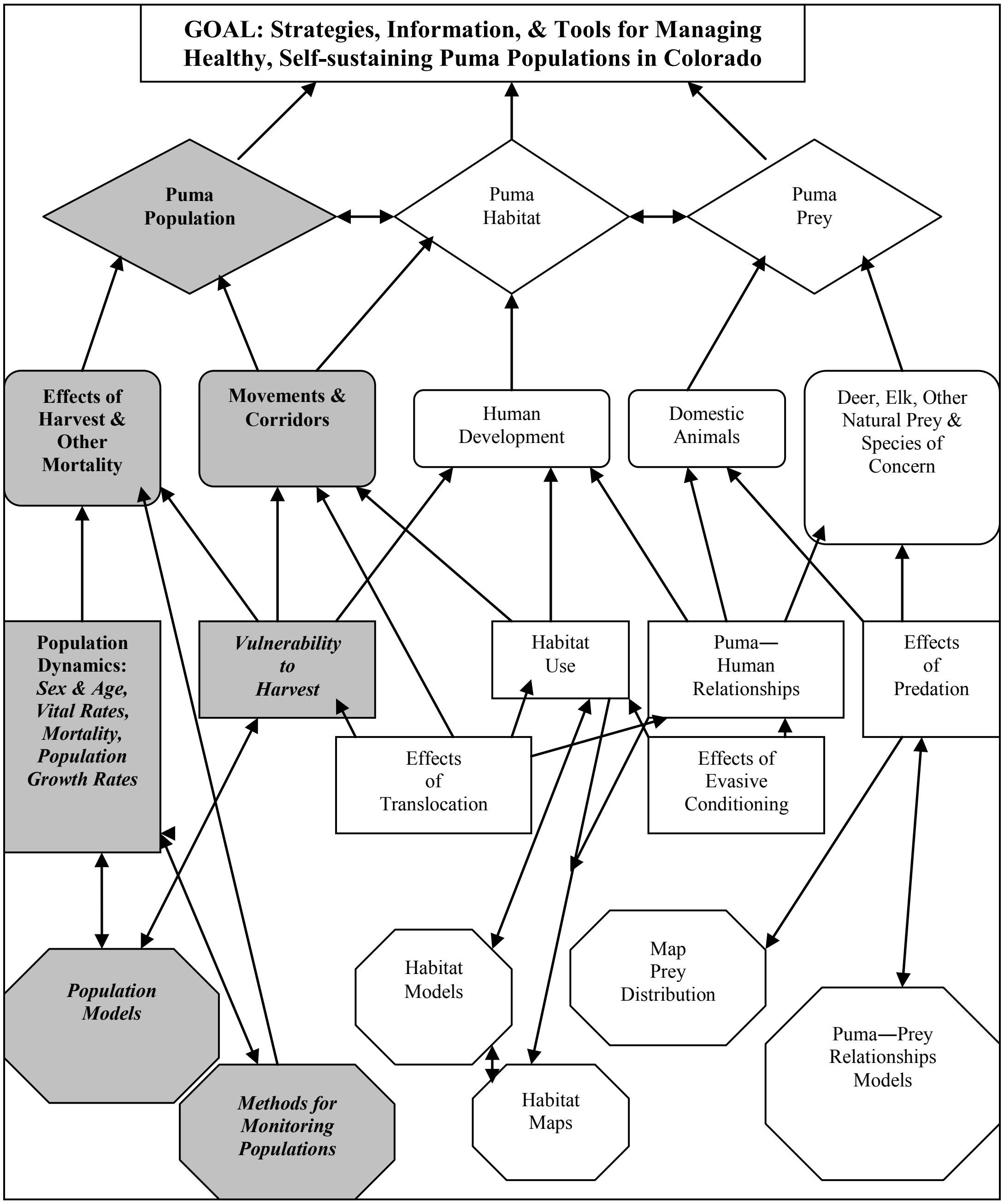

Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by this puma research on the Uncompahgre Plateau for the puma management goal in Colorado (at top).

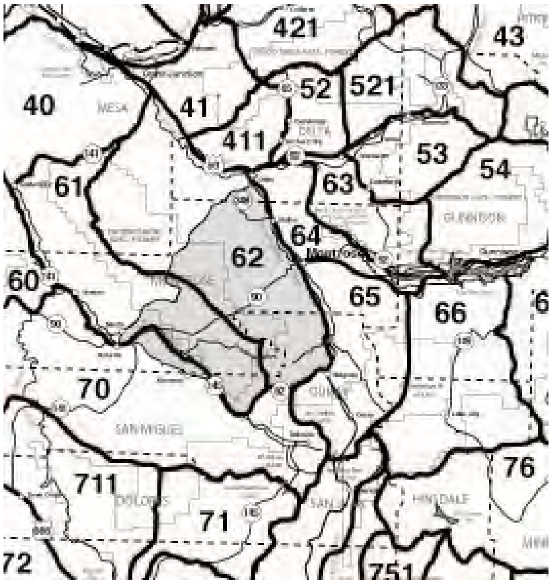

Figure 2. The puma study area on the southern half of the Uncompahgre Plateau, Colorado (shaded in gray) comprising the southern portions of Game Management Units (GMUs) 61 and 62 and a northern portion of GMU 70.

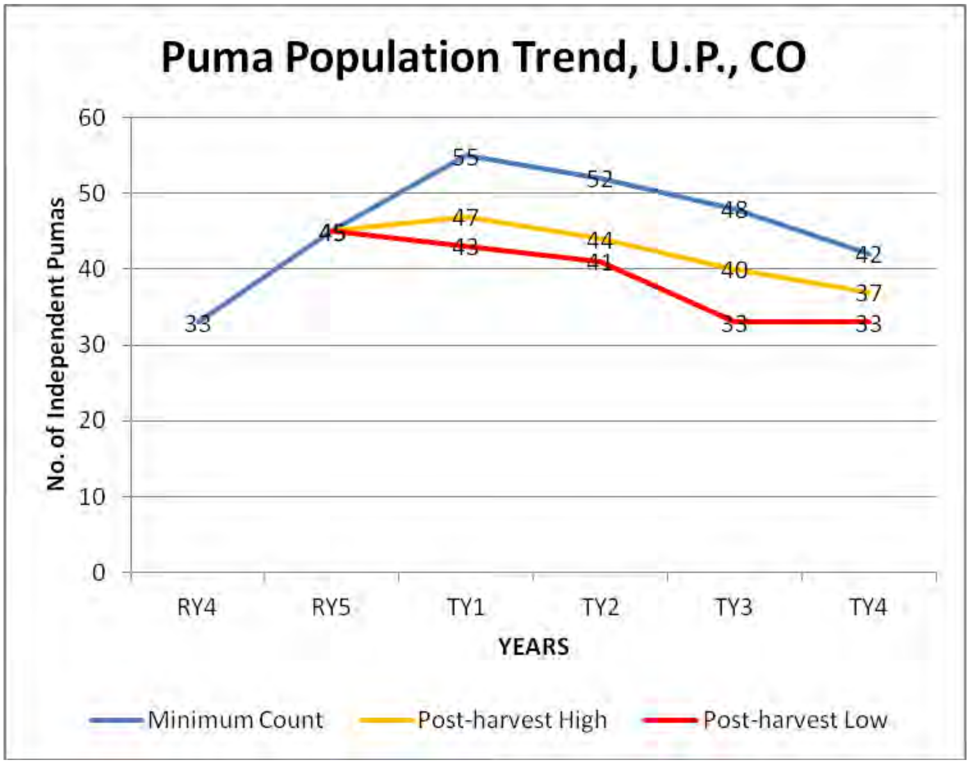

Figure 3. Trends in the population of independent pumas on the Uncompahgre Plateau Puma Study Area, including Reference Years 4 and 5 (RY4, RY5) and Treatment Years 1, 2, 3, and 4 (TY1, TY2, TY3, TY4). Numbers represent minimum counts that include all pumas from known radio-collared pumas, visual observations of non-marked pumas, harvested non-marked pumas, and track counts of suspected

non-marked pumas on the study area during fall to spring hunting and research capture seasons, except RY5 (45), which had to be modeled from RY4 observation data (33) because the state government hiring freeze that year affected search and capture efforts. The actual minimum count for RY5 was 37 independent pumas. The quota of 8 pumas for TY1 represented a 15% harvest of the model projected 53 independent pumas expected in TY1 and was used to set the quota ahead of the hunting season. Starting in TY1, two capture teams were deployed to count pumas on the study area because the hunting season shortened our fall-winter-spring research period. We deployed a team on each the east and west sides of the study area. The minimum count for TY1 was actually 55 independent pumas, consistent with the model expected 53.

Post-harvest high trend line represents the population of independent pumas after pumas harvested only on the study area by hunters. This trend line represents 11.9% to 16.7% harvest of independent pumas.

Post-harvest low trend line represents the population of independent pumas after pumas harvested on the study area and pumas harvested when they ranged onto adjacent GMUs open to hunting and other mortalities are subtracted from the minimum count. TY1 post-harvest low includes 1 adult female and 3 adult males killed off the study area. The TY2 post- harvest low includes 1 adult male killed off the study area and 2 adult female pumas killed in February 2011 on the study area to protect livestock. The TY3 post-harvest low includes 1 adult female and 4 adult males harvested off the study area and 2 adult females that died of natural causes on the study area. The TY4 post-harvest low includes 1 adult female and 1 adult male harvested off the study area and 1 adult female that died of natural cause. This trend line represents 21.2% to 31.2% harvest of independent pumas.

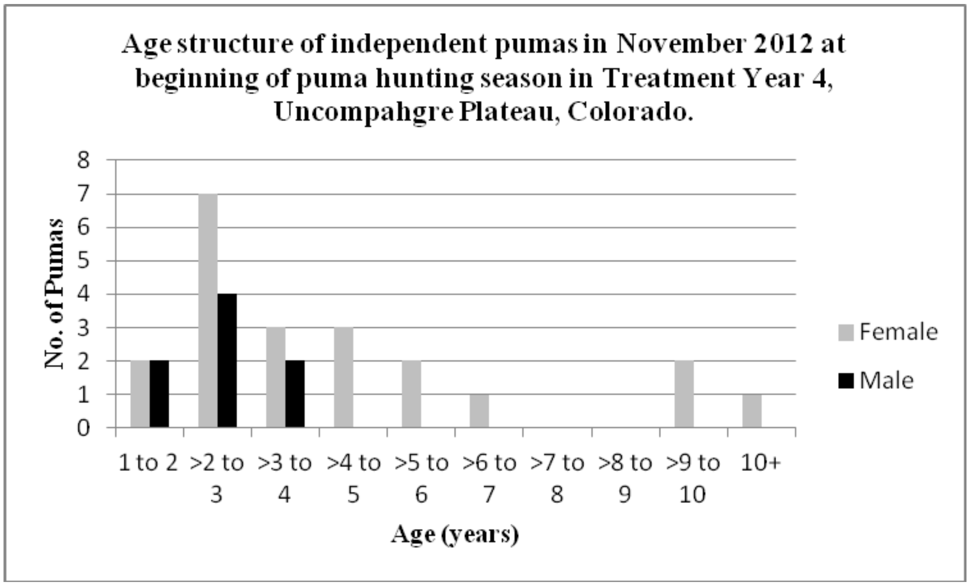

Figure 4. Estimated age structure of independent pumas in November 2012 at the beginning of the puma hunting season in Treatment Year 4 (TY4) on the Uncompahgre Plateau study area, Colorado. All these pumas were captured and sampled by researchers or harvested by hunters and examined by researchers. Mean ± *SD* of independent female and male ages, respectively: 4.29 ± 2.69 yr. (51.48 ± 32.29 mo.), *n* = 21; 2.51 ± 0.86 yr. (30.12 ± 10.37 mo.), *n* = 8.

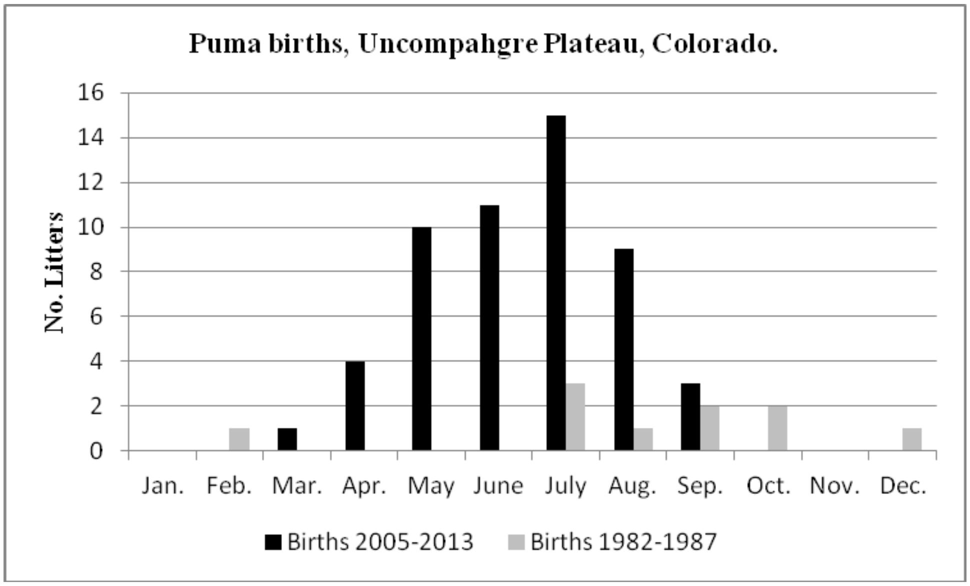

Figure 5. Puma births (black bars) detected by month from May 19, 2005 to July 31, 2013 (*n* = 53 litters of 27 females; 51 of the litters were examined at nurseries when cubs were 26-42 days old and 2 litters confirmed by tracks of ≥1 cubs following GPS-collared mothers F28 and F111 when cubs were ≤42 days old). Also shown (gray bars) are results of the earlier effort by Anderson et al. (1992:48; 1982 to 1987, *n* = 10 litters of 8 females, examined when cubs were <1 to 8 months old), Uncompahgre Plateau, Colorado.

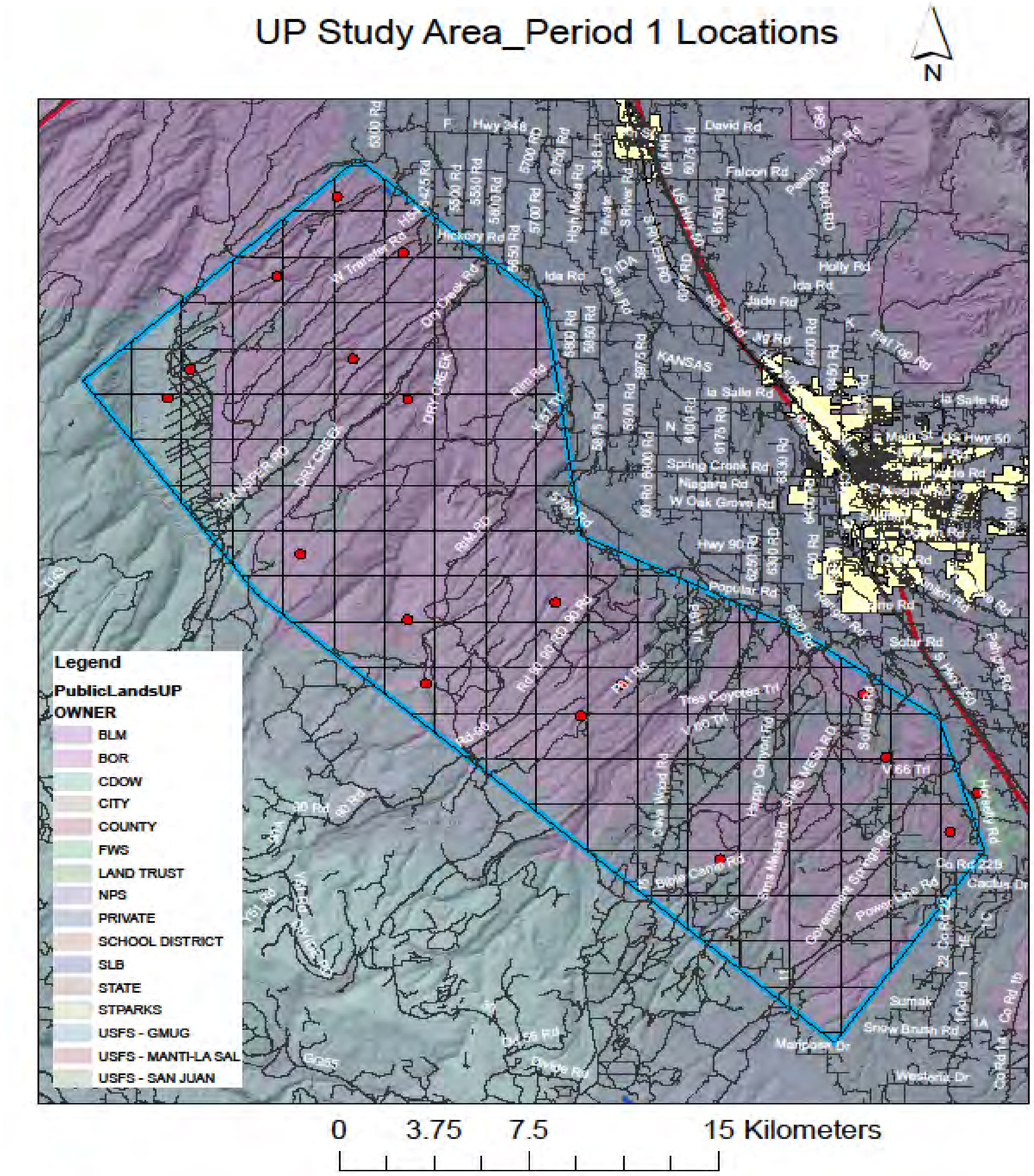

Figure 6. The grid on the east slope of the Uncompahgre Plateau Puma Project study area indicating the 18 camera/call box sites (red dots) in sample period 1. A total of 3 sample periods were used, each 28 days long and each with 18 sites, for a total of 54 random cells surveyed December 2012 to March 2013 to test non-invasive survey methods. Image by M.S. student Kirstie Yeager.

Appendix A. Summary of individual puma cub survival and mortality, 2005 to 2013, Uncompahgre Plateau, Colorado.

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M5	183	~8-1-04	02-04-05 to 02-20-09	~1,664	Radio-collared. Survived to subadult stage by 09-16-05; independent at ~13 mo. old. Dispersed from natal area by 09-29-05 at 14 mo. old. Established territory on NW U.P. Killed by hunter in Beaver Creek, UT 02-20-09 at 54.6 months old.	F3
F9	31	5-28-05	06-27-05 to 4-19-06	326-333	Radio-collared. Shed radiocollar 04-19-06 to 04-26-06.	F2
F10	31	5-28-05	06-27-05 to 11-20-05—12-29-05	176-215	Radio-collared. Dhed radiocollar 08-10-05; last tracks of F10 with mother F2 & siblings F9 & M11 observed 11-20-05. F10 disappeared by 12-30-05.	F2
M11	31	5-28-05	06-27-05 to 12-02-07	918	Radio-collared. Shed collar 10-24 to 11-08-05. Recollared on 04-02-06. Survived to subadult stage by 06-21-06, independent at 13 mo. old. Dispersed from natal area by 07-11-06 at 14 mo. old. Moved to Dolores River valley in SW CO by 12-14-06. Killed by a hunter in SW CO 12-2-07 at 918 days (30 mo.) old.	F2
F12	42	5-19-05	07-01-05 to 12-08-05—01-26-06	203-252	Radio-collared. Shed radiocollar 07-28-05—08-01-05. Tracks of F12 found in association with mother F7 on 12-08-05. F12 disappeared by 01-27-06 when she was not visually observed with F7, and her tracks were not seen in association with F7's tracks.	F7
F13	42	5-19-05	07-01-05 to 08-28-05	101	Radio-collared. Killed and eaten by a puma possibly M5 (13 mo. old) about 08-28-05.	F7
F14	26	6-26-05	07-22-05 to 02-07-06—03-10-06	226-257	Radio-collared. Shed radiocollar 01-20-06 to 01-25-06. Tracks of F14 were observed with tracks of mother F8 & sibling M15 on 02-07-06. Disappeared by 03-11-06, only tracks of F8 & M15 were found.	F8
M15	26	6-26-05	07-22-05 to 06-06 to 14-06	345-353	Radio-collared. Shed radiocollar 06-06-06 to 06-14-06.	F8
F17	34	9-22-05	10-26-05 to 08-18-06	330	Radio-collared. Shed radiocollar 06-06-06 to 06-14-06. Killed by a car on highway 550 on 08-18-06. Probably dependent on F16. Died at 10.8 months old	F16
F18	34	9-22-05	10-26-05 to 07-20 to 27-06	301-308	Radio-collared. Probably killed by another puma. Multiple bite wounds to skull. Died at 10 months old.	F16
M19	34	9-22-05	10-26-05 to 07-27 to 08-02-06	308-314	Radio-collared. Shed radiocollar 07-27-06 to 08-02-06.	F16
M20	34	9-22-05	10-26-05 to 05-24-06	244-245	Radio-collared. Shed radiocollar 05-24-06—05-25-06.	F16

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F21	37	9-26-05	11-02-05 to 08-16-06	324	Radio-collared. Lost contact; radiocollar quit. Last aerial location 8-16-06, live signal.	F3
M22	37	9-26-05	11-02-05 to 12-21-05—12-22-05	86-87	Radio-collared. Killed and eaten by male puma 12-21-05 to 12-22-05.	F3
M26	183	8-1-05	02-08-06 to 03-21 to 24-06	~232-235	Radio-collared. Shed radiocollar 03-21-06 to 03-24-06.	F25
F33	31	5-30-06	06-30-06 to 07-31-06	63-65	Radio-collared. Probably killed and eaten by a male puma 08-01 to 03-06. GPS data on M29 indicate he was *not* involved.	F23
F34	31	5-30-06	06-30-06 to 07-31-06	63-65	Radio-collared. Probably killed and eaten by a male puma 08-01 to 03-06. GPS data on M29 indicate he was *not* involved.	F23
F35	31	5-30-06	06-30-06 to 07-07-06	38	Dead; research-related fatality.[a]	F23
F36	29	6-9-06	07-08-06 to 07-28-06	74	Radio-collared. Killed and eaten by a male puma 08-22-06. GPS data on M29 indicate he was *not* involved.	F28
M37	29	6-9-06	07-08-06 to 07-28-06	74	Radio-collared. Killed and eaten by a male puma 08-22-06. GPS data on M29 indicate he was *not* involved.	F28
M38	41	7-29-06	09-08-06 to 07-16 to 17-07	352-353 1623	Radio-collared. Shed radiocollar found 03-06-07. Photo (trail camera in McKenzie Cr.) of M38 & Unm. F sibling with F2 on 07-16 to 17-07 at 352-353 days old. Dispersed. Killed by puma hunter 01-07-11 in GMU40 Ladder Creek, SW of Grand Junction, CO when he was 53.2 months old.	F2
M39	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255 1307	Radio-collared. Shed radiocollar by 09-20-06, but seen alive on that date. Tracks of 2 cubs following F8 on 04-25-07. Survived to adult stage; dispersed from natal area. Dispersed. Killed by a puma hunter 03-12-10 in GMU 40, Bangs Canyon, when 42.8 months old.	F8
F40	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255	Radio-collared. Shed radiocollar by 09-20-06, but seen alive on that date. Tracks of 2 cubs following F8 on 04-25-07.	F8
F41	29	8-13-06	09-11-06 to 10-05-06	53-61	Radio-collared. Assumed dead. Shed radiocollar or died (blood on collar) between 10-05-06 (last live signal) & 10-13-06 (collar found).	F8
M42	29	8-13-06	09-11-06 to 11-27-06	106	Dead; research-related fatality.[b]	F8

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M43	33	8-13-06	09-15-06 03-01-07	200 899	Radio-collared. Shed radiocollar by 11-7 to 17-06. Dispersed. Killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO GMU41 at 29.5 months old.	F7
M44	33	8-13-06	09-15-06 to 02-14-07	479	Radio-collared. Shed radiocollar by 10-27-06. Treed, visually observed 02-14-07; sibling (?) M56 also captured, sampled, & marked for 1st time. M44 killed by Wildlife Services for depredation control on 12-05-07, for killing 4 domestic sheep. He was still dependent on F7. He was 15.7 months old.	F7
F45	33	8-13-06	09-15-06 to 5-20 to 23-07	280-283	Radio-collared. Multiple puncture wounds on braincase—parietal & occipital regions; consistent with bites from coyote. F45 switched families, moving from F7 to F2 about 12-19 to 20-06. Last date F45 was with F2 was 04-17-07. Died 05-20 to 23-07 when she was 9.2 months old.	F7
M46	31	9-17-06	10-18-06 to 12-15-06	89 360	Radio-collared. Shed collar by 12-14-06. Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon.	F3
M47	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07	89 360	Radio-collared. Shed collar . Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon.	F3
M48	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07 to 12-27-09	89 360 1187	Radio-collared. Shed radiocollar. Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon. Dispersed. Survived to adult stage; dispersed from natal area. Killed by a puma hunter 12-27-09 in Tabaguache Creek, GMU 61N when 38.9 months old.	F3
M49	153	7-1-06	12-05-06 to 07-31-07 to 01-24-09	939	Radio-collared. M49 was orphaned when his mother died on about 03-26-07; he was ~268 days old. M49 dispersed from natal area and onto NE slope of U.P. Shed radiocollar at a yearling cow elk kill about 10-01-07; he was ~428 days old. Dispersed from natal area. Killed by a puma hunter in Blue Creek, northwest Uncompahgre Plateau (GMU 61N) 01-24-09 when ~29 months old.	F50

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F53	183	7-1-06	01-12-07 to 02-23-07 to 09-02-07	42 ~428 subad.	Radio-collared. Shed radiocollar 02-23-07. F53 visually observed by P. & F. Star (Loghill Mesa), on 09-02-07, when F53 was ~14 months old and an independent subadult.	F54
M56[c]	183	~8-13-06	02-14-07 to 03-01-07	200	Radio-collared. Shed radiocollar 2-27-07. M56 observed 03-01-07.	F7 (?)
F57	35	4-16-07	05-21-07 to 06-06-07	52	Radio-collared. Shed radiocollar 06-07-07. Live mode 06-06-07.	F25
M58	34	5-24-07	06-27-07	324 434	Not radio-collared. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde. Dispersed. Survived to adult stage. Killed by a puma hunter 12-27-09 in GMU 521, North Fork Gunnison River, when 31 months old.	F16
F59	34	5-24-07	06-27-07 to 08-21-07	55 324 434	Radio-collared. Shed collar about 02-14-08. Observed with 11-20-07 with F16, but without siblings M58 and F61. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. Three cubs observed with F16 on 08-08-08 by B. & T. Traegde.	F16
M60	34	5-24-07	06-27-07 to 07-11 to 12-07	48-49	Dead; research-related mortality.[d]	F16
F61	34	5-24-07	06-27-07 to 06-29-07	324 434 538	Radio-collared. Radiocollar malfunction. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde. Dead. Died probably as independent subadult at 538 days old; struck by car on Hwy 550 mi. marker 111 N. of Ridgway, CO, euthanized by gunshot on 11-13-08.	F16
M62	34	7-14-07	08-17-07		Not radio-collared.	F24
M63	34	7-14-07	08-17-07 to 01-01-11	1267	Not radio-collared. Dispersed from study area. Killed by a puma hunter 01-01-11 in Calamity Creek, GMU61N when he was 41.5 months old.	F24
M64	34	7-14-07	08-17-07	262	Not radio-collared. Two out of potential of 4 of F24's male cubs were visually observed with her on 4/1/08. Assume that 2 male cubs died before the age of 8.5 mo. Eartags were seen on both cubs, but the numbers were not.	F24

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M65	34	7-14-07	08-17-07 to 11-07-09	262 847	Not radio-collared. Two out of potential of 4 of F24's male cubs were visually observed with her on 04-01-08. Assume that 2 male cubs died before the age of 8.5 mo. Eartags were seen on both cubs, but the numbers were not. Dispersed. Survived to adult stage. Killed by Wildlife Services for depredation control for predation on llamas in Little Dolores River, on 11-07-09 when 27.8 months old.	F24
F66	37	7-17-07	08-23-07 to 05-28-09	682	Radio-collared. Lost contact; last location 11/5/07. No signals after that date. F66 was photographed with one male sibling, either M67 or M68, & F30 on 5/31-6/1/08. F66 was recaptured and radio-collared as a subadult on 11/25/08. She died from massive trauma & bleeding of internal organs possibly resulting from being trampled by an elk or mule deer on about 05-28-09 as an independent subadult 23 months old. Her range overlapped her natal area.	F30
M67	37	7-17-07	08-23-07 to 12-18-11	1615	Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 5/31-6/1/08. Dispersed from natal area. Established adult home range on west side of Uncompahgre Plateau study area. Killed by puma hunter in GMU61N on 12-18-11 when 52.9 months old.	F30
M68	37	7-17-07	08-23-07 to 12-30-08	532	Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 05-31 to 06-01-08. Survived to subadult stage. Dispersed. Killed by a puma hunter in Disappointment Valley, CO (GMU 71) 12-30-08 at 17.5 months old.	F30
F74	259	6-1-07	03-12-08 to 07-09-08	403	Radio-collared. Shed radiocollar between 7-9-08 and 7-15-08, probably while still dependent on mother F75.	F75
M76	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M77	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F78	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M79	30	5-19-08	06-18-08	87	Not radio-collared. Dead. Chewed-off anterior portions of the nasals, maxilla, palate, dentaries, and pieces of the braincase, with 6 or 9 portion of yellow ear-tag and intestines and bits of skin found ~45 m from mother F2's death site on 08/14/08. Cub death probably due to puma-caused infanticide with cannibalism at ~87 days old. Male puma scrapes, about 8, under a rock rim ~50m distance from cub remains, and made ~ time of pumas' deaths.	F2
F80	40	5-23-08	07-02-08		Not radio-collared. Apparently died before 02-04-09; no tracks found in association with F23 & siblings F81 & F97.	F23
F81	40	5-23-08	07-02-08 to 07-29-09	424	Radio-collared. Last live location 7-29-09.	F23
F95	~488	~Aug. 2007	12-29-08 to 07-31-13	2,196	Radio-collared. F95 was offspring of F93. She survived the subadult stage and into the adult stage. Her home range overlapped her natal area.	F93
F97	257	5-23-08	02-04-09 to 01-22-12	1339	Radio-collared. Lost contact after 05-12-09; shed collar at elk kill cache on Mailbox Park. Dispersed from study area. Killed by a puma hunter 01-22-12 in Dry Creek when 43.9 months old.	F23
M82	37	5-29-08	07-05-08 to 12-10-09	560	Radio-collared. Shed radiocollar after 03-20-09. Survived to subadult stage. Dispersed. Killed by a puma hunter in 12-10-09 GMU 65, Beaver Creek fork of East Dallas Creek, when 18.4 months old.	F8
M83	37	5-29-08	07-05-08 to 01-18-11	964	Not radio-collared. Survived; dispersed from study area. Killed by a puma hunter 01-18-11 in Coates Creek west of Glade Park, GMU40. He was 31.6 months old.	F8

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M84	36	6-5-08	07-11-08 to 02-11-09	251	Radio-collared 7-11-08 to 7-22-08; collar removed because of malfunction. Not radio-collared after 7-22-08. Eartag of M84 was found by E. Phillips on 8-25-08 when mother F70's GPS locations located her on either side of the eartag in the East fork Dolores Cyn. M84 recaptured radiocollared again 1-29-09 in Dolores Cyn. in association with F70 & F96's family. Shed radiocollar again about 02-14-09.	F70
F85	36	6-5-08	07-11-08 to 10-01-08	118	Radio-collared. Dead. Probably died of predation or infanticide about 10-1-08 near elk calf kill at age 3.9 months.	F70
F86	36	6-5-08	07-11-08 to 07-23 to 08-03-08	~48-59	Radio-collared 7-22-08. Dead. Radio-collar, orange ear-tag #86 with pinna with green tattoo #86 found by J. Timmer 9-1-08. F86 died ~7-23 to 8-3-08 when mother F70's GPS locations located her at F86 remains. Probable predation.	F70
M87	28	7-3-08	07-31-08 to 12-06-11	1251	Not radio-collared. Dispersed from natal area. Recaptured as adult on west slope of study area on 02-09-11 at 31 months old. Killed by puma hunter on 12-06-11 at 41 months old in GMU61N north of the study area.	F3
M88	28	7-3-08	07-31-08 to 11-30-10	880	Not radio-collared. Dispersed. Killed by a puma hunter in Dawson Creek, Disappointment Valley, GMU711 on 11-30-10 when 28.9 months old.	F3
F89	28	7-3-08	07-31-08		Radio-collared.	F3
M90	36	7-9-08	08-14-08	867	Radio-collared. Recaptured as young adult on study area, adjacent to natal area, on 11-16-10. Killed by a puma hunter during TY2 on 11-23-10.	F72
Male 7A	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for killing domestic sheep.	F7
Male 7B	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7
Female 7C	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died of starvation after orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M91	35	8-19-08	09-29-08	455	Radio-collared. Killed by a puma hunter on study area during TY1 as dependent cub on 11-17-09 at age 14.9 months.	F25
M92	35	8-19-08	09-29-08	976	Radio-collared. Lost contact after 12-12-08. Dispersed from natal area. Recaptured in McKenzie Creek, west slope of study area on 04-22-11 when 32 months old. Due to dangerous tree, could not handle him safely to fit new radiocollar.	F25
F95	16 mo.	June-07	12-29-08		Radio-collared. Survived to adult stage. Established adult home range overlapping mother F93's home range. To date, July 2012, F95's home range mainly adjacent to N side of natal area.	F93
F98	4-5 mo.	Sep-Oct-08	02-12-09 to 03-08-09	146-176	Radio-collared. Died; probably killed by male puma (infanticide).	Unm.F
M99	158	Sep-Oct-08	2-27-09 to 01-2010	488	Radio-collared. Offspring of non-marked female. Last location 4-22-09 on Paterson Mt. Died as 16-month old subadult in San Miguel Canyon. Probably killed by another puma; apparent canine punctures to braincase.	Unm.F
M101	35	4-15-09	05-20-09 to 09-19-09	157	Radio-collared. Died; killed by puma M55 after he was orphaned due to death of mother F16 by vehicle strike.	F16
M102	35	4-15-09	05-20-09		Radio-collared. Lost contact after 09-04-09. Did not find evidence of M102 associated with deaths of siblings M101 and F103. But M102 probably died.	F16
F103	35	4-15-09	05-20-09 to 09-17-09	159	Radio-collared. Died; killed by puma M55 after she was orphaned due to death of mother F16 by vehicle strike.	F16
M105	38	5-7-09	06-14-09 to 02-09-10	278	Radio-collared. Lost contact after 02-09-10 due to shed collar.	F75
F106	38	5-7-09	06-14-09 to 02-27-11	275 661	Not radio-collared at nursery; F75 returned to nursery during handling. Radio-collared later on 2-10-10. Lost contact due to shed collar 3-16 to 29-10. F106 dispersed from natal area and was photographed at 21 months old at camera and scent-rub station on east slope of Uncompahgre Plateau on 02-27-11.	F75
M107	34	5-25-09	06-28-09 to 02-24-10	241	Not radio-collared; too small. Recaptured 02-24-10; not collared. Dispersed. Killed by a puma hunter in Cottonwood Creek near Molina, CO on 12-09-10 when he was 19 months old.	F94

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1^{st} capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F108	34	5-25-09	06-28-09 to 03-05-10	553	Shed radiocollar at nursery; fastener failed. Recaptured and re-collared 2-24-10. Shed collar ~3-5-10. Dispersed from natal area. Killed by a puma hunter on the study area during TY2 on 11-29-11 at 18.1 months old.	F94
M109	34	5-25-09	06-28-09		Not radio-collared; too small.	F94
M112	145	8-31-09	05-04-10 to 01-06-13	1,225	Radio-collared. Lost contact after 05-4-10 (last live signal) possibly due to failed transmitter. Recaptured and re-radio-collared on 01-24-11. Independent subadult during 02-10-11 to 04-18-11. Lost contact after 04-18-11. Dispersed. Killed by a puma hunter 01-06-13 in GMU73 SE of Dolores, CO; age 41 months.	F70
M115	427	Nov.-08	07-21-10	610	Radio-collared. M115 died as a subadult (~20 mo. old) due to complications of a broken left foreleg (natural cause).	F28
M117	193	Aug.-09	02-05-10 to 01-01-11	518	Radio-collared. Lost contact after 5-14-10 (last live signal); shed collar found on 7-15-10 in the natal area. Killed by a puma hunter on the natal area in Beaver Creek, GMU70E, off the U.P. study area on 01-01-11 when he was 17 months old.	F119
P1016(M)	39	6-12-10	06-12-10 to 07-21-10	39	Not radio-collared. Monitored at nursery via mother's GPS/VHF collar. Found dead at nursery due to infanticide by puma M32 on same day as our investigation of nursery.	F72
P1017(M)	39	06-12-10	06-12-10 to 07-21-10	39	Not radio-collared. Monitored at nursery via mother's GPS/VHF collar. Found dead at nursery due to infanticide by puma M32 on same day as our investigation of nursery.	F72
M120	30	06-28-10	07-28-10 to 12-02-10	526	Radio-collared. Lost radio contact after 12-02-10. Killed by a puma hunter on his natal area on 12-06-11 when he was 17.2 months old.	F3
M121	30	06-28-10	07-28-10 to 03-28-11	273	Radio-collared. Lost radio contact after 03-28-11.	F3
M122	35	07-8-10	08-12-10 to 04-28-11	931	Radio-collared. Lost radio contact after 04-28-11. Tracks of 2 other siblings of M122 observed on 01-11-11 (neither cub marked). M122 killed by a puma hunter in Tatum Draw, Dry Fk. Escalante Cr., GMU62N, 01-23-13; age 30 months.	F104
F123	29	07-15-10	08-13-10 to 02-17-11	217	Radio-collared. Killed on 02-17-11 for depredation control on domestic elk by Wildlife Services agent.	F94
F124	29	07-15-10	08-13-10 to 02-16-11	216	Radio-collared. Killed on 02-16-11 for depredation control on domestic elk by elk farm manager.	F94

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M125	29	07-15-10	08-13-10 to 02-01-11	201	Radio-collared. Killed on 02-01-11 for depredation control on domestic elk by Wildlife Services agent.	F94
M126	28	08-08-10	09-05-10 to 01-08-12	221	Radio-collared. Lost radio contact after 03-17-11; shed his radiocollar at a mule deer cache. Dispersed from natal area. Killed by a puma hunter on 01-08-12 in Tuttle Draw WNW of Nucla, CO, GMU61N, as 17-month-old subadult.	F118
M127	28	08-08-10	09-05-10 to 09-10-11	398	Radio-collared. Lost radio contact after 07-01-11; shed his radiocollar about 07-01-11. Found dead 09-14-11 on natal area; killed by another puma on about 09-10-11 at age 13 months.	F118
M128	28	08-08-10	09-05-10 to 02-22-11	198	Radio-collared. Lost radio contact after 02-22-11; radiocollar probably quit.	F118
F129	35	08-21-10	09-25-10 to 02-02-12	530	Radio-collared. Fate unknown. Transmitter on mortality mode on 04-28-11. Unable to get to collar until 06-23-11 due to high spring run-off, by then the transmitter had quit. Survived to recapture on 02-02-12 at 17.4 months old, with sibling M131; neither handled due to dangerous trees.	F96
M130	35	08-21-10	09-25-10 to 02-02-12	530	Radio-collared. Died of natural causes associated with injury to right shoulder during first move away from nursery about 10-23-10.	F96
M131	35	08-21-10	09-25-10 to 07-21-11	334	Radio-collared. Lost contact after 07-21-11. Shed his radiocollar about 07-27-11. Survived to recapture on 02-02-12 at 17.4 months old, with sibling F129; neither handled due to dangerous trees. Dispersed. Killed by a puma hunter in Lion Cr., extreme western CO, GMU60; age 29 months.	F96
F132	35	08-21-10	09-25-10	35	Not radio-collared. Too small for collar design. Fate unknown. Apparently died; not with F96 and siblings F129 and M130 on 02-02-12.	F96
M134	~18 mo.	~June-09	12-14-10 to 06-10-11	740	Radiocollared as dependent large cub. Independent by about 03-28-11. Dead; killed for depredation control by Wildlife Services agent on 06-10-11. He was about 24 mo. old	Unm. F
M139	36	04-18-11	05-24-11 to 07-29-11	102	Radio-collared. Dead of infanticide and cannibalism along with sibling F148; killed and eaten by female or subadult male puma about 07-29-11.	F8
F148	36	04-18-11	05-24-11 to 07-29-11	102	Radio-collared. Dead of infanticide and cannibalism along with sibling M139; killed and eaten by female or subadult male puma about 07-29-11.	F8

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F140	~5 mo.	~Aug.-10	01-02-11 to 07-31-13	1,096	Radio-collared. Lost contact. Shed first collar about 01-24-11. Recaptured and re-collared on 04-01-11. Shed second collar after 04-18-11. Recaptured and re-collared 01-12-12 as 17-month-old subadult on natal range. Survived to adult stage.	Unk./ F28?
M141	~5 mo.	~Aug.-10	01-02-11 to 04-01-11	509	Radio-collared. Lost contact; shed radiocollar about 03-29-11. Recaptured, but could not be handled safely on 04-01-11. Killed by a puma hunter on 12-23-11 in his natal area; age 16 months.	Unk./ F28?
M142	~5 mo.	~Aug.-10	01-02-11 to 04-18-11	258	Radio-collared. Lost contact after 04-18-11 due to shed collar.	Unk./ F28?
P1030	~ 6 mo.	~Aug.-10	02-16-11	183	Struck by vehicle and killed on state highway 62 in Leopard Creek, south boundary of study area on 02-16-11.	Unk.
F147	~7 mo.	~Sep.-10	04-21-11 to 07-31-11	315	Radio-collared. Orphaned at about 12 months old when her mother F24 was killed by a male puma on 09-16-11. She ranged in her natal area until her radiocollar quit after 04-12-12.	F24
F149	45	04-22-11	06-06-11 to 07-16-12	451	Radio-collared. F149 (sibling of M161) was orphaned when her mother F23 was killed by a male puma on 06-06-12; she was 411 days (13.5 mo.) old. F149 dispersed from the natal area by 07-16-12 when she was 14.8 months old.	F23
M150	525	08-31-09	02-07-11 to 04-11-11	588	Radio-collared. M151 was independent by 03-28-11 at 19 mo. old. He dispersed from the natal area by 04-11-11 at 19.5 mo. old. Contact lost after 04-11-11.	F70
M151	253	06-16-10	02-24-11 to 03-07-11	264	Radio-collared. Lost contact after 03-07-11 (GPS location of mother F111 at shed collar of M151).	F111
F152	271	06-16-10	03-14-11 to 12-23-12	776	Radio-collared. Lost contact after 03-21-11; shed collar. Recaptured 01-18-12; fit with GPS collar at 19 months old. Ranged on natal area as adult (philopatric). First litter on 08-08-12 at 26 mo. old. Killed by puma hunter on 12/23/12.	F93
M154	42	07-06-11	08-16-11 to 09-21-11	77	Radio-collared. M154 probably died of starvation following natural death of his mother F135. Sibling M155 also died.	F135
M155	42	07-06-11	08-16-11 to 09-25-11	81	Radio-collared. M155 died of starvation following death of his mother F135. Sibling M154 also died.	F135
M156	43	07-08-11	08-20-11 to 09-05-11	56	Radio-collared. M156 shed the collar about 09-05-11. He was 59 days old.	F137

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F157	40	08-18-11	09-27-11 to 01-15-12	150	Radio-collared. F157 with sibling F158 died of starvation following death of his mother F70 due to hunter harvest on 12-22-11. Cubs died 24 days after their mother died. The cubs were 150 days old.	F70
F158	40	08-18-11	09-27-11 to 01-15-12	150	Radio-collared. F158 with sibling F157 died of starvation following death of his mother F70 due to hunter harvest on 12-22-11. Cubs died 24 days after their mother died. The cubs were 150 days old.	F70
M159	40	08-18-11	09-27-11 to 12-01-11	105	Radio-collared. M159 probably died about 12-01-11 when he was located with his family (F70, siblings F157, F158). He was not located with them on 12-12-11 and was not observed with them on 12-13-11. He was 105 days old on 12-01-11.	F70
M161	276	04-22-11	01-23-12 to 10-15-12	543	Radio-collared. M161 (sibling of F149) was orphaned when his mother F23 was killed by a male puma on 06-06-12; he was 411 days (13.5 mo.) old. M161 dispersed from the natal area by 06-29-12 when he was 14 months old. Shed his expandable collar about 08-03-12. Was struck and killed by a vehicle on Dallas Divide, Hwy 62 in October 2012 when 18 mo. old.	F23
M162	183	07-25-11	01-25-12 to 06-11-12	322	Radio-collared. M162 probably was orphaned cub of non-marked adult female puma killed on Pinto Mesa 01-18-12. M162 died of starvation on 06-11-12 when he was 322 days (10.6 mo.) old.	Unm.F
M168	37	07-27-12	09-02-12 to 09-12-12	47	Radio-collared. Cub M168 was offspring of F96; sibling of F169 & F173. It died of infanticide, probably of a male puma, based on track sizes (fhpw = 60 mm; hhpw = 50 mm).	F96
F169	37	07-27-12	09-02-12 to 09-12-12	47	Radio-collared. Cub F169 was offspring of F96; sibling of M168 & F173. It died of infanticide, probably of a male puma, based on track sizes (fhpw = 60 mm; hhpw = 50 mm).	F96
M170	137	08-29-11	01-13-12 to 03-12-12	199	Radio-collared. M170 died about 03-15-12 of unknown natural cause. He was 199 days (6.5 mo.) old.	F171
P1033	22	07-10-11	NA	22	Radio-collared. Cub P1033 was offspring of F136. It died of predation, probably killed by a puma or black bear in the nursery when about 22 days old, before researchers could examine the entire litter to sample and mark the cubs.	F136

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F173	37	07-27-12	09-02-12 to 09-12-12	47	Radio-collared. Cub F173 was offspring of F96; sibling of M168 & F169. It died of infanticide, probably of a male puma, based on track sizes (fhpw = 60 mm; hhpw = 50 mm).	F96
M174	32	08-08-12	09-11-12 to 03-10-13	181	Radio-collared. Cub M174 was offspring of F152; sibling of M175. He was orphaned after his mother was killed by a hunter on 12-23-12. He was 137 days old. M174 was recaptured at 181 days old and removed from the wild to be rehabilitated at the CPW Del Norte wildlife center for re-release to the wild at a later date.	F152
M175	32	08-08-12	09-11-12 to 12-11-12	126	Radio-collared. Cub M175 was offspring of F152; sibling of M174. He was mauled to death probably by puma hunting dogs on about 12-11-12 when he was 126 days old.	F152
F184	208	08-25-12	03-20-13 to 07-29-13	339	Radio-collared. Cub F184 was offspring of F111; one other sibling track was observed, but the puma was not captured. F184 still dependent on F111 on 07-29-13.	F111
F185	~183	~Oct.-2012	03-23-12 to 03-27-13	190	Radio-collared. Cub F185 was offspring of a non-marked female puma in Roubideau Cyn. F185 shed her expandable collar about 7 days after initial capture. Lost contact. Fate unknown.	Unm.F
F187	31	05-14-13	06-14-13 to 07-29-13	77	Radio-collared. Cub F187 was offspring of F96; sibling of F188.	F96
F188	31	05-14-13	06-14-13 to 07-29-13	77	Radio-collared. Cub F188 was offspring of F96; sibling of F187.	F96
F189	38	06-18-13	07-26-13 to 07-31-13	44	Radio-collared. Cub F189 was offspring of F136; sibling of F200 and M201.	F136
M191	~183	~July 2012	01-03-13 to 01-20-13	~210	Radio-collared. Cub M191 apparently was offspring of F28 (with non-functional GPS collar). He was sibling of PM1068 and one other non-marked cub. M191 was killed by a non-marked male puma on about 01-20-13 along with PM1068.	F28
PM1068	~183	~July 2012	01-03-13 to 01-20-13	~210	PM1068 was not captured and tagged. It was apparently offspring of F28; sibling of M191 and one other non-marked cub. PM1068 was killed and partially eaten by a non-marked male puma.	F28
M192	199	06-20-12	01-04-13 to 07-01-13	376	Radio-collared. M192 was offspring of F118; sibling of M193 & F195. M192 was independent of F118 at ~11.7 mo. old. He shed his expandable collar at a mule deer kill after 07-01-13.	F118

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M193	199	06-20-12	01-04-13 to 07-01-13	376	Radio-collared. M193 was offspring of F118; sibling of M192 & F195. M192 was independent of F118 at ~11.7 mo. old. He shed his expandable collar at a mule deer kill after 07-01-13 like sibling M192, but the siblings were not associating (kills were at different locations).	F118
F195	227	06-20-12	02-01-13 to 03-04-13	258	Radio-collared. F195 was offspring of F118; sibling of M192 & M193. F195 shed her expandable radiocollar at an elk kill on about 03-04-13; contact lost afterwards.	F118
M198	274	~June 2012	04-10-13 to 07-31-13	417	Radio-collared. M198 was offspring of non-marked female PF1074 (sampled by bio-dart). He was sibling of F199.	PF1074
F199	292	~June 2012	04-18-13 to 07-31-13	417	Radio-collared. F199 was offspring of non-marked female PF1074 (sampled by bio-dart). She was sibling of M198.	PF1074
F200	38	06-18-13	07-26-13 to 07-31-13	44	Radio-collared. Cub F200 was offspring of F136; sibling of F189 and M201.	F136
M201	38	06-18-13	07-26-13 to 07-31-13	44	Radio-collared. Cub M201 was offspring of F136; sibling of F189 and F200.	F136
F202	35	06-25-13	07-30-13 to 07-31-13	36	Radio-collared. Cub F202 was offspring of F172. No siblings were observed at the nursery; but some could have hidden.	F172

[a] Cub F35 probably starved between 06-30-06 & 07-07-06 after the transmitter on the expandable collar got in its mouth.

[b] Cub M42 died after being captured by dogs, probably from stress of capture associated with severe infection of laceration under right foreleg caused by expandable radiocollar.

[c] Cub M56 was captured in association with F7 and her cubs M43 and M44. He may have been missed at the nursery when M43 and M44 were initially sampled and marked.

[d] Cub M60 died probably of starvation. The expandable radiocollar was around the neck and right shoulder, probably restricted movement.

Colorado Division of Parks and Wildlife
July 2012 - June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Predatory Mammals Conservation
Task No.:	2	:	Cougar Demographics and Human Interactions
		:	Along the Urban-Exurban Front Range of
		:	Colorado
Federal Aid Project No.	W-204-R1		

Period Covered: July 1, 2012 - June 30, 2013

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ABSTRACT

The use of telomeres as a method to determine the age structure of bear and cougar populations has continued to be examined. The age-to-length relationship for bears is near completion and should be completed in the coming year for cougars. We have completed the second year of a Ph.D. project with the University of Wisconsin to examine telomeres in detail for bears. This project will also look at stable isotopes to examine foraging ecology and bear use of human food sources. We have also completed the first year of a M.S. project with the University of Wisconsin to examine telomeres and stable isotopes for cougars relative to predation on domestic animals and cougar foraging ecology.

Our principal research objective is to assess cougar population ecology, prey use, movements, and interactions with humans along the urban-exurban Front Range of Colorado. This year capture efforts focused on re-collaring previously collared cougars, and capturing previously unmarked independent age cougars and cubs. In addition to recollaring cougars we collared 10 new cougars, primarily younger individuals. Mortality was very high over the year with 11 mortalities for independent age cougars (predominantly human related, unknown causes and vehicle collisions) (Table 1). Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing limited results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Removing caches does appear to be effective to get cougars to leave the immediate area, but this does not necessarily mean they leave the urban area.

Cougar/human interactions were minimal again this year compared with initial years of the study. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males will also utilize elk regularly.

WILDLIFE RESEARCH REPORT

COUGAR AND BEAR DEMOGRAPHICS AND HUMAN INTERACTIONS IN COLORADO

MATHEW W. ALLDREDGE

PROJECT NARRITIVE OBJECTIVE

1. To assess cougar (*Puma concolor*) population demographic rates, movements, habitat use, prey selectivity and human interactions along the urban-exurban Front Range of Colorado.
2. Develop methods for delineating population structure of cougars and black bears (*Ursus americanus*), assessing diet composition and estimating population densities of cougars for the state of Colorado.

SEGMENT OBJECTIVES

Section A: Telomeres and Stable Isotopes

1. Evaluate the potential to develop a model for estimating age of bears and cougars based on telomere length.
2. Determine diet composition of bears and cougars using stable isotopes.

Section B: Front Range cougars

3. Capture and mark independent age cougars and cubs to collect data to examine demographic rates for the urban cougar population.
4. Continued assessment of aversive conditioning techniques on cougars within urban/exurban areas, including use of hounds and shotgun-fired bean bags or rubber bullets.
5. Continue to assess relocation of cougars as a practical management tool.
6. Assess cougar predation rates and diet composition based on GPS cluster data.
7. Model movement data of cougars to understand how cougars are responding to environmental variables.
8. Develop non-invasive mark-recapture techniques to estimate cougar population size.

SECTION A: BEAR AND COUGAR TELOMERES AND STABLE ISOTOPES

BY M. ALLDREDGE

OVERVIEW

Understanding the age structure of a population is very useful to managers, especially for hunted populations. Age structure can provide indications about the appropriateness of current harvest levels, changes that may need to occur in harvest, and the general health of a population. Typical approaches involve estimating age structure based on sampling harvested animals and obtaining ages based on tooth wear and replacement characteristics or from analyzing tooth annuli. Recently, a new approach has been developed for some species that estimates the age of animals based on examining the length of telomeres in relation to the age of the animals.

Telomeres are repetitive DNA sequences that cap the ends of eukaryotic chromosomes, whose nucleotide sequence $(T_2AG_3)_n$ is highly conserved across vertebrate species (Meyne et al. 1989). During each cell cycle telomeric repeats are lost because DNA polymerase is unable to completely replicate the 3' end of linear DNA (Watson 1972). Thus, telomeres progressively shorten with each cell division; past research has demonstrated age-related telomere attrition in a variety of laboratory and wild species and has correlated telomere length with individual age (e.g. Hausmann et al. 2003, Hemann and Greider 2000). Using real-time quantitative polymerase chain reaction (Q-PCR; Cawthon 2002), we have demonstrated the potential for quantifying telomere length for black bears of known-age in Colorado (Alldredge 2010).

Understanding diet composition and foraging ecology of bears is also useful to managers, especially in urban areas, as bears continually interact with humans and human derived food sources. The dynamics of this interaction and the extent to which bears utilize human food sources is largely unknown. The use of stable isotope analysis is one approach to understanding the amount and timing of utilization of various food sources within a bear's diet. Examining different tissue types from bears can explain patterns of use for various food sources and will provide managers a better understanding of this problem at a population level.

We have initiated a graduate study with the University of Wisconsin and Wisconsin Department of Natural Resources to develop methods of identifying population age structure using telomeres and examining diet composition and foraging ecology using stable isotopes for bears. See attached report for a complete project overview and objectives (Appendix I).

During 2011, we collected blood, tissue, hair, and bone samples from 400 bears across the state. These bears were either nuisance bears or hunter harvested bears. Samples from these bears are being utilized for both the telomere and stable isotope components of this project. Preliminary assessments indicate high genetic quality from samples for use in the telomere work. Initial data from stable isotope analyses indicate significant variation in $\delta^{13}C$ and $\delta^{15}N$ (Figure 1) among bears which suggests that differentiation in diets based on stable isotope analysis will be possible. Starting in the summer of 2012, bears along the Front-Range of Colorado were also collared and repeatedly sampled to examine a detailed time series for the shortening of telomeres, especially relative to hibernation.

Additional work has also continued in collaboration with the University of Wisconsin to further examine stable isotope techniques for bears and cougars. This work is specifically designed to look at diet composition of bears within specific temporal windows relevant to current management issues. Similarly, stable isotope analyses for cougars is focused on identifying cougar predation on specific species guilds, identifying the use of small prey items, and determining factors associated with differences in prey utilization. For a complete summary of this project, see the attached report (Appendix II).

As an initial step to investigate the utility of using stable isotopes to assess cougar diets, we collected hair samples from prey species found at cougar kills. Additionally, hair samples were collected from domestic animals (llamas, goats, cats, dogs, etc.) that could potentially be preyed on by cougars. Stable isotope analysis has been done on these prey items and initial findings suggest that examining prey by species guilds does result in significant differences in $\delta^{13}C$ and $\delta^{15}N$ content (Figure 2).

We attempted to develop hair growth curves for bears using captive bears at the Wild Animal Sanctuary located in Keensburg, CO. This collaboration did not work. However, we have been examining hair growth rates for cougars using 3 captive animals at our Foothills Wildlife Research Center. This involves adding Rhodamine B to their food once per month and pulling hair. The Rhodamine B will appear as a UV mark on the hair and provide a time stamp so that growth curves for hair can be developed.

SECTION B: FRONT RANGE COUGARS
BY M. ALLDREDGE

INTRODUCTION

We have continued the cougar/human interaction study on the Front Range of Colorado. Given that cougars currently coexist with humans within urban/exurban areas along Colorado's Front Range, varying levels of cougar-human interaction are inevitable. The CPW is charged with the management of cougars, with management options ranging from minimal cougar population management, to dealing only with direct cougar-human incidents, to attempted extermination of cougars along the human/cougar spatial interface. Neither inaction nor extermination represent practical options, nor would the majority of the human population agree with these strategies. In the 2005 survey of public opinions and perceptions of cougar issues, 96% of the respondents agreed that it was important to know cougars exist in Colorado, and 93% thought it was important that they exist for future generations (CPW, unpublished data).

There is a growing voice from the public that CPW do more to mitigate potential conflicts, and the leadership of CPW has requested that research efforts be conducted to help minimize future human/cougar conflicts. In order to meet these goals, CPW believes it is necessary to directly test management prescriptions in terms of desired cougar population and individual levels of response.

Long-term study objectives for the Front Range Cougar Research project involve directly testing management responses of cougars at various levels of human interaction, as well as collecting basic information about demographics, movement, habitat use, and prey selection. The Cougar Management Guidelines Working Group (CMGWG) (2005) recommended that part of determining the level of interaction or risk between cougars and humans is to evaluate cougar behavior on a spectrum from natural, to habituated, to overly familiar, to nuisance, to dangerous. The CMGWG (2005) clearly stated that there is no scientific evidence to indicate that cougar habituation to humans affects the risk of attack. As a continuation from the pilot study efforts, we have continued to assess the effectiveness of aversive conditioning as a method to alter interaction rates between cougars and humans. We also continue to monitor relocated cougars to determine the effectiveness of relocation as a management tool.

The use of GPS collars obtaining up to 8 locations per day also allows for a detailed examination of demographic rates. We are monitoring cougars that utilize natural habitats and cougars that use a mixture of natural and urban habitats. This allows for an assessment of demographic rates, movement patterns, and habitat use among cougars utilizing these two habitat configurations. We have also begun monitoring cubs (approximately 6 months of age or older), primarily to determine survival but potentially to understand movement patterns and dispersal.

The use of GPS collars also allows us to study predator-prey relationships and diet composition. GPS locations are divided into selection sets based on the likelihood of the set of locations (clusters) representing a kill site. A random sample of these clusters is investigated to determine what a cougar was doing at the site, and whether or not it represents a kill site. Kill sites are thoroughly investigated to determine as much information as possible about what was killed at the site.

STUDY AREA

The original pilot study was conducted in Boulder and Jefferson counties, in an area near Interstate 70 north to approximately Lyons, Colorado, which was also a likely area for addressing long-term research objectives (see Figure 3). The study area for the long term study includes this original area but was expanded south to highway 285. Research efforts in the additional southern portion are generally limited to capturing cougars that are in the urban setting and/or have interacted directly with humans. The study area is comprised of many land ownerships, including private, Boulder city, Boulder County, Jefferson County, and state and federally owned lands. Therefore, we have been directly involved with Boulder city and Boulder and Jefferson county governments to obtain agreements from these entities on conduct of research and protocols for dealing with potential human/cougar interactions prior to conducting any research efforts. We have also acquired permission to access numerous private properties to investigate cougar clusters and to trap cougars.

METHODS

Baiting, using deer and elk carcasses, has been conducted throughout the year, with a focus on areas that do not allow the use of hounds. Bait sites are monitored using digital trail cameras to determine bait site activity. Cage traps were generally used for capture when cougars removed the bait and cached it. Beginning in November, 2012, and continuing through April, 2013, hounds were also used when snow conditions were favorable to capture cougars. Snares were used in situations where hounds could not be used and cougars would not enter cage traps. Captured cougars were anesthetized, monitored for vital signs, aged, measured, and ear-tagged. All independent cougars (> 18 months old) were fitted with GPS collars. All cubs greater than 15 kg (approximately 6 months or older) were ear-tagged with 22 g ear-tag VHF transmitters or 22g ear-tag ptt Argos transmitters.

When cougars interact with humans and elicit a response from CPW District Wildlife Managers (DWMs), they are potential candidates for aversive conditioning. Most incidents prompting response from a DWM occur in neighborhoods, where relocating the cougar is necessary prior to any application of an aversive conditioning treatment. For these situations, all treatments require the relocation of the offending individual to an adjacent open-space property or similar area. In other situations, a cougar can be directly conditioned or chased from the area without relocation. Initial data suggested aversive conditioning had mixed results. Here, we compare cougar behavior between situations when the cougar is undetected in urban areas, versus situations when they are detected and hazed or their kills are removed. Interactions have been limited so we have limited data to assess these activities.

Cougars are only relocated for management purposes, generally in conjunction with human conflict or livestock depredation. Research cougars that have been collared for other purposes of the study may also become part of the relocation group if their levels of human interaction warrant such a management action. Because only a few cougars are relocated each year, we collar and monitor all cougars that are relocated in the northeast region. Cougars are ear-tagged and fitted with a telemetry collar (VHF or GPS collars may be used depending on the situation).

Release area is critical to the success of any relocation; however, suitable relocation areas may be difficult to find. Such an area must be far enough from the problem area, have suitable prey and be remote enough so that the individual will not be presented with problem opportunities at or near the release site. Understanding the minimum release distance that has a reasonable chance for relocation success is useful for both logistical reasons and to increase the number of potential release sites.

We evaluated cougar diet composition by using GPS location data to identify likely kill sites. Characteristics of clusters of GPS locations representing cougar-killed ungulate sites (Anderson and Lindzey 2003, Logan 2005) were used to develop a standard algorithm to group GPS points together, to provided a sound sampling frame from which statistical inference could be made about clusters that were not physically investigated. GPS collars collected locations 7 to 8 times/day to reflect time periods when cougars were both active and inactive.

The clustering routine was designed to identify clusters in five unique selection sets (S_1, S_2,…, S_5) in order to identify clusters containing two or more points, those that contained missing GPS locations, and those that were represented by single points. S_1 clusters consist of multiple GPS locations with a 4 day window and within 200 m, while other sets are single points close together in time within varying distance bands. The clustering algorithm was written in Visual Basic and was designed to run within ARCGIS (Alldredge and Schuette, CDOW unpubl. data 2006). The widths of the spatial and temporal sampling windows were user specified, in order to meet multiple applications and research needs. This also enabled adjustment of the sampling frames to improve cluster specifications as needed.

We used the following protocol to investigate cougar GPS clusters in the field. For S_1 clusters, we investigated each cougar GPS location in the cluster by spiraling out a minimum of 20 m from the GPS waypoint, while using the GPS unit as a guide, and visually inspected overlapping view fields in the area for prey remains. Normally, this was sufficient to detect prey remains and other cougar sign (e.g., tracks, beds, toilets) associated with cougar. If prey remains were not detected within 20 m radius of the cluster waypoints, we then expanded our searches to a minimum of 50 m radius around each waypoint. For S_2 through S_5 clusters, we went to each cougar GPS location and spiraled out 50 m around each waypoint, while using the GPS unit as a guide. Depending on the number of locations, topography, and vegetation type and density, we spent a minimum of 1 hour and up to 3 hours per cluster to judge whether the cluster was a kill site.

Kevin Blecha is currently finishing his M.S. research on predator-prey dynamics related to the sampling described above. He is specifically looking at predator-prey relationships relative to various habitat types and levels of human density across the landscape. An assessment of prey availability or reliability is also being made through the use of camera traps within these habitat types and levels of human density. Finally, an assessment of cougar use on domestic animals (livestock and pets) is being made (see Appendix III for more details).

Joe Halseth and Matt Strauser are also conducting a study to examine prey selection and kill site dynamics with regard to conspecifics and scavenging. Kill sites are being investigated within 24 hours of the kill to determine prey species, to place cameras and to sample ungulates for age and to test for CWD. Some work has indicated that cougars may select for CWD positive animals, but sample sizes have been limited. We intend to sample a large number of ungulates and address this topic further. Additionally, we have documented significant amounts of prey sharing among cougars and significant amounts of scavenging from cougar kills. Understanding these kill site dynamics will provide information on kill rates, consumption rates and intra/interspecific interactions (see Appendix IV for more details).

We have also continued the M.S. project with Bill Kendall at CSU through the Fish, Wildlife, and Conservation Biology Department to examine techniques to develop non-invasive population estimation methodology for cougars (Appendix V). Following the positive results of the first year, we intensified survey efforts to detect cougars using calls and hair snags. We also expanded this work to include a study area on the Uncompahgre Plateau, in collaboration with Ken Logan (CPW researcher) and his cougar study.

RESULTS AND DISCUSSION

Collared cougars from the previous year were captured and re-collared to replace exhausted batteries throughout the year. An additional 10 independent age cougars were also captured and collared during the year (Table 1). Currently there are 21 independent age cougars in the study with functioning GPS collars.

Home ranges for collared cougars have been determined using minimum convex polygons (MCP) to depict the general pattern of use and potential overlap, but likely over-represent the actual area used by an individual. Home ranges exhibit similar patterns to previous years (Figures 4 and 5), being fairly linear in a north-south direction. Adult male home ranges (Figure 6) were much larger than adult female home ranges (Figure 7). Subadult male home ranges were smaller than adult male home ranges, but were also characterized by large movements and significant overlap with adults. Female home ranges were smaller with sizes between 80 and 120 km^2. Female home ranges also had significant overlap, especially among related individuals. We have also seen significant long-range movements and dispersals (Figure 8). Long-range movements are significant movements outside of a cougar's typical home range with the individual returning to the original area. Dispersals are similar movements, but the individual does not return to its original area.

There were a total of 11 mortalities for adult collared cougars during the 2012-13 year (Table 1). Causes of death included vehicle collision (2), unknown sources (3), and management or landowner related death (6). One of the landowner-related mortalities was from a hunter who was called in after the landowner's dog was killed.

Cougar-human interaction was comparable to the previous year, which appears to be less interaction than in the first years of the study. This gives us little opportunity to test aversive conditioning techniques. Given the minimal response to aversive conditioning, we are altering our methods of examining it as a management tool. We will now have managers aversively condition any cougar that they encounter interacting with humans and that warrants such action. We will then compare the cougar's responses to this aversive conditioning to events where the cougar was in the same situation but was undetected by humans and therefore not aversively conditioned.

In January 2013, the Front Range Cougar Project began to more aggressively visit and remove cougar kills within Boulder city limits. This effort was conducted in an attempt to judge cougar responses to see if cougars were deterred from the city after prey items were removed. Between 1/2/2013 and 5/14/2013, 21 kill sites were visited. Fifteen of these kill sites contained prey items with consumable portions remaining and were removed while the cougar was off site. Project staff has observed that within city limits, cougars most often leave their kills during daytime hours and return after dark. Movements from the collared cougars were analyzed the night following a carcass removal to observe any changes in movement patterns in response to the removed carcass.

The GPS collars on project cougars transmit four GPS coordinates each night at three-hour intervals. Given that some GPS locations were missed and significant movement occurred between GPS locations, it was difficult to decipher cougar responses to the removed carcasses. The cougar almost always came back to the prey item; however, no discernible pattern of movement could be detected immediately following the removal of a carcass.

In spring of 2013, new GPS fix schedules were programmed into the collars of cougars known to frequent town. Using Vectronics GPS collar software, collars of these cougars were programmed with a new fix schedule to more accurately document their movements within the city limits. Using a 'virtual fence' design, the new collar schedules are designed to transmit GPS locations every 20 minutes once the cougar crosses the fence, drawn roughly along the city boundary. Preliminary results show that the increased amount of GPS locations provide more detailed movement analysis which we can use to better judge possible cougar response to carcass removal. However, the new collar schedules were uploaded in the spring when cougars begin to spend less time within city limits, as was observed in previous years. There have been few instances of cougars spending significant time in Boulder since the new schedules were downloaded.

Relocation of cougars is also a management technique that we have evaluated in the past and has shown mixed results relative to age, sex and relocation distance. The NE region has expressed renewed interest in this and we will begin pilot work to investigate this in more detail. We will evaluate relocation distance relative to Directive W2 and the distance recommendations made for management as well as some more long-distance relocations. As this proceeds, we will develop a more detailed study to thoroughly investigate cougar relocation parameters.

From August 1, 2008 through December 30, 2012, we have visited over 4,000 clusters (S1-S5 types). However, not all of these clusters were considered to be random samples, and thus preliminary inferences have only been drawn from this subset. Starting in January 2012, 130 cameras were deployed in random locations representing the range of habitat types and human densities. Cameras have been checked as needed and results appear to be promising with regard to the number of species that have been detected and the perfromance of the cameras. For a detailed summary of the predator-prey component of the project, prelimary results and prey composition in cougar diets (see Appendix III).

The prey selection and kill site dynamics study was initiated in January, 2012 (see Appendix IV for study objectives and preliminary results). To date, we have collected close to 100 individual samples from deer killed by cougars and tested these for CWD. A proportion of these have been positive for CWD, primarily those collected during the spring. We have investigated numerous potential kill sites and placed cameras on fresh kill sites to document the activity. We have documented multiple occasions when multiple cougars shared a kill and several scavenging events. Many scavenging events occur after the cougar has consumed the prey and has left. Other scavenging events have occurred while the cougar was still consuming the prey item, including cases where bears have usurped the prey item killed by the cougar.

Starting in November, 2011, we began investigating snow tracking and lures as potential techniques to estimate cougar abundance. Snow tracking proved to be very difficult because there was limited snow throughout the winter and snow conditions were poor. When snow tracking was feasible tracks of collared cougars were followed and samples (primarily hair) were collected. This approach is highly dependent upon environmental conditions and therefore may not be broadly applicable.

Efforts documented in the literature to lure cougars to specific locations and capture an individual with either a photograph or genetic sample have been limited and relatively unsuccessful. We have finished testing various options to lure cougars to specific locations and extract genetic samples. One option that had not been tested in other studies is the use of game calls to attract cougars. We placed 4 different types of sites at random locations to determine which types of lures or combinations of lures (bait, bait and scent, bait and call, bait, scent and call) would be the most reliable method of attracting cougars. We found that calls have been significantly more effective at attracting cougars to a site (see Appendix VI for a detailed summary).

Although we were relatively effective at luring cougars to a specific location with calls, initial efforts were not successful in extracting genetic samples at these locations. Cougars appeared to ignore scratch pads and were hesitant to take any meat reward left at the site. Cougars did seem interested in the calls and on several occasions investigated the call or stole the call from the site. This year, we investigated methods of extracting genetic samples from cougars approaching the callusing cubbies and barbed wire hair snags. Study efforts for this approach included both the Front-Range of Colorado and the Uncompahgre Plateau (see Appendix V for a summary and preliminary results).

SUMMARY

The use of telomeres as a method to determine the age structure of bear and cougar populations is promising and will be investigated further in the coming year to develop the relationship in more detail with regard to covariates. Further refinement of the age-to-length relationship for both species is warranted. In addition to this, length relationships relative to genetic relatedness and individual stressors will give further insight into interpreting results from future data. We will also be investigating the effects of hibernation on telomere length using wild bears.

The use of stable isotopes from bears and cougars is beginning to show some very interesting results. Examining stable isotopes from various bear tissue types will help elucidate temporal patterns in diet composition, including the use of human foods by bears. It has also become clear that stable isotopes will be a useful tool in examining cougar diets, especially in the use of small prey items that are likely overlooked with other traditional techniques.

In addition to re-collaring previously collared cougars, an additional 10 independent age cougars were collared during the year. Mortality remained high over the year, with 11 cougar mortalities. Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. It is likely that for aversive conditioning to work, methods will have to become more extreme. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males also utilize elk regularly. We will continue to assess predator-prey dynamics, population estimation techniques, and movement patterns during the coming year.

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Table 1: Capture history, aversive conditioning treatments and current status of all independent age cougars captured as part of the Front Range cougar study.

Cougar ID	Sex	Age	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AM02	M	1	6/14/07	Lacey Prop.	Baiting	Cage	On-site	NA	Alive
		1.5	1/10/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		1.5	2/9/08	Coal Creek	Intraspecific mortality				Dead
AM04	M	7	7/14/07	White Ranch	Baiting	Cage	On-site	NA	Alive
		7	10/17/07	Eldorado Springs	Livestock depredation	Cage	White Ranch	Beanbag	Alive
		8	4/29/08	Magnolia/Flagstaff	Replace Collar	Hounds	On-site	NA	Alive
		8	5/5/08	South Boulder	Seen in town	Free-dart	Lindsey	Beanbag	Alive
		8	8/4/08	North Boulder	Killed deer in town	Cage	Centennial Cone	Beanbag	Alive
		9	2/24/09	Boulder Canyon	Punctured intestine				Dead
AM06	M	5	11/21/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		6	12/30/08	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		7	2/2/10	Reynolds Ranch	Replace Collar	Hounds	On-site	NA	Alive
		7	2/15/10	White Ranch	Hunter				Dead
AF03	F	4	11/29/07	Flagstaff	Deer kill	Cage	On-site	NA	Alive
AF01	F	2	12/17/07	Table Mesa	Deer kill	Cage	On-site	NA	Alive
		4.5	12/15/10	White Ranch	Replace Collar	Hounds	On-site	NA	Alive
			3/12/12	BCOS Lindsey	Deer kill	Free-dart	On-site	NA	Alive
AM05	M	2	12/19/07	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		4	12/4/09	White Ranch	Replace collar	Hounds	On-site	NA	Alive
		5	4/4/10	Golden	Roadkill				Dead
AM07	M	1.5	12/26/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
			4/19/08	Highway 7	Roadkill				Dead
AF08	F	1.5	12/26/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		3	6/18/09	West Horsetooth	Deer kill-remove collar	Cage	On-site	NA	Alive
AM09	M	1.5	12/28/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		2.5	12/27/08	Hwy 34 (mile 70)	Roadkill				Dead
AF10	F	7	1/15/08	Apex Open Space	Deer Kill	Cage	On-site	NA	Alive
			2/13/08	I-70	Roadkill				Dead

AF19	F	8+	3/4/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		8+	3/18/09	North Boulder	Deer Kill	Cage	Heil Valley Ranch	Beanbag	Alive
			4/13/09	Left Hand Canyon	Deer Kill	Cage	Heil Valley Ranch	NA	Alive
		8+	1/20/09	Dowe Flats	Deer Kill	Cage	On-site	NA	Alive
			11/5/10	Foothills Hwy, N. Boulder	Roadkill				Dead
AF11	F	1.5	3/5/08	South Table Mesa	Deer Kill	Cage	On-site	NA	Alive
			8/20/08	US-40/Empire	Roadkill				Dead
AM20	M	4	3/6/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			5/18/08	West of White Ranch	Livestock Depredation	Shot			Dead
AF15	F	6	3/18/08	Coffin Top	Capture effort	Hounds	On-site	NA	Alive
		7	4/2/09	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
			3/25/10	Coffin Tip	Replace Collar	Hounds	On-site	NA	Alive
		8-9	2/4/11	Hall Ranch	Deer Kill	Snare	On-site	NA	Alive
		9+	2/2/12	Longmont Dam Rd	Deer Kill	Snare	On-site	NA	Alive
		9+	11/8/12	Button Rock	Natural Mortality				Dead
AF17	F	9+	3/29/08	Sugarloaf	Pet depredation	Cage	Within 1 mile	Beanbag	Alive
			5/20/08	Four-mile Canyon	Unknown mortality				Dead
AF12	F	2	5/8/08	N. Boulder	Deer Kill	Cage	US Forest Boulder Canyon	Beanbag	Alive
			5/29/08	N. Boulder	Livestock depredation	Cage	Near Ward	Beanbag	Alive
			2/13/09	N. Boulder	Deer Kill/Shot	Snare	None		Dead
AM13	M	2	5/8/08	Sugarloaf	Livestock depredation	Cage	On-site	Beanbag	Alive
			12/17/08	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		3	12/17/09	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
			3/27/12	Hall Ranch	Detected by camera				Alive
			5/30/13	Apple Valley Rd.	Shot/depredation				Dead
AM14	M	2	5/15/08	South Boulder	Seen under deck	Free-dart	Lindsey	None	Alive
			5/20/08	South Boulder	Deer kill	Free-dart	West of Rollinsville	Beanbag	Alive
			4/14/09	Rollins Pass	Replace Collar	Hounds	On-site	NA	Alive
		3	2/16/10	Left Hand Canyon	Replace Collar	Hounds	On-site	NA	Alive
		4.5	6/22/11	Allenspark	Elk Kill	Cage	On-site	NA	Alive

		4-5	11/9/11	Hwy 72	Raccoon Kill	Free-dart	On-site	NA	Alive
		4-5	12/4/11	Allenspark	Shot/depredation				Dead
AF34	F	1.5	12/5/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
			3/18/09	N. Boulder	Deer kill	Cage	Heil Valley Ranch	Beanbag	Alive
		2.5	1/4/10	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		3.5	12/31/10	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
		4.5	12/28/11	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
		5.5	2/13/12	W of Hall Ranch	Unknown mortality				Dead
AM18	M	1.5	12/24/08	Evergreen	Deer kill	Cage	Mt. Evans SWA	None	Alive
			3/14/09	Evergreen	Livestock depredation	Cage	None		Dead
AF16	F	3	12/29/08	Evergreen	Deer Kill	Snare	Flying J Open Space	None	Alive
			3/20/09	Evergreen	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
AF45	F	5	1/2/09	Gold Hill	Deer kill	Cage	On-site	NA	Alive
			11/24/10	N.Boulder	Euthanized/Lisa Wolfe			NA	Dead
AF40	F	1.5	1/27/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		1.5	1/28/09	White Ranch	Replace Collar	Hounds	On-site	NA	Alive
		2.5	2/22/10	White Ranch	Replace Collar	Snare	On-site	NA	Alive
		4-5	3/4/12	Idaho Springs	Fawn Kill	Snare	On-site	NA	Alive
		5	10/13/12	Idaho Springs	Shot by hunter				Dead
AF24	F	10+	2/12/09	North Boulder	Deer Kill	Cage	Hall Ranch	None	Alive
			2/25/09	Hwy 7	Replace Collar	Hounds	On-site	NA	Alive
			4/4/09	North Boulder	Raccoon Kill	Free-dart	Heil Valley Ranch	None	Alive
			5/31/09	North Boulder	Encounter	Shot			Dead
AM31	M	1.5	12/31/08	Evergreen	Chicken coop	Hounds	On-site	None	Alive
			3/29-09	Conifer	Livestock depredation	Cage	Mt. Evans SWA	None	Alive
		2.5	2/16/10	Douglas, WY	Hunter				Dead
AF37	F	1.5	12/31/08	Evergreen	Chicken coop	Free-dart	On-site	None	Alive
			8/11/09	I-70	Roadkill				Dead
AM21*	M	1.5	8/29/09	N. Boulder	Encounter	Free-dart	Ward	None	Alive
		2	3/01/10	Loveland	Livestock depredation				Dead
AF32	F	1.5	9/28/09	Indian Hills	Livestock depredation	Cage	Within 1 mile	None	Alive
		3.5	11/28/10	Golden	In neighborhood	Free-dart	White Ranch	None	Alive

		3.5	12/1/10	Golden	In neighborhood	Cage	Radium	None	Alive
			9/23/11	Green Mtn. Res.	Found dead				Dead
AM46	M	2	11/13/09	Evergreen	Elk kill	Cage	On-site	None	Alive
			3/5/10	Genesee	Livestock depredation	Shot			Dead
AF50	F	3	11/24/09	West of Boulder	Deer kill	Cage	On-site	NA	Alive
AM44	M	6	12/15/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			3/18/10	White Ranch	Replace collar	Hounds	On-site	NA	Alive
		7-8	3/20/11	White Ranch	Elk kill	Snare	On-site	NA	Alive
		9	5/30/12	SW of White Ranch	Shot/depredation				Dead
AM606	M	2	1/6/10	Boulder	Seen in town	Free-dart	MacGregor Ranch	None	Alive
			9/23/11	Laporte	Shot killing goat				Dead
AF54	F	4	1/14/10	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			5/16/11	White Ranch	Deer Kill/Replace Collar	Cage	On-site	NA	Alive
		7	3/14/13	White Ranch	Replace Collar	Hounds	On-site	NA	Alive
AF52	F	4	1/28/10	Hall Ranch	Capture effort	Hounds	On-site	NA	Alive
		5-6	3/24/11	Hall Ranch	Deer Kill	Cage	On-site	NA	Alive
AM51	M	1.5	1/28/10	Hall Ranch	Capture effort	Hounds	On-site	NA	Alive
AF56	F	1.5	2/22/10	Conifer	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
			5/24/12	Conifer	Shot				Dead
AF55	F	4	2/23/10	Conifer	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
			3/13/10	Conifer	Pet Depredation	Cage		Euthanized	Dead
AM53	M	4	3/13/10	Genesee	Elk Kill	Cage	On-site	NA	Alive
			3/3/11	Medved property	Shot/hunter				Dead
AM60	M	2	3/29/10	Walker Ranch	Baiting	Cage	On-site	NA	Alive
AF58	F	1.5	4/4/10	Table Mesa	Baiting	Cage	On-site	NA	Alive
			6/3/10		Roadkill				Dead
AF62	F	5	4/13/10	Walker Ranch	Elk Kill	Cage	On-site	NA	Alive
		6	4/13/11	Walker Ranch	Baiting	Cage	On-site	NA	Alive
			12/10/11	Gross Dam	Non-target/released	Cage	On-site	NA	Alive
		6	11/14/12	Walker Ranch	Recollar	Cage	On-site	NA	Alive
			2/16/12	Walker Ranch	Natural Mortality				Dead
AF59	F	5	4/22/10	Blue	Deer Kill	Cage	On-site	NA	Alive

				Jay/Jamestown					
		5	1/6/11	N. Boulder	Deer Kill	Cage	On-site	NA	Alive
		5-6	12/29/11	Sunshine Canyon	Deer Kill	Free-dart	On-site	NA	Alive
		6	3/6/12	NW of Boulder	Unknown mortality				Dead
AM63	M	1	9/22/10	Paradise Park	Deer Kill	Cage	White Ranch	None	Alive
			9/30/10		Road Kill				Dead
AF57	F	3	11/3/10	Lacy Property	Baiting	Snare	On-site	NA	Alive
		4-5	2/4/12	JCOS Ralston Buttes	Replace Collar	Hounds	On-site	NA	Alive
		5-6	3/5/13	Boulder/OSMP	Recollar	Cage	On-site	NA	Alive
AF61	F	4-5	11/18/10	Flagstaff	Deer Kill	Free-dart	On-site	NA	Alive
		4-5	3/2/11	Coal Creek Canyon	Raccoon Kill	Cage	Walker Ranch	None	Alive
		5	12/10/11	Gross Dam Rd	Baiting	Snare	On-site	NA	Alive
AF64	F	1.5	1/20/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
		3-4	7/19/12	N of Nugget Hill	Kill	Snare	On-site	NA	Alive
AM67	M	1.25	12/16/10	White Ranch	Baiting	Cage	On-site	NA	Alive
			3/4/12	Big Thompson	Shot/Depredation	Snare			Dead
AF69	F	1.5	12/1/10	N. Boulder	Deer Kill	Free-dart	On-site	NA	Alive
		2	4/6/11	N.Boulder/Town	Deer Kill	Free-dart	Reynolds Ranch	None	Alive
		4	3/31/12	Wonderland	Deer Kill	Cage	On-site	NA	Alive
AM70	M	2	1/23/11	Gold Hill	Deer Kill	Cage	On-site	NA	Alive
			3/2/11	Boulder Heights	Dog Kill	Cage	Reynolds Ranch	None	Alive
		3	2/26/12	Buckhorn Rd	Unknown mortality				Dead
AM71	M	2	1/27/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
		3	12/23/11	Casper, WY	Shot/hunter	Hounds			Dead
AM72	M	4	2/6/11	Heil Valley Ranch	Baiting	Snare	On-site	NA	Alive
		5	5/2/12	Heil Valley Ranch	Unknown mortality				Dead
AF73	F	4	3/6/11	Sunshine Canyon	Baiting	Cage	On-site	NA	Alive
		3-4	10/28/11	Four Mile Canyon	Deer Kill	Cage	On-site	NA	Alive
		4-5	3/27/13	Magnolia	Recollar	Hounds	On-site	NA	Alive
AM74	M	4	2/23/11	White Ranch	Baiting	Cage	On-site	NA	Alive

		5	3/7/12	Golden Gate Canyon	Deer Kill	Snare	On-site	NA	Alive
			12/31/12	Crawford Gultch	Shot				Dead
AM76	M	2-3	3/6/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
		3	12/27/11	Heil Ranch	Replace collar	Hounds	On-site	NA	Alive
		4	2/13/13	Heil Ranch	Recollar	Snare	On-site	NA	Alive
AF77	F	5	3/9/11	Morrison Mountain	Baiting	Cage	On-site	NA	Alive
		5	11/15/12	Indian Hills	Recollar	Snare	On-site	NA	Alive
AM78	M	2	3/18/11	W. Evergreen	Deer Kill	Cage	On-site	NA	Alive
			5/12/11	Soda Creel/I-70	Road Kill				Dead
AF79	F	4	3/18/11	Mt. Evans	Dumpsite	Cage	On-site	NA	Alive
		4-5	2/17/12	Mt. Evans	Replace Collar	Hounds	On-site	NA	Alive
AM80	M	1.75	3/18/11	Mt. Evans	Dumpsite	Cage	On-site	NA	Alive
AM84	M	2	4/9/11	Shield Park HOA	Sheep depredation	Cage	Deer Creek Canyon	None	Alive
		3	5/4/12	S. Deer Creek	Shot/depredation				Dead
AF86	F	1.5	3/13/12	Gross Dam Road	Recollar	Snare	On-site	NA	Alive
		2	1/31/13	Flagstaff	Recollar	Cage	On-site	NA	Alive
AF91	F	1.5	2/4/12	Cotter Mine	Capture effort	Hounds	On-site	NA	Alive
		2	7/20/12	I-70	Road Kill				Dead
AF86*	F	1.5	3/13/12	Gross Dam Rd.	Collared	Snare	On-site	NA	Alive
AF22	F	1.5	2/29/12	Golden	Baiting	Cage	On-site	NA	Alive
		2	10/5/12	Idaho Springs	Road Kill				Dead
AF87	F	4-5	11/18/11	Heil Ranch	Baiting	Snare	On-site	NA	Alive
		4	12/7/11	Hall Ranch	Deer Kill	Cage	On-site	NA	Alive
		5	3/11/13	Hall Ranch	Recollar	Hounds	On-site	NA	Alive
AF88	F	1.5	10/14/11	N. Boulder	Deer Kill	Cage	On-site	NA	Alive
		2	1/11/12	White Ranch	Possible Intraspecific				Dead
AF26	F	1.5	2/27/13	White Ranch	Initial Collar	Hounds	On-site	NA	Alive
AF27	F	1.5	10/31/12	White Ranch	Initial Collar	Cage	On-site	NA	Alive
			1/26/13	White Ranch	Non-target	Snare	On-site	NA	Alive
			2/14/13	Ralston Creek	Non-target	Cage	On-site	NA	Alive
AM98	M	1.5	1/4/13	Eldorado Springs	Deer Kill	Cage	On-site	NA	Alive

			5/31/13	Big Thompson	Unknown Mortality				Dead
AM99	M	1.5	12/2/12	Lyons	Human conflict	Free dart	New Hall	None	Alive
			1/6/13	Lyons	Human conflict	Free dart	HWY 72	None	Alive
			1/16/13	Boulder	Human Conflict	Free dart	Buckhorn Rd.	None	Alive
			1/31/13	Livermore	Depredation/Shot				Dead
AM100	M	2	12/23/12	Boulder	Initial Collar	Cage	On-site	None	Alive
			5/27/12	Boulder	DWM Capture Mort	Dart			Dead
AM109	M	1.5	7/23/13	Sugarloaf	Initial Collar	Cage	On-site	None	Alive
AF122	F	1.5	3/19/13	Hall Ranch	Initial Collar	Cage	On-site	NA	Alive
AM123	M	1.5	3/19/13	Hall Ranch	Initial Collar	Cage	On-site	NA	Alive
AM124	M	2	3/30/13	Hall Ranch	Initial Collar	Cage	On-site	NA	Alive
AF126	F	1	5/16/13	W. Boulder	Human Conflict	Cage	Sugarloaf	None	Alive
SW023	F	1	4/9/09		Rehab	Release	Pike forest	None	Alive
			11/14/09	Lost Valley Ranch	Found dead				Dead
SW026	M	1	10/20/09		Rehab	Release	Hermit Park	NA	Alive
		3	8/19/11	New Mexico	Shot/hunter				Dead
SW107	M	1	5/7/10		Rehab	Release	Radium	NA	Unkn
			3/22/11		Shot/hunter				Dead
AF995	F	1	8/25/11		Rehab	Release	Reynolds Ranch	NA	Alive
		2	6/23/12	Sunshine Canyon	Road Kill				Dead

Table 2: Capture history, aversive conditioning treatments and current status of all cougar cubs captured as part of the Front Range cougar study.

Cougar ID	Sex	Age	Mother	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AF35	F	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				12/31/08	Evergreen	Roadkill				Dead
AM36	M	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				1/8/09	Evergreen	Starvation				Dead
AM30	M	8	AF01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive
										Dead
AM38	M	8	AF01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive
				3/27/09	S. Boulder	Encounter	Free-dart	Lindsey	Beanbag	Alive
				3/30/09	S. Boulder	Pet Depredation	Free-dart	Centennial Cone	None	Alive
				4/9/09	Morrison	Encounter	Free-dart	None	Euthanized	Dead
AM29	M	6	Euth.	2/11/09	N. Boulder	Deer Kill	Free-dart	Hall Ranch	None	Alive
		12		6/15/09	N. Boulder	Encounter	Free-dart	Masonville	Beanbag	Alive
				10/23/09	Big Thompson	Goat Depredation	Shot			Dead
AM21* collared	M	12	Unkn	3/25/09	Table Mesa	Baiting	Cage	On-site	NA	Alive
										Dead
AM25	M	12	Unkn	5/22/09	Indian Hills	Deer Kill	Cage	On-site	None	Alive
				9/13/09		Raccoon	Free-dart	Perforated intestine		Dead
AM41	M	12	Unkn	5/22/09	Indian Hills	Deer Kill	Free-dart	On-site	None	Alive
					Indian Hills	Encounter	Shot			Dead
AM65	M	4-5	AF32	11/28/10	Golden	In Neighborhood	Free-	White Ranch	None	Alive

							dart			
AM66	M	4-5	AF32	11/28/10	Golden	In Neighborhood	Free-dart	White Ranch	None	Alive
				12/1/10	White Ranch	Recapture	Hounds	Radium	None	Alive
AF68	F	10	AF50	2/9/11	Flagstaff	Deer Kill	Cage	On-site	NA	Alive
AM83	M	9	AF52	3/24/11	Hall Ranch	Deer Kill	Cage	On-site	NA	Alive
AM85	M	9	AF62	4/13/11	Walker Ranch	Baiting	Cage	On-site	NA	Alive
AF86*	F	9	AF62	4/13/11	Walker Ranch	Baiting	Snare	On-site	NA	Alive
collared										Alive

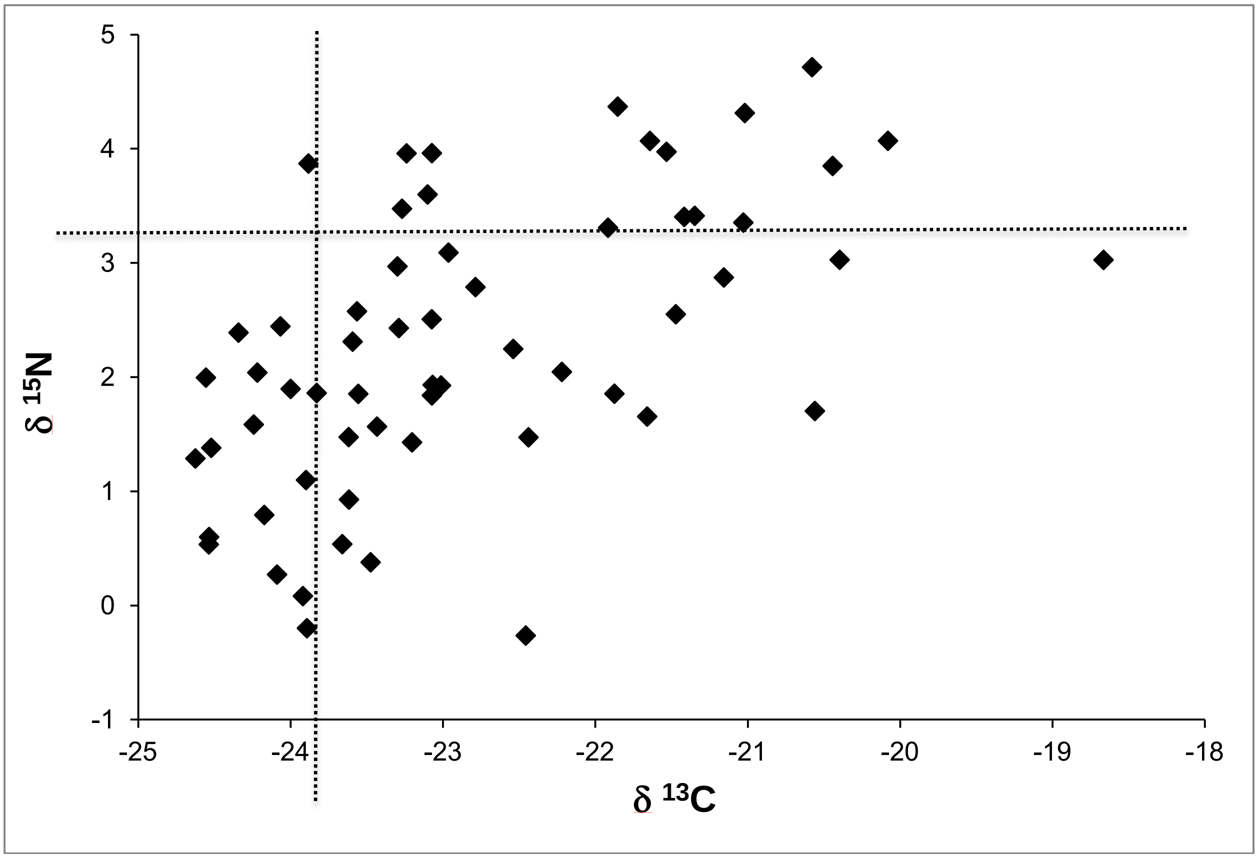


Figure 1: Carbon and nitrogen in hair from 60 bears harvested in Colorado during the 2011 hunting season showing the variability in concentrations reflecting dietary differences.

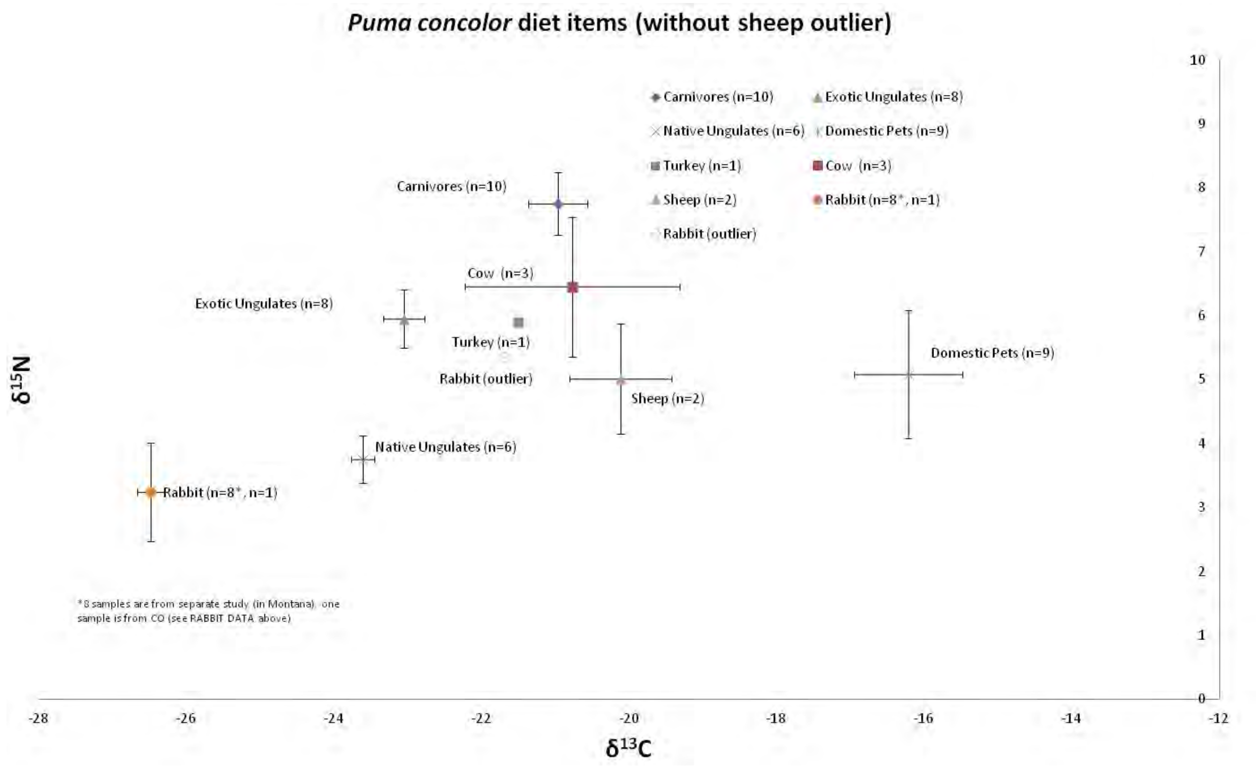


Figure 2: Carbon and nitrogen content in hair samples from cougar prey items found in the Front Range of Colorado. Prey items grouped into guilds demonstrates differences in carbon and nitrogen content based on similarities in prey species diet.

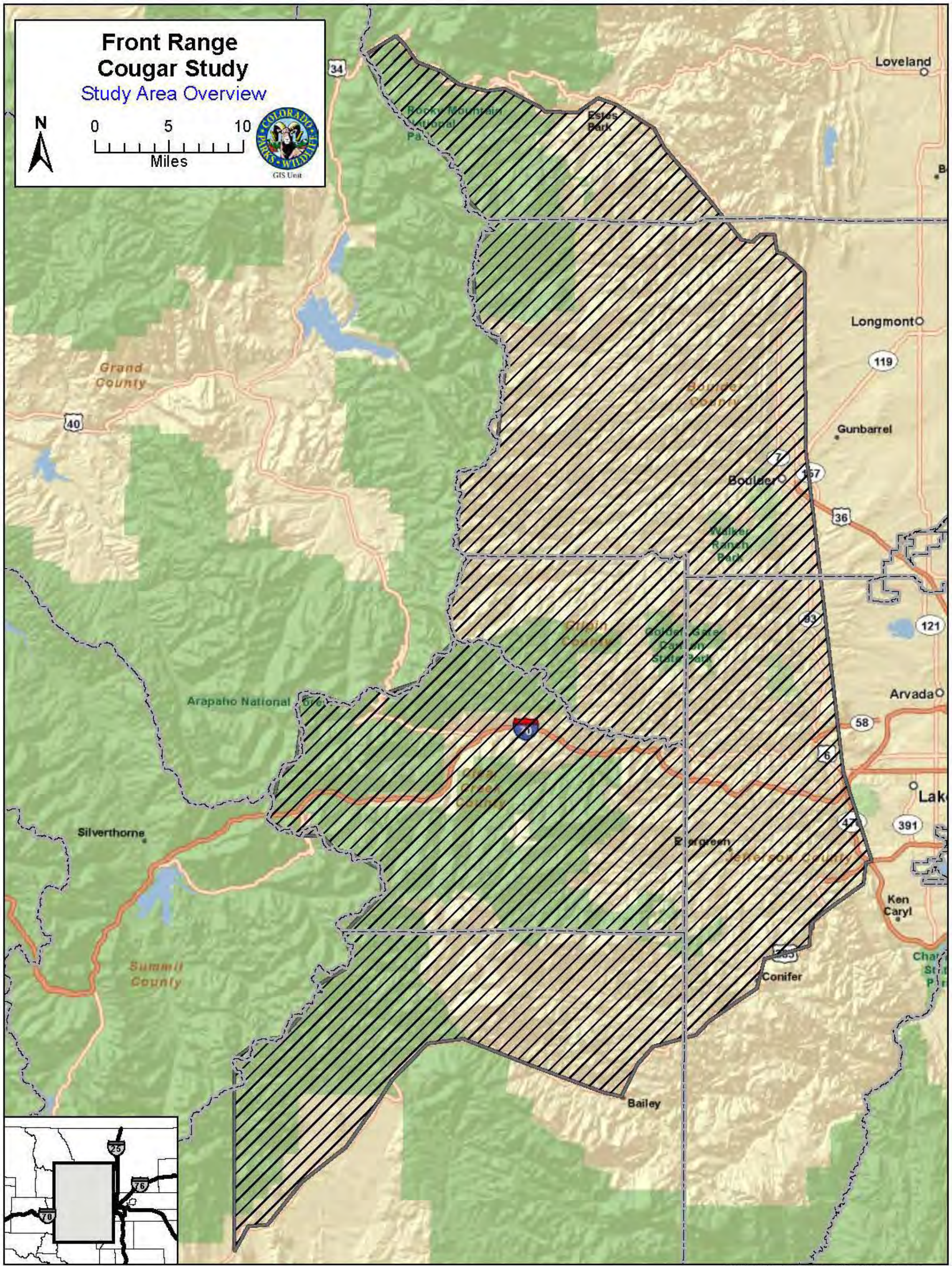


Figure 3: Study area for the main Front Range cougar study where most capture effort and field work is conducted.

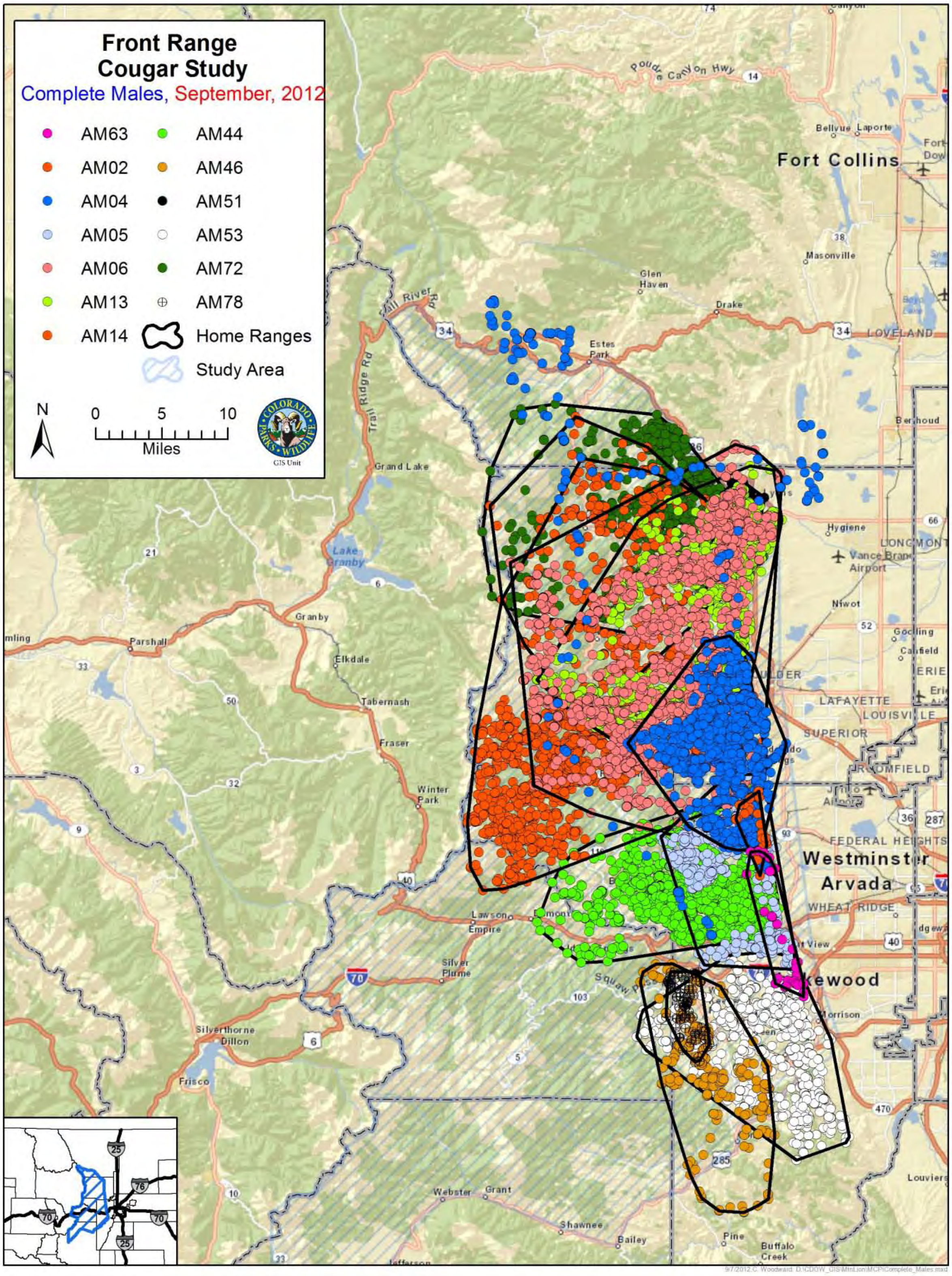


Figure 4: MCP home-ranges for male cougars that have previously been collared but are no longer in the study because of mortality or dispersal.

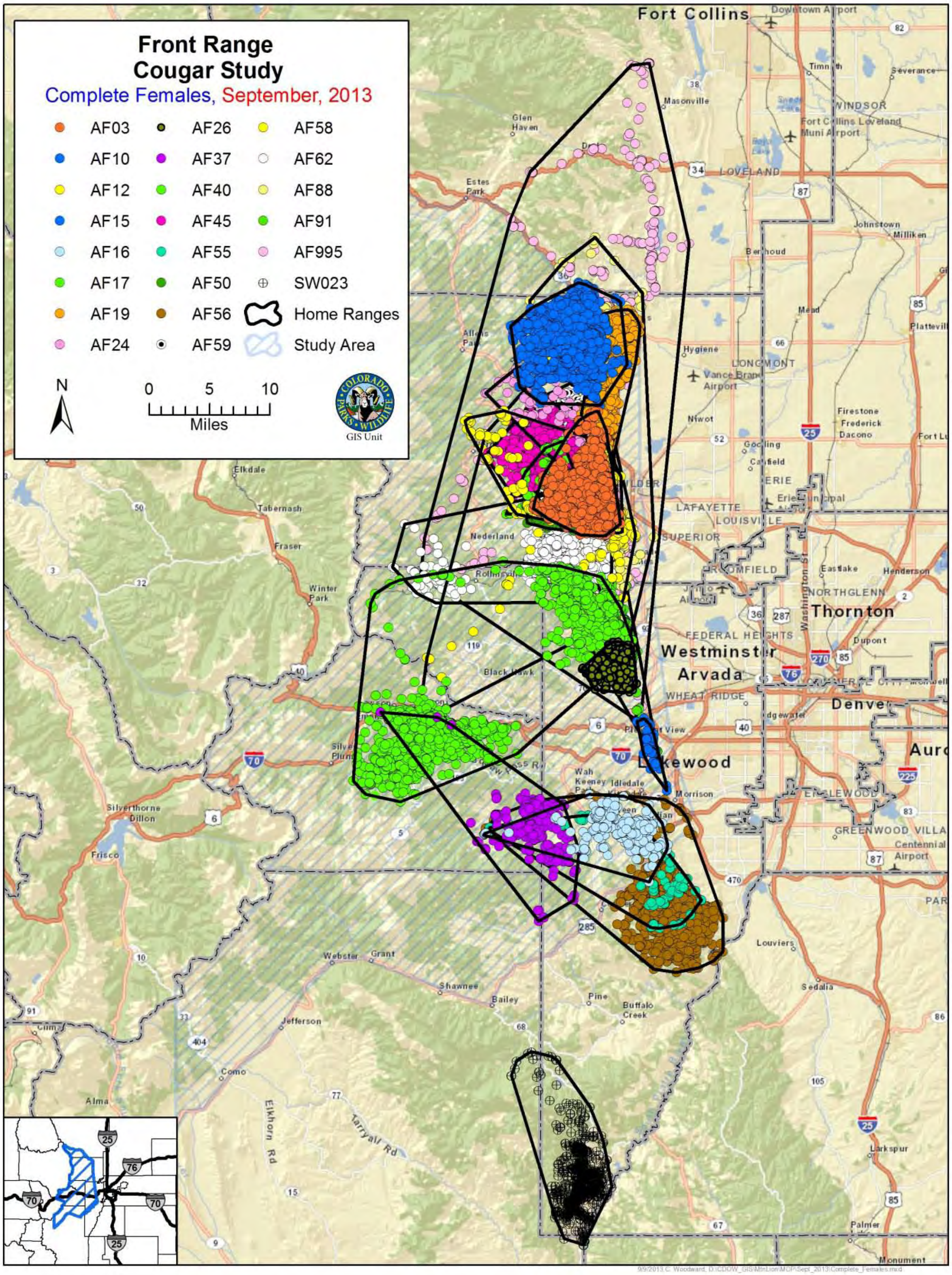


Figure 5: MCP home-ranges for female cougars that have previously been collared but are no longer in the study because of mortality or dispersal.

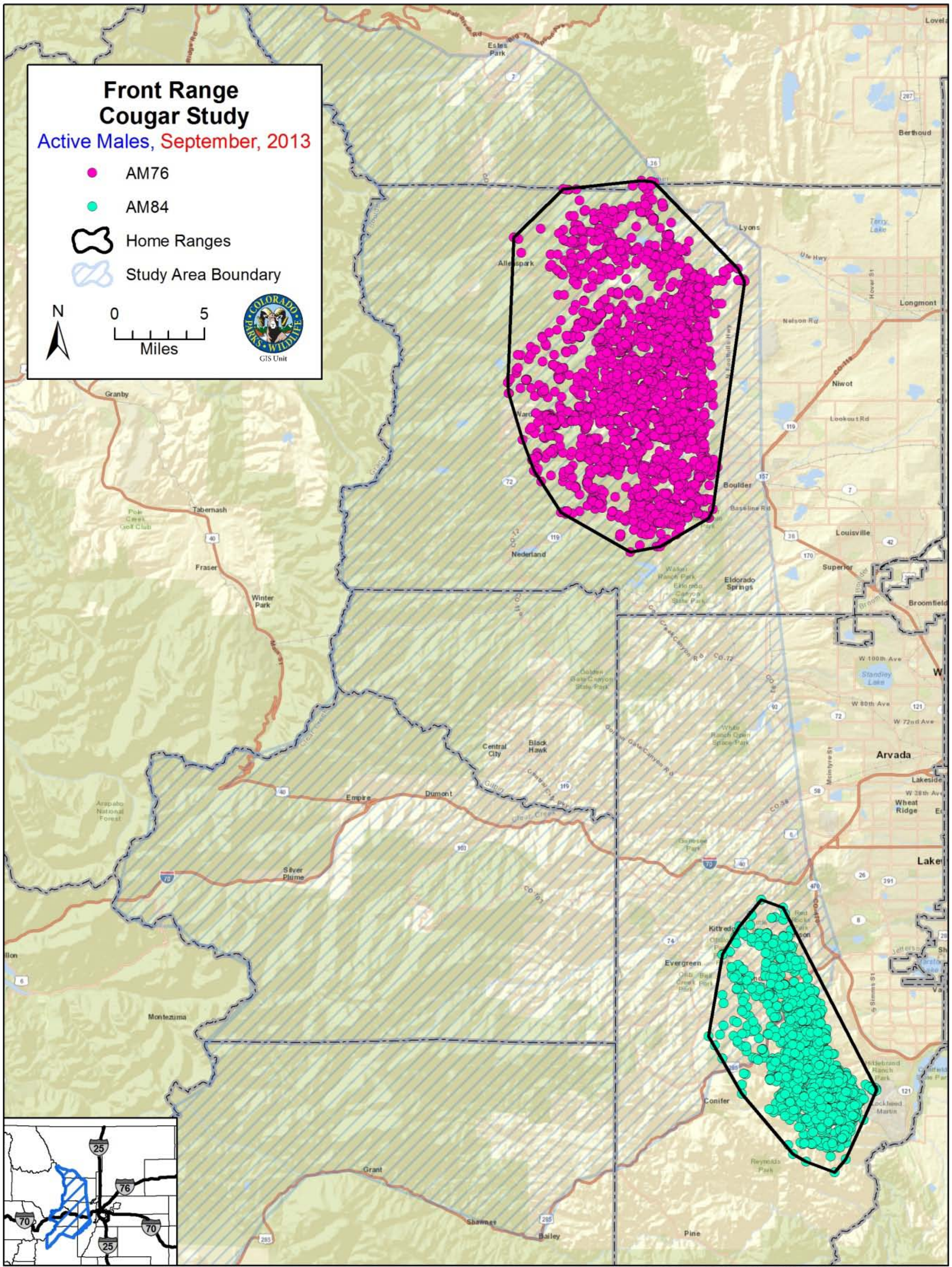


Figure 6: MCP home-ranges for male cougars that are currently in the study and being monitored.

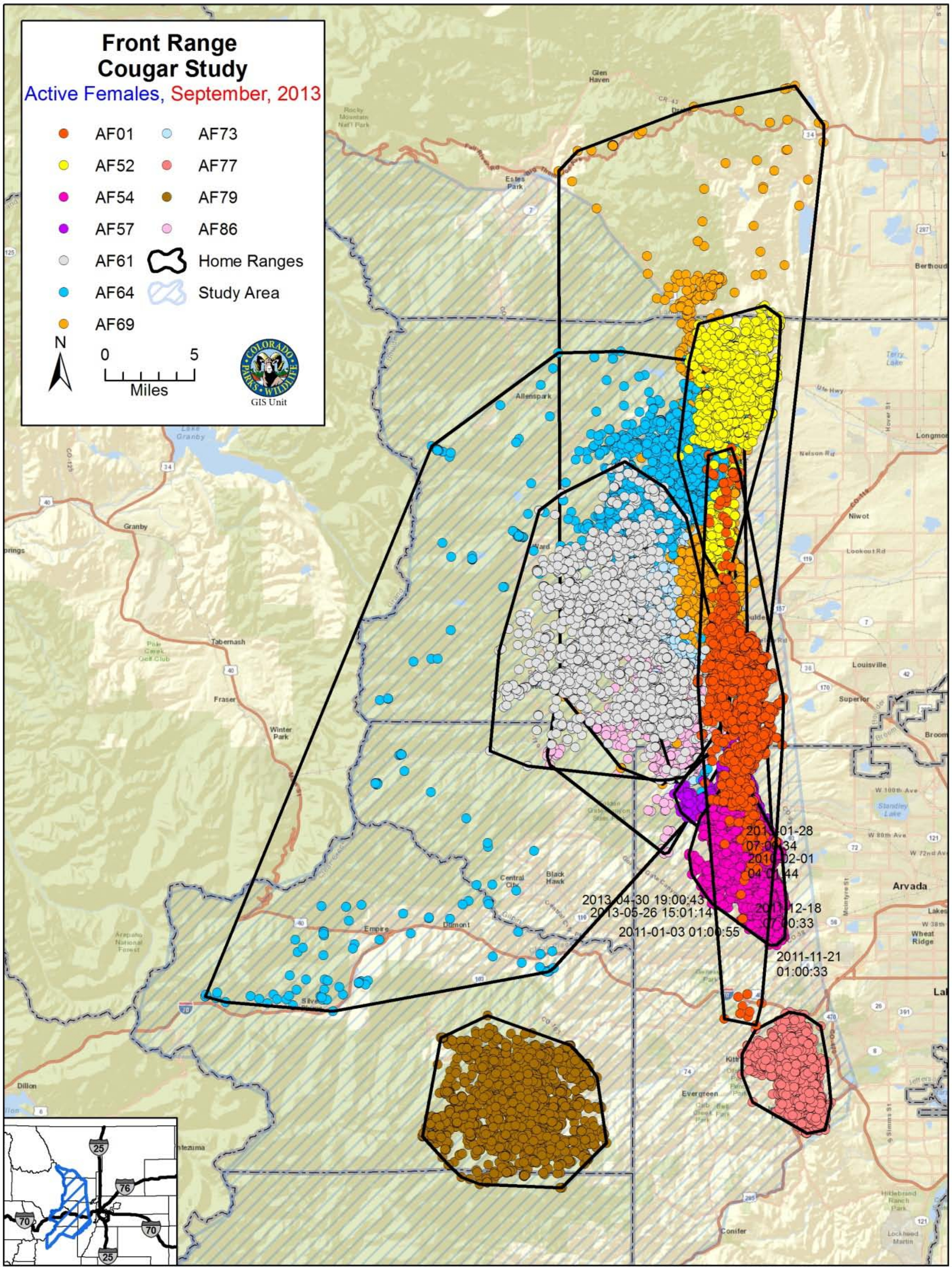


Figure 7: MCP home-ranges for male cougars that are currently in the study and being monitored.

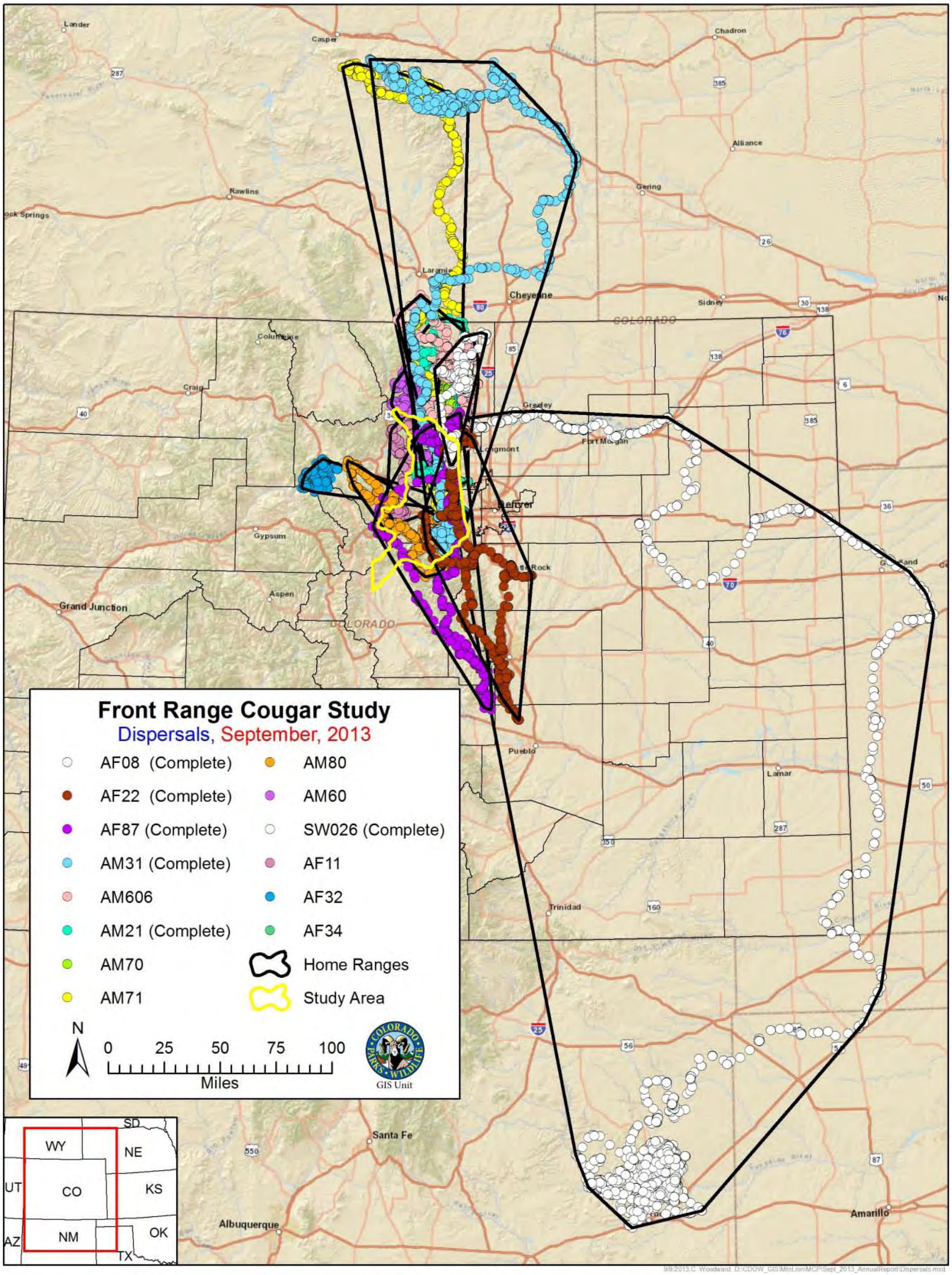


Figure 8: Dispersal/movement paths for cougars collared within the study area but traveled large distances outside of the study area.

Appendix I

Front Range Cougar Research

2012-2013

SPATIO-TEMPORAL PATTERNS OF DIET AND TELOMERE LENGTH IN COLORADO BLACK BEARS

UW-Wisconsin & Colorado Parks and Wildlife

Becky Kirby

Jonathan Pauli

Mat Alldredge

Research Report

SPATIO-TEMPORAL PATTERNS OF DIET AND TELOMERE LENGTH IN COLORADO BLACK BEARS

Becky Kirby, Ph.D. student, UW-Madison

Introduction

The effect of human-derived food on free-ranging wildlife populations is recognized as a growing problem across North America. This has been particularly evident among carnivore populations and especially related to human-wildlife conflict. In the past twenty years, American black bear (*Ursus americanus*) conflicts have expanded along the wildland-urban interface, and are generally attributed to access to human foods (Beckmann et al. 2008; Greenleaf et al. 2009), but still exhibit high geographical and temporal variation (Baruch-Mordo et al. 2008; Beston 2011). Whether increased conflicts are due to growing populations, or alternatively environmental-mediated behavioral changes, remains unknown; and without a thorough understanding of individual, environmental, and population characteristics that contribute to nuisance bears, effective management has proven difficult. As conflicts are predicted to continue to rise, multi-pronged approaches that quantify the influence of anthropogenic foods are needed, as well as those that can assess regional population trends.

To help monitor population trends, quantifying the age structure of a population is critical. The age of bears, as well as other mammals, is typically determined by pulling a vestigial premolar and counting cementum annuli (Schroeder and Robb 2005). The estimated age from counts of cementum annuli is highly accurate, but requires the animal to be captured or harvested. With rising numbers of studies using noninvasive sampling for DNA analyses of hair, feather, and scat samples, an aging technique that could be applied to these samples would be desirable. Previous research has demonstrated age-related telomere attrition in a variety of species and has correlated telomere length with individual age (e.g. Hemann and Greider 2000, Haussmann et al. 2003, Pauli et al. 2011). Telomeres are repetitive DNA sequences that cap the ends of eukaryotic chromosomes, whose nucleotide sequence $(T_2AG_3)_n$ is highly conserved across vertebrate species (Meyne et al. 1989). During each cell cycle telomeric repeats are lost because DNA polymerase is unable to completely replicate the 3' end of linear DNA (Watson 1972); thus, telomeres progressively shorten with each cell division. Though the relationship between chronological age and telomere length is highly variable among species, Pauli et al. (2011) successfully demonstrated that after accounting for covariates thought to influence telomere length (sex of the animal, size of the population, and geographic location), they could obtain accurate estimates of age class in martens (*Martes* spp.), and that age estimation via their model in fact exceeded those typically obtained from counts of cementum annuli. Thus, they concluded that quantification of telomere length could be a promising tool to age carnivores and estimate demographic structure for noninvasively collected hair samples (Pauli et al. 2011).

This project aims to assess broad-scale patterns of diet and telomere length in black bears across Colorado in hunter-harvested and nuisance bears. We are also collaborating with Mark Vieira collaring bears on the Front Range to longitudinally examine telomere length attrition, in order to inform our understanding of broad patterns of telomere length.

Objectives

1. Quantify diet via stable isotopes in hunter-harvested and nuisance bears
2. Quantify telomere length in hunter-harvested bears
3. Investigate individual telomere attrition rate longitudinally in wild bears

Methods

Objective 1: Quantify diet via stable isotopes in hunter-harvested and nuisance bears

In 2011, Colorado Parks and Wildlife opportunistically collected samples from ~400 hunter-harvested and nuisance bears. When possible, managers collected 5-10 mls of whole blood, >50 guard hairs (with follicles intact), 5 grams of muscle tissue, and a vestigial premolar from each bear. Hair, blood, and teeth are being analyzed with stable isotopes for diet reconstruction, and hair and blood are being used for telomere length analyses. Other measures collected included sex and head width, as well as age and reproductive history (for females) obtained from the teeth (Matson's lab; Milltown, MT), and GPS coordinates of harvest location (about 300 of the harvests appear to have reasonable coordinates) (Figure 1). In April 2013, an additional 50 samples from hunter-harvested and nuisance bears from fall of 2012 were sent to the UW-Madison, which are currently in queue for processing.

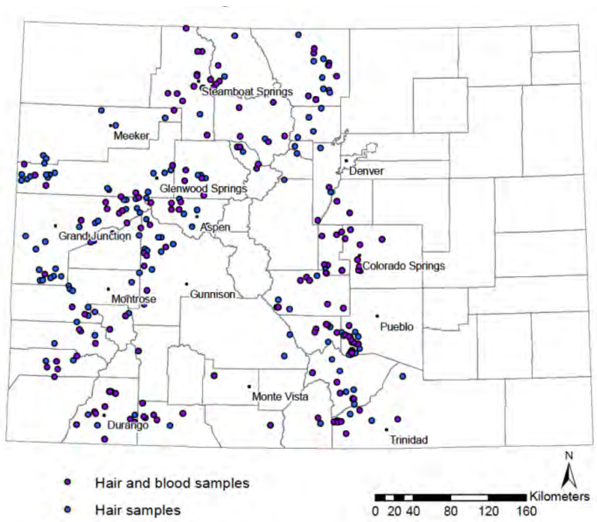


Figure 1. Locations of bears sampled in fall 2011

Stable isotope analysis has yielded significant contributions to wildlife ecology in the last several decades (Kelly 1999, Crawford et al. 2008); of particular interest to managers has been quantifying diet components of free-ranging vertebrates using carbon and nitrogen isotopes. Because corn and sugar utilize a distinct photosynthetic pathway from native plants in temperate North America, corn-dominated human food (waste and agriculture) exhibit distinct carbon ($\delta^{13}C$) values, which can be measured in consumer tissues (Jahren et al. 2006). In addition, measuring nitrogen ($\delta^{15}N$) values can indicate trophic position and animal content in the diet; higher nitrogen values reflect higher trophic positions (Hobson and Welch 1992). Traditional diet reconstruction methods (such as scat or stomach content analyses) tend to underestimate highly digestible resources. Because diet analysis with stable isotopes uses the abundance of two elements (^{13}C and ^{15}N), it avoids this bias. Further, sampling tissues with different metabolic rates allows for higher resolution of temporal patterns of resource use (Hilderbrand et al. 1996). Using isotopic mixing models, we can calculate the percent of diet obtained from native plants, heterotrophs and human-derived food items (Phillips et al. 2005).

We have processed 353 hair samples and 152 blood samples thus far. Follicles are first clipped off hair samples and placed aside for DNA extraction. The remaining hair shaft is rinsed three times with 2:1 chloroform:methanol solution to remove surface oils (Cryan et al. 2004), dried for 72 hours at 60°C, and homogenized with surgical scissors. Whole blood samples are dried for 72 hours at 60°C, and homogenized with a spatula. Teeth are awaiting processing, but will undergo collagen extraction by soaking in 32% HCl for 24 hours to remove biogenic carbonates, followed by drying at 60°C for one week, then freeze drying for three days, and homogenized in a ball mill (Mixer Mill MM200, Restch Inc. Newton, PA, USA) (Owen et al. 2011). Diet samples will also be dried for 72 hours at 60°C and homogenized in a ball mill. For ^{13}C and ^{15}N analysis, samples are weighed, placed in tin capsules and submitted to the Stable Isotope Facility at the University of Wyoming to be analyzed with a Costech 4010 elemental analyzer attached to a Thermo Finnigan DeltaPLUS XP Continuous Flow Isotope Ratio Mass Spectrometer. Results are provided as per mil (parts per thousand [‰]) ratios relative to the international standards of Peedee Belemnite (PDB; $\delta^{13}C$) and atmospheric nitrogen (AIR; $\delta^{15}N$) with calibrated internal laboratory standards.

By quantifying the isotopic signature in tissues of bear and that of diet sources, we can quantify the contribution of isotopically distinct items to the diet of the bear. CPW is collecting potential diet samples from CO this summer/fall 2013 from six major regions where bears were harvested (Northern Front Range, Southern Front Range, Southwest San Juan Mountains, Uncompaghre Plateau, Piceance Basin, and Northwest Colorado) including spring beauty, fireweed, glacier lily, dandelions, cow parsnips, oak acorns, chokecherries, blueberries, currants, buffaloberries, elk, mule deer, small mammals, ants, and wasps (Irwin and Hammond 1985, Raine and Kansa 1990, Baldwin and Bender 2009). We will first group prey samples into biologically relevant and isotopically distinct source groups (likely human-derived food, animal matter, native vegetation), and use ANOVA or K nearest-neighbors randomization tests (Rosing et al. 1998) to test for normality within the group. We will then explore MixSIR models (Parnell et al. 2010, Layman et al. 2012), which incorporate prior information on variability in isotopic signatures and proportional contributions of sources, resulting in more precise estimates of consumption. For the hunter-harvested and nuisance bears, we will compare differences in diet between black bear age-sex groups, and other human and land use covariates ANOVA-type analyses, and explore dietary shifts within individuals with a GLM approach, attempting to discern if particular variables are predictive of nuisance bears. Further, isotopic signatures will be included as possible predictor variables in the telomere length models. Preliminary analyses on stable isotope signatures have been conducted using t-tests to examine group mean differences.

Objective 2: Quantify telomere length in hunter-harvested bears

We are using the same hair and blood samples collected in Objective 1 for telomere length analysis. As telomeres shorten with cellular replication, they are potentially a useful marker for chronological age. Telomerase, a reverse transcriptase, counteracts this loss in the germline, but tends to be far less active in somatic cells; this activity seems to vary with body mass, with larger animals having less telomerase activity (Seluanov et al. 2007). Additionally, as lifestyle-related activities, in particular oxidative stress, can affect telomere length negatively (von Zglinicki 2002, Monaghan and Haussmann 2006), knowing what other factors influence telomere length is essential to any potential aging model.

Hair samples were extracted with standard procedures using Qiagen Dneasy tissue extraction kit. We are quantifying the relative length of telomeres using real-time quantitative polymerase chain reaction (Q-PCR) (Cawthon 2002). This approach has been found to be highly accurate, in particular for within species comparison (Cawthon 2002, Nakagawa et al. 2004). The method determines relative telomere length by comparing the ratio of telomere repeat copy number (T) to single copy gene number (S) in a particular DNA sample to that of an arbitrary reference DNA. Relative differences in telomere length between individuals then, is exhibited by contrasting the T/S ratio of one individual to that of another. Any single copy gene sequence can be employed for standardization, and after exploring several possibilities we found HNRPF specific to bears (Fedorov et al. 2009) to be the most readily amplified. Telomere primers developed by Cawthon (2009) generate a short, fixed length product, reducing variability within sample replicates.

Telomere and single-copy gene PCR are conducted on separate 96-well plates, but preparation is identical except for the primers. A standard curve is generated from an arbitrarily chosen sample from 0.5 ng/µl to 10 ng/µl (exact concentrations determined on a Qubit - Invitrogen). Each reaction contains 8 µl sample DNA (diluted to 3 ng/µl), 10 µl SYBR Select Master Mix (Life Technologies - Applied Biosystems), telomere primers (250 nM each final concentration) or single copy gene primers (500 nM each final concentration), and distilled water to total 20 µl reaction volume. Real-time PCR is conducted with an Eppendorf Mastercycler, with the following thermocycling conditions: telomere: 50°C for 2 min, 95°C for 5 min, followed by 2 cycles of 94°C for 15 sec and 49°C for 15 sec, and then 35 cycles of 95°C 15 sec, 62°C 10 sec, 74°C 15 sec (telomere) or 95°C 15 sec, 62°C 15 sec, 72°C 45 sec (HNRPF). Based on the amplification and the standard curve, each sample has an amount of SYBR Green calculated, and the telomere to single copy gene is presented as relative telomere length (T/S).

We will explore relationships to age and other covariates beginning with simple correlations and t-tests, and linear regression. If as expected, more complex modeling is necessary, we will develop and test models using a Bayesian network modeling framework (Netica, Norsys Software Corp. Vancouver, Canada) with various covariates that all include telomere length (Marcot et al. 2006, Pauli et al. 2011).

Objective 3: Investigate individual telomere attrition rate longitudinally in wild bears

Dunshea et al. (2011) recently called for more longitudinal studies to elucidate factors affecting telomere dynamics. Further, recent studies of hibernating rodents have effectively demonstrated that spending more time in torpor retards the rate of telomere attrition (Turbill et al. 2012, 2013). Thus, we will longitudinally examine telomere length in bears, as well as the relationship between telomere attrition and bear hibernation. To do so, we will take multiple samples from free-ranging black bears. Working with Mark Vieira, we have already GPS collared and sampled 6 bears on the Front Range in Colorado during 2012; in summer 2013 we are working to increase our sample size to 10. Bear hair samples will be taken 3 times (summer, winter hibernation, and spring emergence); blood will be taken twice (summer capture and winter). Bears are being captured and anesthetized using CPW standard protocols in summer and relocated in winter dens. Hair will be obtained during spring emergence from barbed wire over the den opening, or relocating the bear at a hair snag.

Hibernation length and activity will be determined from GPS movement data. Measuring hibernation physiology throughout the winter has proven difficult, and frequently is invasive, most methods requiring surgery. However, we can measure oxidative stress which will increase with more disrupted hibernation, indicating more active winters. To measure oxidative stress in blood samples, we will use d-ROMs and OXY-Adsorbent tests (Diacron, International, Italy). These tests were developed for human diagnostics, but have successfully been used in a variety of animals (Beaulieu et al. 2011, Stier et al. 2012). The d-ROM tests measures oxidative damage by the concentration of hydroperoxide (a reactive oxygen metabolite), and the OXY-Adsorbent test measures the total antioxidant capacity of the sample. Together, the imbalance of these can be taken as a measure of the oxidative status of an individual animal. We will explore relationships between calculated rates of telomere change and oxidative status, hibernation length and activity, and den temperatures using generalized linear mixed models (Beaulieu et al. 2011, Turbill et al. 2013). We will use results to inform telomere models.

Preliminary Results and Discussion

Objective 1: Quantify diet via stable isotopes in hunter-harvested and nuisance bears

We have stable isotope data from 353 hair samples and 152 blood samples, and present preliminary analyses here. Another 50 samples collected in 2012 are in queue for processing, as well as teeth from 2011. Hair samples indicate diet composition during the period of growth (mid-summer through fall), whereas blood samples represent more recent diet (last 2-4 weeks). Enriched (higher) $\delta^{13}C$ and $\delta^{15}N$ likely indicate greater consumption of human-derived foods and animal matter, respectively. Preliminary analyses show wide variation among individual bears and a general linear relationship between $\delta^{13}C$ and $\delta^{15}N$ (Figure 2).

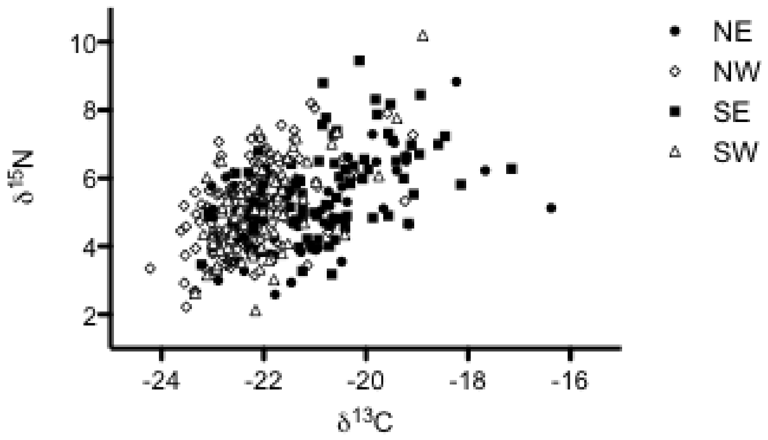


Figure 2. Stable isotope signatures of Colorado bear hair sampled in fall 2011, categorized by broad geographic region. Higher $\delta^{13}C$ signatures indicate more corn/C4 plants (human-derived foods) in diet (during late summer/early fall) and higher $\delta^{15}N$ signatures indicate more protein (animal matter). Eastern bears are on average significantly enriched in $\delta^{13}C$ and $\delta^{15}N$ compared to western bears.

We compared isotopic signatures between mortality, sex, age class, and geographic groups using t-tests. These results indicate significantly enriched $\delta^{13}C$ and $\delta^{15}N$ in nuisance/roadkill bears, males, adults, and eastern Colorado as compared to their corresponding group (Table 1). The differences between eastern and western Colorado bears may be due to different isotopic signatures of diet items (analyses forthcoming), or the availability of human-derived food. Adult male bears also may consume more human-derived foods and high quality forage than females and subadults (e.g. McCarthy and Seavoy 1994). Nuisance bears are on average significantly enriched compared to hunter-harvested bears, but roadkill bears are not significantly different from either group (Figure 3). When grouping nuisance and roadkill bears together, there are still significant mean differences in $\delta^{13}C$ and $\delta^{15}N$ compared to hunter-harvested bears (Table 1). While unsurprising, these signatures indicate that nuisance and roadkill bears are probably consuming more human-derived foods than hunter-harvested bears. A study on Yosemite black bears found a similar relationship between higher $\delta^{15}N$ and human food-conditioned bears, though they found no relationship with $\delta^{13}C$ (Hopkins et al. 2012). Linear regression shows no significant relationship between isotopic signatures and head width or age of bears. It is important to note that these results reported are differences only in isotopic values; once converted to diet proportions they may group more broadly.

Table 1. Group mean comparisons of isotopic signatures from hair samples of fall 2011 bears. P-values for t-tests shown.

Group Comparisons	**Stable Isotope Signature** $\delta^{13}C$	$\delta^{15}N$
Hunter-harvested	-21.77	5.15
Nuisance/Roadkill	-20.55	6.02
p-value	*0.55*	*0.001*
Male	-21.8	5.32
Female	-21.47	5.06
p-value	*0.01*	*0.06*
SubAdult (≤4)	-21.9	4.97
Adult	-21.45	5.52
p-value	*0.0005*	*<0.0001*
Eastern CO	-21.02	5.41
Western CO	-22.16	5.08
p-value	*<0.00001*	*0.014*

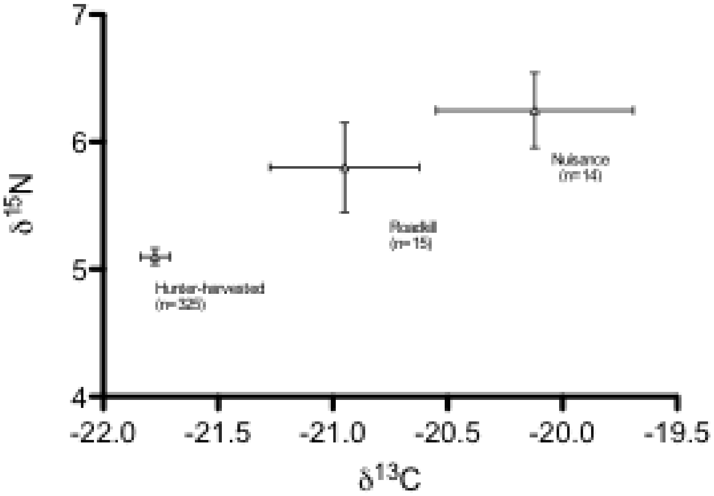


Figure 3. Mean stable isotope signatures of Colorado bear hair sampled in fall 2011 grouped by mortality type (shown with standard error bars). Hunter-harvested and nuisance bears have significantly different means from one another, but not from roadkill bears.

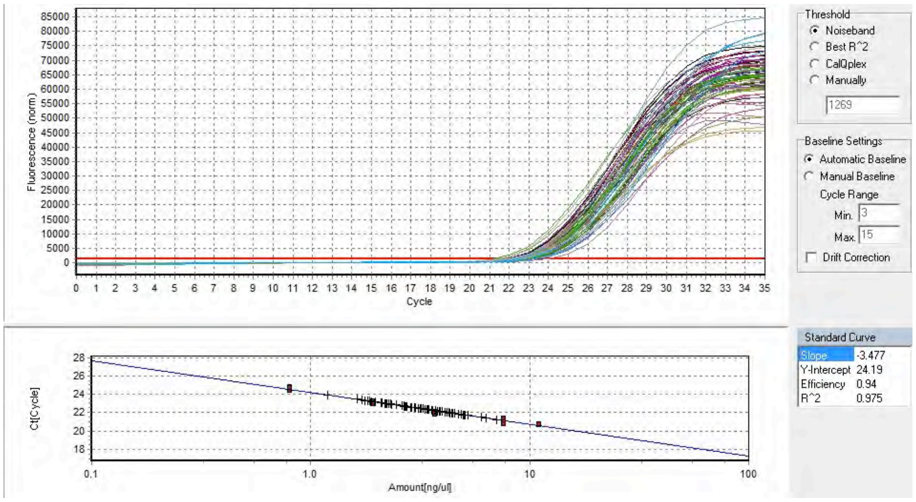
Analyses of blood samples compared to hair samples of hunter-harvested bears are significantly less enriched in $\delta^{13}C$ ($p<0.0001$, after correcting blood to hair with +1 $\delta^{13}C$, Hilderbrand et al. 1996). This could suggest a shift towards consumption of more native vegetation in the early fall. These preliminary results indicate individual diet specialization and warrant further investigation to determine habitat and individual characteristics that could be predictive of these differences.

As of mid-July CPW had collected 155 herbaceous plant samples, 43 insects, and 24 mammal hair, which have been brought to UW-Madison for preparation for stable isotope analyses. Soft and hard mast will be collected during the remaining summer and early fall. Once we have isotopic signatures of diet items, we can use these in mixing models to estimate proportional contributions of prey groups to bear diet, and more thoroughly explore individual differences.

Objective 2: Quantify telomere length in hunter-harvested bears

We extracted DNA from all bear hair samples that had high quality follicles (>300 samples) and whole blood (~150 samples). Quantifying telomere length accurately is based on careful optimization of the qPCR reactions (described in Methods), and choice of a reliably amplifiable single copy gene. For reactions to be considered adequate, standard curve efficiencies of both the telomere and the single copy gene reactions need to be between 0.9 and 1.05. Standards are run in triplicate and samples in duplicate (coefficient of variation for C_t), and we use the mean T/S as relative telomere length in subsequent analyses.

We have quantified relative telomere length from hair follicles in 39 individuals, all harvested in southeastern Colorado (19 females ranging in age from 1-20 and 20 males from age 1-11, as estimated by cementum annuli). We report preliminary analyses here.



Threshold
● Noiseband
○ Best R^2
○ CalQplex
○ Manually
1269

Baseline Settings
● Automatic Baseline
○ Manual Baseline
Cycle Range
Min. 3
Max. 15
☐ Drift Correction

Standard Curve

Slope	-3.477
Y-Intercept	24.19
Efficiency	0.94
R^2	0.975

Figure 4. Example quantification plot and standard curve for telomere reaction (0.94 efficiency).

These samples exhibit wide variation among T/S across ages, and comparisons of females to males show a non-significant trend toward higher T/S in females (Figures 5 and 6).

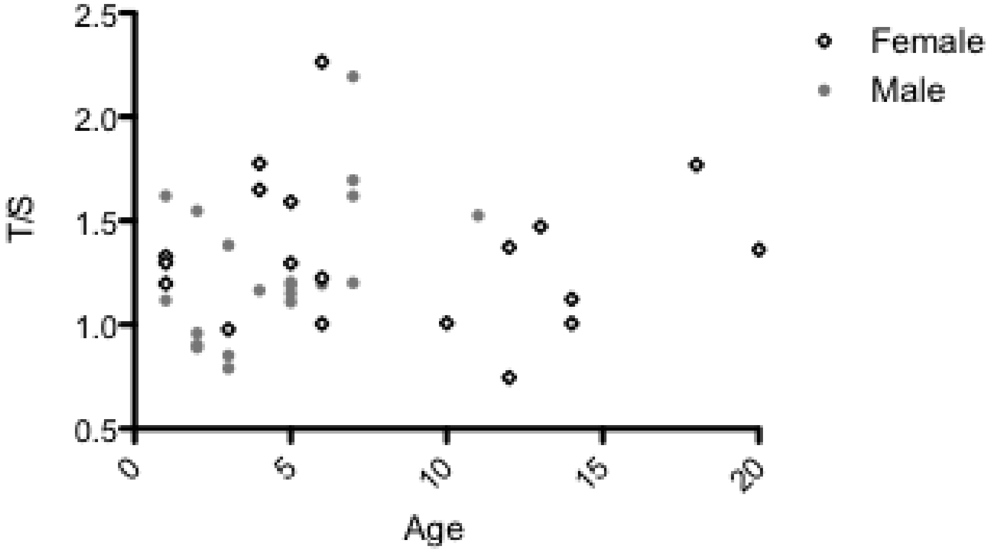


Figure 5. Relative telomere length (T/S) compared with age by cementum annuli of 19 females and 20 males from DNA from hair follicles.

We ran simple linear regression for T/S against age, and found no significant relationships. However, when examining only subadult bears (<4) or adult bears (>4), decreasing linear trends were observed.

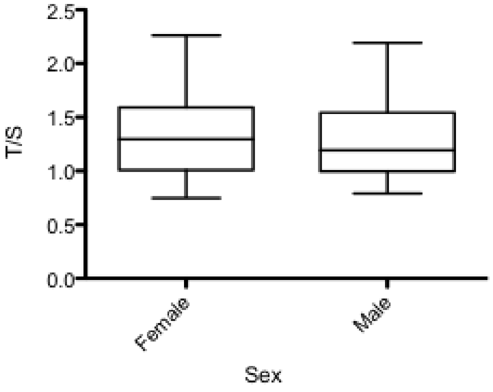


Figure 6. Females tends to have slightly higher T/S than males (though not statistically significant).

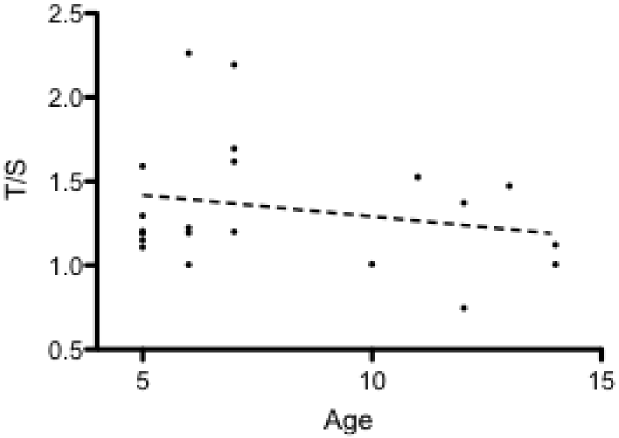


Figure 7. Relative telomere length (T/S) compared with age in a subset of adult bears ages 5-14 shows a non-significant decreasing linear trend.

We also examined relationships between T/S and stable isotope signatures and T/S and head width, and found no significant relationships; though there appears to be a trend toward a positive correlation between higher $\delta^{15}N$ and larger T/S ratio (Figure 8).

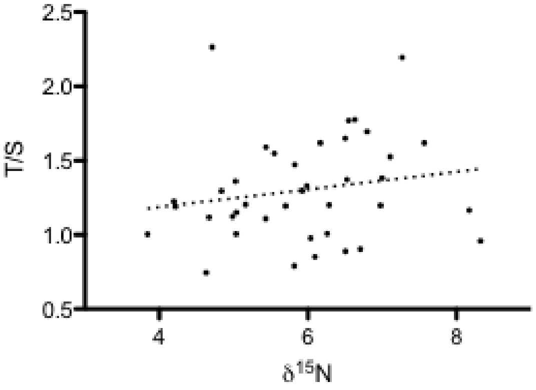


Figure 8. Relative telomere length (T/S) compared to $\delta^{15}N$ hair signatures show a non-significant positive trend.

These results are only preliminary with a small sample of 39 individuals. As we analyze additional individuals and covariates, we will be able to better examine what factors influence telomere length and how we might account for them in a potential aging model.

Objective 3: Investigate individual telomere attrition rate longitudinally in wild bears

During summer 2012, we captured and collared 7 bears (4 females, 3 males) in the northern Front Range. Age estimates ranged from 2-9 and weights from 99-280 lbs. Hair and blood samples were collected for telomere and isotope analyses. During late January-March 2013, we visited dens of the 6 bears whose collars continued working to obtain additional hair and blood samples which are being prepped for analysis. During summer 2013, effort is ongoing to capture and collar an additional 4 bears, as well as obtain hair samples via snags from the previously collared six. Telomere length will be quantified from each blood and hair sample and differences will be examined along age, sex, hibernation characteristics, and habitat use.

Continuing Plans

This summer CPW will continue diet collection, and samples will be prepared for stable isotope analyses and subsequent diet reconstruction. We will quantify telomere length from the remaining hair samples, and begin to investigate covariates to explore the potential aging model. We plan to resample collared bears this winter, and will examine telomere length changes in those samples, ultimately to inform our understanding of patterns of bear diet and telomeres across Colorado.

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Appendix II

Front-range Cougar Research

Non-invasive approaches to quantifying cougar diet and age structure

UW-Wisconsin & Colorado Parks and Wildlife

Wynne Moss
Jonathan Pauli
Mat Alldredge

Research Report

INTRODUCTION

Cougars (*Puma concolor*) are high-level predators that play a strong role in shaping ecosystem processes. Cougars influence the spatial distribution of prey (Hornocker 1970), support scavenging species by providing significant quantities of carrion (Elbroch and Wittmer 2012), and affect plant communities via the regulation of herbivore populations (Ripple and Beschta 2006). However, anthropogenic habitat change may be eroding the regulatory role of cougars by altering both their foraging behavior and their demography. Shifts in the diet and age-sex structure of Colorado's cougars could have wide-ranging effects on the conservation and management of cougars and their prey. We are currently developing methods to monitor these parameters that, if successful, would enable large-scale, non-invasive studies of cougar diet and age-sex structure.

Cougar diet composition

Cougar are adaptable carnivores capable of utilizing a wide variety of species, including ungulates, mesocarnivores, small-bodied mammals, domestic livestock, and pets. In most populations, primary prey consists of the most abundant native ungulate species (Murphy and Ruth 2009). However, the degree to which cougar specialize on ungulates is variable, both within and across populations. While cougars may switch to alternative prey when primary prey are rare (Logan and Sweanor 2001, Knopff 2010), not all populations do so (Cooley et al. 2008, Villepique et al. 2011). Further, within populations, some individuals specialize on alternative prey, which can exert strong top-down effects on those species (Festa-Bianchet et al. 2006, Sweitzer et al. 2011). The mechanisms leading to specialization are poorly understood (Knopff and Boyce 2007). How anthropogenic habitat change will further influence reliance on alternative prey species is unknown, but has strong implications for the regulation of communities in urban-exurban habitats. Habitat change significantly impacts the availability of prey (Prange and Gehrt 2004), principally by increasing the abundance of domestic species and synanthropic wildlife, especially mesocarnivores. In theory, this could lead to a lowered reliance on native ungulate prey in these environments. Only one study (Kertson et al. 2011) has monitored prey use in relation to anthropogenic habitat change, and found a higher proportion of mesocarnivore and domestic species at urban relative to wildland kill sites. The use of domestic prey in particular represents a significant risk to cougars; identifying what factors predispose individuals to depredate pets and livestock could help mitigate human-cougar conflict.

Quantifying diet composition for cougars is a challenge, given their low densities and cryptic behavior. In the past decade, advances in GPS technology have enabled numerous studies of cougar diet using GPS-aided kill-site investigations (Anderson and Lindzey 2003). Importantly, this approach gathers data on the spatial distribution and rate of cougar kills. Yet, kill site investigations overestimate the importance of larger prey species, like native ungulates (Knopff et al. 2009). Further, these studies require the capture and handling of individuals to assign GPS collars, and therefore can be limited in the number of individuals monitored or restricted to one geographic area. The ability to estimate diet through non-invasive sampling would enable more cost-effective diet studies across a wider geographic scale.

The analysis of naturally occurring stable isotopes has become an increasingly useful tool for ecologists and managers in understanding a myriad of animal behaviors, including dispersal, prey selection, and resource use (Kelly 2000). Dietary analysis using stable isotopes evaluates the isotopic signature (i.e. the ratio of heavy and light isotopes of carbon and nitrogen) of consumer tissue, and compares it to the signatures of potential diet items. The distance between consumer isotopic signature and the isotopic signature of a given prey species indicates the relative importance of that diet item. Because isotopic analysis directly estimates diet in terms of proportional biomass consumed, it avoids the need for correction factors or extrapolating from a small quantity of kill sites visited. Additionally, the analysis of different tissue types can provide information on foraging at different temporal scales. For example, hair, which can be collected non-invasively, reflects items consumed during active phases of hair growth, whereas blood reflects the isotopic signature of food consumed over the previous two months (Hilderbrand et al. 1996).

We will use stable isotope analysis of hair to quantify cougar proportional resource use, and compare diet compositions between individuals with varying degrees of urban-exurban habitat use to assess how anthropogenic habitat change may alter cougar foraging strategy and predator-prey dynamics.

Cougar population structure

Monitoring cougar population structure is of fundamental importance to predicting demographic trends and setting sustainable harvest goals. Current methods of estimating cougar age (using gum recession and tooth wear, cementum annuli counts, or individual history) can only be carried out on captured or necropsied individuals; as a result, the structure of cougar populations is generally extrapolated from harvest composition or from research studies conducted in limited geographic areas. Therefore, current methods provide an incomplete picture of cougar population ecology.

Telomeres are repetitive DNA sequences that cap the ends of eukaryotic chromosomes and shorten with each round of cellular replication and animal age (Watson 1972). A predictable relationship between telomere length and age has been found for several species (Hemann and Greider 2000, Haussmann et al. 2003, Pauli et al. 2011), indicating the potential for using telomere length as an indicator of age. Telomere length can be quantified using real-time quantitative polymerase chain reaction (Q-PCR), using non-invasively collected genetic material, like hair follicles. This technique has been used to successfully age martens, with greater accuracy than counts of cementum annuli (Pauli et al. 2011). The relationship between cougar age and telomere length has not yet been explored. If cougar telomere length can be modeled as a function of age and other available covariates, this could present an extremely valuable tool for aging a cryptic species.

We are exploring the accuracy of telomeres as an aging tool in cougars by quantifying the relationship between age and telomere length in blood and hair samples collected from known-age individuals.

OBJECTIVES

In order to better quantify elusive aspects of cougar ecology, we will advance non-invasive methods for monitoring cougar diet and population structure. Specifically, I will:

1) Estimate cougar diet composition using stable isotope analysis.
    a) Characterize cougar molt chronology to improve the temporal inference of stable isotope analysis.
    b) Investigate diet shifts between urban-exurban (Front Range) and wildland (Uncompahgre Plateau) populations.
    c) Determine how age-sex class and habitat use influence cougar diet on the Front Range.
2) Explore telomere length quantification as a method to non-invasively age cougars.

METHODS

All cougar captures and sampling have been done as part of ongoing CPW projects: *Cougar Demographics and Human Interactions Along the Urban-Exurban Front Range of Colorado* and *Puma Population Structure and Vital Rates on the Uncompahgre Plateau.*

Objective 1: Estimate cougar diet composition using stable isotope analysis

We will sample hair from GPS-collared individuals who are captured as part of the Front Range Cougar project. These samples will form the basis of our diet reconstruction study. In addition, we will analyze hair sampled from collared individuals on the Uncompahgre Plateau to compare broad-scale differences in diet between the two populations. Analyzing the diet of individuals from both of these study areas provides us with a unique opportunity to compare resource use over wide geographic areas with differing levels of human density. The Front Range study area has a higher proportion of urban-exurban habitat and greater human density than the Uncompahgre Plateau; these differences in habitat and human density may drive shifts in diet.

Prey hair will be collected from roadkills and cougar kill sites, as well as from shed hair (for domestic species). We will sample prey species within the Front Range and Uncompahgre Plateau study sites, because isotopic signature can vary with geographic area, and samples collected outside the study areas can reduce the accuracy of our diet analysis. We will collect species that have been found at kill sites or have been identified as important components of cougar diet by other studies (Table 1).

All hair samples will be washed three times with 2:1 chloroform:methanol to remove surface oils and debris (Cryan et al. 2004), homogenized, and dried for 72 hours at 55°C. Samples will be weighed into tin combustion capsules and analyzed with a

Thermo Finnigan Delta Plus XP Elemental Analyzer. Results will be provided as per mil (parts per thousand [‰]) ratios relative to the international standards of Peedee Belemnite (PDB; $\delta^{13}C$) and atmospheric nitrogen (AIR; $\delta^{15}N$) with calibrated internal laboratory standards.

Table 1: Potential prey items from which we will sample hair. Species have been grouped into ecologically meaningful groups. Cougar diet will be presented as proportionate use of these five major groups.

Group	Common Name	Species
Small mammals	Cottontail rabbit	*Sylvilagus nuttallii*
Mesocarnivores	Striped skunk	*Mephitis mephitis*
	Raccoon	*Procyon lotor*
	Fox	*Vulpes vulpes*
	Coyote	*Canis latrans*
Large domestics	Llama	*Lama glama*
	Alpaca	*Vicugna pacos*
	Goat	*Capra aegagrus hircus*
	Horse	*Equus ferus caballus*
	Donkey	*Eqqus africanus asinus*
	Sheep	*Ovis aries*
	Cow	*Bos taurus*
Small domestics	Dog	*Canis familiaris*
	Cat	*Felis catus*
	Chicken	*Gallus domesticus*
Native ungulates	Mule Deer	*Odocoileus hemionus*
	Elk	*Cervus elaphus*
	Bighorn Sheep	*Ovis canadensis*

Diet reconstruction with stable isotopes relies upon comparing the isotopic signature of the consumer to the signatures of potential diet items, which are classified into biologically relevant and isotopically distinct groups. To group prey samples, we will apply a K nearest-neighbor randomization test (Rosing et al. 1998). Diet composition will be estimated as proportional use of each of these prey groups with the software package SIAR (Parnell et al. 2008). This analysis uses Bayesian prior probabilities to estimate the distribution in possible diet compositions for each individual (Parnell et al. 2010). Prior probabilities will be calculated using percent occurrence at kill site investigations and corrected for average biomass consumed from each diet source.

We will estimate diet by individual, as well as mean estimates across populations and age-sex classes. We will test for differences in proportional resource use between the Front Range and Uncompahgre Plateau populations using compositional analysis (Aebischer et al. 1993). In addition, for GPS-collared cougars on the Front Range, we will model the effects of age-sex class and habitat use on diet using mixed linear models, with proportion of native ungulate in diet as a response variable. We will use housing density at GPS locations as a metric of habitat use, because houses are likely to be associated with differences in prey availability, and cougars may show a selective response to houses (Wilmers et al. 2013).

Finally, in order to better understand the temporal window of our diet estimates, we will characterize cougar molt chronology using captive individuals at the Wildlife Health Lab in Fort Collins. Because hair represents assimilated diet during the period of growth, our analysis will provide information about diet in these months only. Like most temperate mammals, feline hair growth generally occurs from late spring to early fall (Baker 1974, Ryder 1976); however, molt chronology has not been quantified in cougars. To better understand the timing of cougar molt, we will use a topically applied dye and an orally administered biomarker to mark the hair of captive cougars ($n = 2$) at the Wildlife Health Laboratory in Fort Collins.

The nontoxic permanent dye Nyanzol-D (Greenville Colorants, Jersey City, NJ) has been used as a marker in numerous wildlife studies and can be applied topically (Jones 2012; Teichroeb et al. 2005). Each month, we will administer Nyanzol-D to a patch of hair on the back and sample this hair in subsequent months to monitor the shedding and regrowth of hair. We will continue this process for a full year (February 2013-February 2014).

In addition to using an externally applied dye, we will administer the oral biomarker Rhodamine B (RB) once per month for one year, beginning in February 2013. RB is incorporated into actively growing hair and other keratinous tissue, forming a fluorescent band that is visible under UV-light (Palphramand et al. 2011; Fry et al. 2010; Fisher 1999). Every month, hair samples will be taken and examined under an epifluorescent microscope to measure the position of fluorescent bands. The distance between bands represents hair grown in the month-long interval between dosages and can be used to calculate hair growth rates. We will also opportunistically apply RB to kill sites of collared cougars on the Front Range to determine whether free-ranging cougars undergo similar cycles of hair growth and molting as captive individuals. In addition, if successful, this approach could be useful in a myriad of other applications, including detection of scavenging at kill sites.

By using both RB and externally applied dye, we will be able to detect the timing of molt and turnover time of individual hairs (by noting the rate of shedding of dyed hair) as well as more precise growth rates (by measuring the distance between fluorescent bands). This information will be used to interpret the results from stable isotope analyses of free-ranging cougars. Additionally, hair growth rates could be used to further sub-section hair to estimate diet during a particular season.

Objective 2: Develop methods for and evaluate the accuracy of using telomere length to non-invasively age cougars.

Because tissue types differ in their rate of cellular replication, we will examine telomere length in two commonly sampled tissue types, blood and hair. Blood and hair will be collected from cougars captured on the Front Range research study, or from necropsied individuals at the Wildlife Health Laboratory. We will derive a “known” age via gum-line recession, tooth wear, capture history, and cementum annuli counts (when available).

DNA will be extracted from blood and hair follicles using a Qiagen DNeasy kit (Qiagen, Valencia, CA). Telomere length will be quantified with real-time quantitative polymerase chain reaction (Q-PCR) (Cawthon 2002). This method determines relative telomere length by calculating the ratio of telomere repeat copy number (T) to single copy gene number (S), standardized by an arbitrary reference DNA. We will compare standardized T/S ratios among individuals. For a single copy reference gene, we will use the nuclear gene 36B4, which is highly conserved across vertebrates and was used to quantify telomere length in humans (Cawthon 2002).

We will run telomere and single copy gene q-PCRs using similar PCR protocols, with the only difference being the primer set. To generate a standard curve, we will dilute DNA from an arbitrarily chosen individual to 1 ng/µl, 2.5 ng/µl, 4 ng/µl, and 6 ng/µl and amplify these concentrations in adjacent wells. Each reaction will contain 8 µl sample DNA (diluted to 3 ng/µl), 10 µl SYBR Select Master Mix (Life Technologies), telomere primers (250 nM each final concentration) or single copy gene primers (500 nM each final concentration), and distilled water to total 20 µl reaction volume. Real-time PCR will be conducted with an Eppendorf Mastercycler, with the following thermocycling conditions: 50°C for 2 min, 95°C for 5 min, followed by 2 cycles of 94°C for 15 sec and 49°C for 15 sec, and then 35 cycles of 95°C 15 sec, 62°C 10 sec, 74°C 15 sec (telomere) or 95°C 15 sec, 62°C 15 sec, 72°C 45 sec (36B4). Based on the fluorescent signal of SYBR Green and the standard curve, the telomere-to-single copy gene will be calculated, and presented as relative telomere length (T/S).

We will explore the relationship between T/S and age using linear regression, for blood and hair separately. To improve the model, we will explore the use of other covariates, like sex or habitat type. If a predictable relationship can be found, we will develop a model that can assign age to non-invasively sampled cougars using telomere length and other available covariates.

PRELIMINARY RESULTS AND DISCUSSION

Objective 1: Estimate cougar diet composition using stable isotope analysis

We have collected and analyzed 129 prey hair samples representing 16 species. In a K-nearest-neighbor test, we identified five major classes of prey which can be distinguished based on isotope values (Table 2). Thus, we will be able to quantify cougar diet in terms of proportional use of these five diet classes, which represent important ecological groups. Namely, using stable isotope analysis, we can distinguish the use of several alternative prey types, including domestic species, which are of interest to managing cougar-human conflict.

Table 2. Stable isotope values for cougar and potential prey in the Colorado Front Range. Domestic species and mesocarnivores are enriched in heavy isotopes of C and N; cougars with higher δ values are consuming higher proportions of these diet items.

		δ^{13}C (‰)	δ^{15}N (‰)
Sample	*n*	Mean ± SD	Mean ± SD
Cougar[1]			
Adult female	18	-24.1±0.4	4.3±0.6
Adult male	4	-23.7±0.6	5.3±0.8
Subadult female	9	-23.9±0.7	4.9±0.9
Subadult male	7	-23.6±0.3	5.1±0.4
Prey			
Large Domestics	39	-22.8±1.6	6.8±1.6
Mesocarnivores	26	-20.4±1.6	7.2±0.9
Native Ungulate	35	-24.1±0.7	4.2±1.4
Rabbit	7	-25.5±1.2	1.5±2.0
Small Domestics	22	-16.4±2.5	6.2±1.2

[1] Cougar isotopic signatures are corrected by trophic discrimination factors (δ^{13}C=-2.6; δ^{15}N =-3.4) as described by Roth and Hobson (2000).

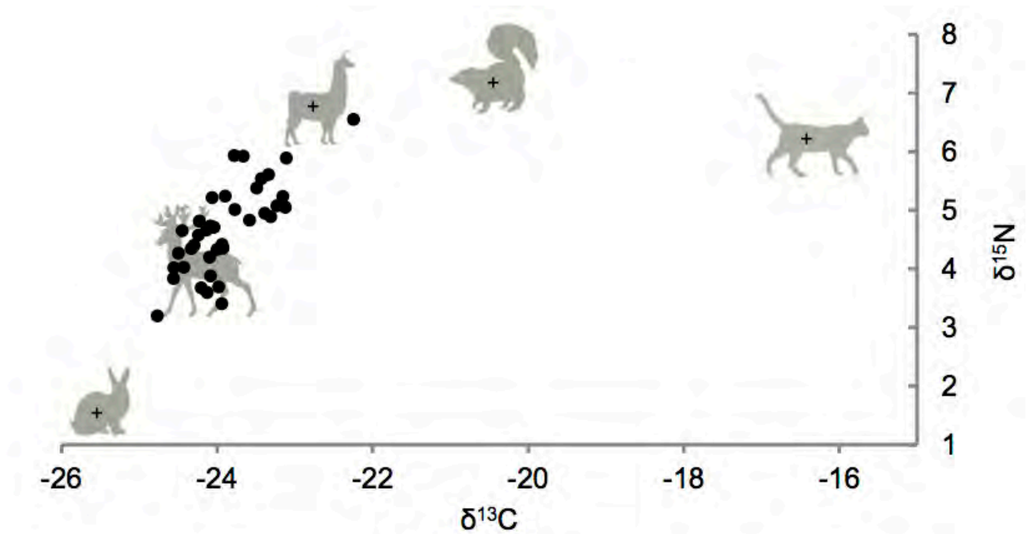

Figure 1. Stable isotope signatures of cougar and potential prey. Cougars are represented by black circles. The average of each prey group is represented by a cross (Table 2). Prey groups, from left to right are: rabbits, native ungulates, large domestics, mesocarnivores, small domestics. Cougars are generally clustered near ungulates, indicating this is the largest component of diet.

We have analyzed the stable isotope signature of 38 GPS-collared individuals from the Front Range. Signatures of these individuals (Table 2) fall within the stable isotope mixing space (Figure 1), indicating that cougar diet does consist of some mixture of these five prey groups. Although we have not yet quantified proportional resource use, native ungulates appear to be the most important prey group to cougars, as expected. Adult female cougars, in particular, show an average isotopic signature ($\delta^{13}C = 24.1 \pm 0.4$; $\delta^{15}N = 4.3 \pm 0.6$) almost identical to native ungulates ($\delta^{13}C = 24.1 \pm 0.7$; $\delta^{15}N = 4.2 \pm 1.4$), indicating adult females are the group that most heavily uses primary prey. There also appears to be a slight trend, with alternative prey use being more prevalent in subadult individuals and males, though differences between age-sex groups are not significant. Rabbits do not appear to be an important diet source to any individuals. Finally, a few individuals appear to use much higher proportion of non-ungulate prey, likely mesocarnivores or domestic species. Analysis of this data is ongoing and we are currently using Bayesian mixing models to estimate diet composition for these individuals. Subsequent analyses will investigate how human development (measured by housing density) and age-sex class are related to diet composition.

We have also collected hair samples from 69 cougar individuals in the Uncompahgre Plateau and are currently analyzing their isotopic signature. Using stable isotope analysis, we will test for differences in diet between the two populations to make inferences about how human expansion may alter cougar foraging behavior.

Beginning in February 2013, we began monthly marking of captive cougars with Nyanzol-D and RB to quantify molt chronology. Both techniques have showed preliminary success (Figure 2). As of July 2013, some hair samples showed up to four fluorescent bands, demonstrating that hair growth begins as early as March. We have applied RB to the kill sites of five free-ranging cougars, and subsequent sampling of these individuals confirmed that hair was marked with RB even in the winter months, when hair growth is purportedly at a minimum. Observations of Nyanzol-D spots indicated that cougars do undergo a fairly distinct molt in spring, rather than a gradual molting throughout the year. Hair samples may then include some inputs from winter diet, although, bulk hair analysis is likely biased towards diet in late spring to fall. We will continue marking cougar individuals to collect data through the summer and fall, which will likely represent the most rapid period of hair growth.

Objective 2: Develop methods for and evaluate the accuracy of using telomere length to non-invasively age cougars

We have gathered hair and blood samples from live-captured and necropsied individuals to evaluate telomere analysis. In addition to the 38 hair samples from live-captured, Front Range cougars (described above), we have obtained 29 hair samples from uncollared, necropsied cougars in the Front Range area. We have also sampled blood from 104 cougar captures, which represent 73 unique individuals. For live cougars, we estimated age from tooth wear and gum recession, reproductive status, and known capture history. For necropsied individuals, ages were estimated via tooth wear and gum recession; additionally, for a subset of these individuals, we are currently obtaining age estimates with cementum annuli counts.

DNA extraction from hair follicles and blood is ongoing. Using previously extracted DNA from cougar blood, we have had success in using Q-PCR to amplify telomeres. Amplification efficiencies were consistent for both single copy and telomere genes, and we were able to obtain robust estimates of relative telomere length. For a given age, there was considerable variation in telomere length between individuals; however, preliminary regression analysis indicates a relationship between age and relative telomere length, with telomere length declining with age. Further samples from a wide spread of ages will help further characterize this relationship, Additionally, we will also assess the relationship between biological age class and telomere length. Because obtaining a precise "known age" is difficult, we will assign biologically meaningful age categories (i.e. juvenile, sub-adult, adult, senior adult) as an alternative to chronological age and determine whether this strengthens our analysis.

This study will yield novel insights into cougar foraging ecology, primarily how diet is affected by human density and demographic class. Such information is vital to understanding cougar predator-prey relationships and to reducing livestock and pet depredation. Further, this study is the first to use stable isotopes to assess cougar diet; this technique can be applied to non-invasively collected samples. Finally, we will assess a genetic technique for aging cougars, which, if effective, would enable non-invasive monitoring of cougar population structure.

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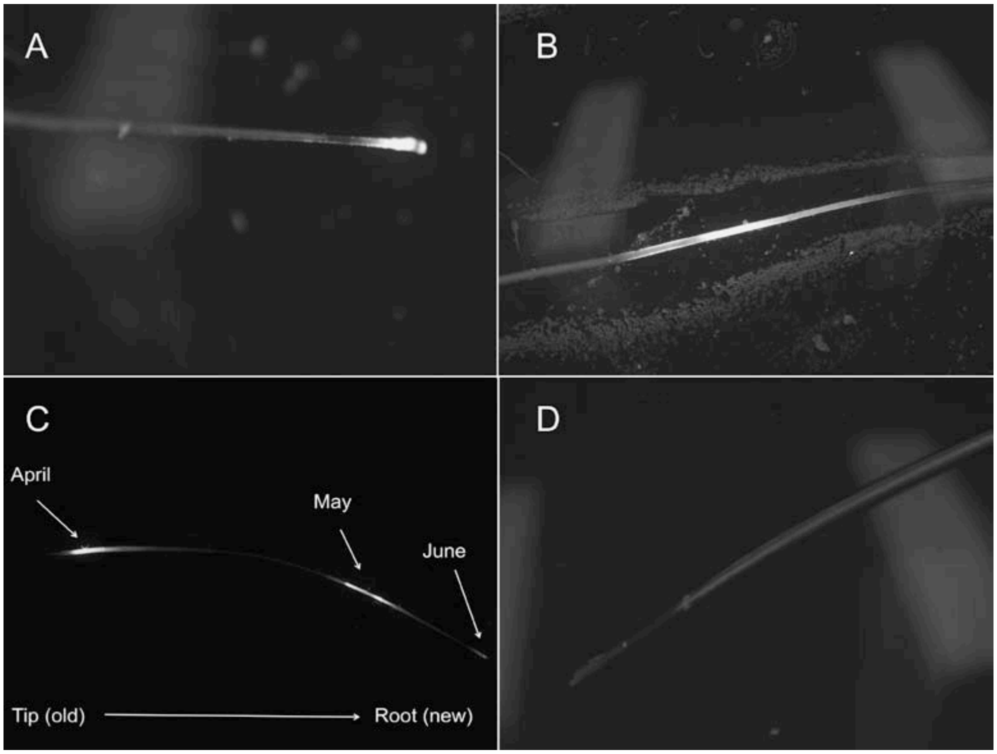

Figure 2. Fluorescent bands in hair samples, illustrating incorporation of Rhodamine B marker. As hair grows, new keratin is formed, moving the band away from the root. A: Hair collected in March, one month after first dose, showing band at root. B: Hair collected in April, showing a band at mid-shaft. C: Hair collected in July, with three bands. D: Negative control, collected before first RB dose.

Appendix III

Front Range Cougar Research

Winters, 2011–2012 & 2012–2013

PUMA FORAGING IN AN URBAN TO RURAL LANDSCAPE

CSU & Colorado Parks and Wildlife

Kevin Blecha

Randy Boone

Mat Alldredge

Research Summary

June 30, 2013

PUMA FORAGING IN AN URBAN TO RURAL LANDSCAPE

Kevin Blecha, M.S. student, CSU

INTRODUCTION

The Rocky Mountain Front Range of Colorado has experienced drastic increases in human population, and a surge of suburban and exurban landscapes are sprawling into areas occupied by cougar (*Puma concolor*). Some evidence suggests that cougar show avoidance to these areas of high human density. However, cougar use of human developed landscapes does occur at some level and thus conflicts arise between cougar and humans. This study examines cougar predation characteristics and prey selection in reference to landscape features such as prey availability, anthropogenic development, and hobby livestock.

A current paradigm in cougar management revolves around the idea that cougar populations may not be sustained without ungulate prey (CMGWG 2005). Exurban and suburban landscapes of the Front Range are relatively free of human hunting pressure, which is possibly linked to elevated levels of cougar's primary ungulate prey (mule deer [*Odocoileus hemionus*]). Cougar may be drawn to these areas because they are more likely to increase their encounter with deer, as landscape features used by a primary prey species may be the primary driver for selection of feeding locations of cougar (Pierce et al. 1999, Pierce et al. 2000, Atwood et al. 2007). However, contrary to the idea that increased cougar use of a landscape is a function of increasing prey availability, other recent studies have found that cougar exhibit avoidance to areas of high human activity such as exurban and suburban landscapes (Mattson 2007, Burdett et al. 2010, Kertson 2011). Therefore, it is unclear which primary factor may drive landscape use by cougar in the Colorado Front Range. Optimal foraging theory (MacArthur and Pianka 1966, Emlen 1966) predicts that an animal may sacrifice hunting in areas with high forage availability for the security provided by areas further away from risks. However, it is untested whether or not cougar forage optimally in reference to prey availability and human disturbance factors. Testing whether cougar's selection of feeding locations is dependent on certain combinations of prey-encounter probability and human disturbance levels may shed light on the optimal foraging behaviors in cougar. Creating statistical models to test whether cougar forage optimally with respect to human risk and prey availability is important for determining when and why cougar feed in certain localities.

Cougar have the ability to prey on all species of livestock, but the highest losses in Colorado occur in commercial sheep ranching. In the Front Range region however, hobby livestock depredations represent a majority of the owner losses. Hobby livestock owners inhabiting the sprawling exurban and developing rural areas of the Front Range that live in or adjacent to highest suitable cougar habitat are at the highest risk of experiencing a hobby livestock depredation (Torres et al. 1996, Michalski et al. 2006). When a cougar is observed or found on property containing livestock, that cougar may be wrongly accused or suspected of hunting livestock as prey. Destroying a cougar for the protection of livestock, including hobby livestock, is often enough legal justification for wildlife managers/livestock owners. It is unknown whether or not cougar, while hunting, select for areas with hobby livestock or whether cougar hunt near hobby livestock selectively or opportunistically. Detailed information on whether or not certain classes (sex/age) of cougar are more likely to seek hobby livestock is important for predicting which type of cougar may be more likely to commit a depredation offense. Knowing whether cougar that have committed a livestock depredation in the past are more likely to hunt near properties containing hobby livestock will shed light on whether or not individual cougar may behave as a specialist toward livestock prey items.

Understanding what biological and environmental factors influence cougar predation is important to the management of cougar and the subsequent prey species. It has been hypothesized that stimuli from human disturbances may increase energetic costs (Frid and Dill 2002), thus a decrease in fitness may occur through decreased mating opportunities (Schoener 1971, Pyke et al. 1977) or through lowered survival of offspring. If human activities increase an animal's search time for acquiring food, through direct disturbances or alterations in landscape configuration, the energetic demands are increased, and thus changes in foraging characteristics may reflect the disturbance/alteration (Gill and Sutherland 2000, Blumstein et al. 2005). Kertson (2010) did find a shift in prey composition in residential areas toward higher proportions of smaller and/or domestic prey. In addition, cougar are known to show individual differences in predation characteristics based on sex, age, and reproductive status (Ackerman et al. 1986, Murphy 1998, Laundre 2005, Laundre 2008, Cooley et al. 2008, Knopff et al. 2010). To assess how different landscapes, seasons, and individual cougar differences influence prey consumption, I will examine characteristics of cougar dietary composition/overlap and feeding rates.

Long-term Objectives:

1) *Test whether cougar exhibit optimal foraging behavior by examining cougar selection of feeding sites in relation to:*
    a. *Human density/activity*
    b. *Prey availability*
    c. *Hobby livestock availability*
2) *Examine cougar dietary compositions and kill rates in relation to:*
    a. *Individual cougar characteristics (i.e. sex/age)*
    b. *Landscape characteristics*

Adequately testing certain tenets of optimal foraging theory on an elusive mobile predator with respect to mobile prey species (that are also sometimes illusive) and associated human risks can be inherently difficult. Statistical resource selection function models examining cougar's selection of feeding sites will be developed to answer questions regarding optimal foraging behaviors. Prior to completing the long-term objectives, much effort is required to develop the input datasets and precursor models. Figure 1 depicts a schematic of inputs that will be used in the final model developed for testing optimal foraging behavior (Long-term Objective 1). Major research activities conducted in the past year supporting the overarching long-term objectives can be summarized under the following segment objectives.

Segment Objectives:

1. **Advance model-based methods for identifying feeding events/locations from GPS cluster data.**
    a. **Recover and compile GPS location data for final cluster classification processing.**
2. **Develop spatial layers depicting human developments.**
3. **Develop a model for depicting primary cougar prey distribution in relation to general habitat and human development.**
    a. **Retrieve camera units and photographs from the field and process data set for final analysis**
4. **Develop a thematic map of hobby livestock presence/absence.**

METHODS

This study is an extension of a parent project: *Cougar Demographics and Human Interactions Along the Urban-Exurban Front-range of Colorado* (see elsewhere in this annual report) project initiated by the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]), which is charged with managing Colorado's cougar population. Conflicts between cougar and humans have increased dramatically in the past two decades, thus the parent project was initiated to address questions regarding cougar natural history, population estimation, response to aversive conditioning, response to relocation, livestock depredation opportunity, and predator/prey relationships.

The 2,862 km^2 extent of the study area, shown in Figure 2, encompasses the foothill/mountainous regions of Boulder County, north Jefferson County, and portions of Clear Creek, Gilpin and Larimer Counties. This area is characterized by a patchwork of private and publicly owned land held by federal, state, and municipal governing agencies. However, if a subject leaves the study area, standard GPS tracking and field data will be collected on the subject until it establishes what appears to be a maintained home range. All objectives listed below require using cougar fitted with GPS radio collars, and thus only subjects captured in the parent project (See elsewhere in this annual report) are utilized in this project.

Segment Objective 1) Advance model-based methods for identifying feeding events/locations from GPS cluster data:

Long-term objectives of this project require determining the exact location and timing (±30 meters) of feeding/predation events from a sample of cougar subjects. Global Positioning System (GPS) radiocollars (Lotek 4400S, [Lotek Engineering, ON, Canada], Northstar Globalstar, [Northstar Science and Technologies, VA, USA], GPS Plus Collar [Vectronics Aerospace GmbH, Berlin, Germany]) deployed on a sample of cougar, collect GPS locations (a.k.a: GPS points) 7 to 8 times/day, at 3 or 4 hour intervals. GPS locations collected from collars deployed prior to January 2009 were retrieved from the collar using a hand-held remote communication device, which required a technician to locate the cougar subject within a short-range and maintain line-of-site with the subject until data was retrieved. GPS locations collected from collars deployed after January 2009 were retrieved from the collar via satellite communication (Globalstar satellite network). While the satellite retrieval method drastically eased the recovery process and allows a researcher to visualize the exact location of the subject under the scheduled GPS location interval in almost real-time, communication failures arose from inadequate line of site between the collar and the satellite. Therefore, the collar would store all GPS locations with on-board memory. Retrieval of the complete data set could be made by either downloading the data directly from the on-board memory via USB communication (if collar was retrieved after cougar death/recapture), or by communicating to the collar using a hand-held remote communication device as done with the collars deployed prior to 2009.

GPS locations alone do not allow objective identification of feeding sites, so the locations for each subject are classified into clusters (groups of GPS locations), based on the spatial and temporal relationships of a GPS location to other GPS locations (Anderson and Lindzey 2003). These GPS clusters are classified into selection sets based on the likelihood of it being a kill site (Alldredge et al. 2008), thus providing a sound sampling frame from which statistical inferences can be made about GPS clusters that are not physically investigated.

To identify unique clusters of GPS locations, a rule-based clustering algorithm was written in Visual Basic and was designed to run within ArcGIS (Alldredge and Schuette, *CDOW*, 2006). The algorithm was designed to classify clusters into five selection sets (S1, S2, S3, S4, and S5), in order to stratify cluster investigation efforts over a range of different GPS location characteristics for each collared cougar and specified time period (1 month intervals). S1 clusters consists of ≥2 GPS locations within 200 meters and within a 4 day window. To help account for missing GPS locations; S2 clusters consist of any two consecutively collected GPS points, separated by a range of 200-500 meters, but are missing the scheduled GPS fix acquisition in between the two points. To account for the potential that a cougar may engage and consume prey in shorter handling times, S3, S4, and S5 clusters were created to sample locations collected along presumed travelling paths. S3 clusters are any two locations within a range of 200 – 500 meters, while S4 clusters are any two locations separated with a range of 500-1000 meters. S5 cluster types are any single GPS location separated ≥1000 meters from any other GPS location. In addition to the spatial and temporal distance criteria, ≥1 of the points comprising the cluster must have been collected during the night-time.

S1 cluster types have spatial and temporal attributes very similar to the characteristics of GPS clusters defined in previous published research on cougar predation. These studies identified clusters as $\geq$2 GPS points (fix acquisition frequency of 3-4 hour intervals) within a 1-2 day period (Anderson and Lindzey 2003) or $\geq$2 GPS points (3 hour intervals) within a 6 day period (Knopff et al. 2009) within 200 m. White et al. (2011) identified clusters as $\geq$2 GPS points within 100 m recorded within a 1-2 day period, and then Kertson et al. (2011) identified clusters as $\geq$3 locations within 100 m during a 24 hour period. Unique to our study is the effort placed on non-S1 cluster types (S2, S3, S4, S5 types).

To verify the presence/absence of feeding activities at GPS location clusters, a sample of clusters were investigated by trained biologists to determine the probable action carried out by the cougar (feeding/resting). Visiting a sample of these locations allows the creation of a training data set of clusters that have been classified into a binary 0 (non-feeding) or 1 (feeding) variable, which can then eventually be used to model the probability of clusters not visited by biologists. Dividing the study period into monthly sub-periods, GPS locations are passed through the clustering algorithm script at the end of each month, for each cougar subject. Sampling each of the 12 monthly sub-periods allowed continuous monitoring to ensure a temporal continuum of conditions (i.e. changes in season, weather, human activities) are represented throughout an annual period. For each cluster of GPS points a random number was assigned so that a sampling frame could be created for each of the five cluster selection sets (S1, S2, S3, S4, S5). For each month and each cougar, the top two random S1 clusters, top random S2 cluster, top random S3 cluster, top random S4 cluster, and top random S5 cluster are visited by a trained investigator. In some months, S2, S3, or S4 cluster types are not created for every subject, and therefore not represented in every combination of month and cougar. Additionally, if no feeding remains are found at these randomly selected sites, S1's constituent of at least three points at night would be visited until at least two clusters revealed evidence of feeding activities.

Because GPS locations were accumulated in monthly intervals (~30 days) technicians would spend an entire month visiting the GPS location clusters accumulated in the previous month. Therefore, the lag between the time that a cougar initiated a feeding event and the time that it would be investigated by a technician could range between 0 and 60 days. The probability of a field technician successfully finding evidence of cougar feeding activity is negatively correlated with the visitation lag time (Elbroch and Whitmer 2013) which induces heterogeneity when estimating observer success. Besides the obvious misclassification of sites as being non-feeding sites rather than feeding sites, heterogeneity in detection probability would ultimately cause a negative bias in kill rates. As aforementioned, near real-time retrieval of collar locations would have been possible, thus allowing us to decrease the visitation lag to zero and removing heterogeneity in detection probability induced by a time lag. However, there are five reasons why the monthly visitation period was chosen and not visit GPS locations immediately after initiation by the cougar or in shorter intervals: 1) Immediate visitation may cause researcher induced disturbance to the cougar while feeding causing it to alter the behavior while at the site, 2) Some S1 clusters may span a few weeks, thus accumulating the GPS locations over this 30 day period was necessary in order to generate a sufficient population of clusters to randomly sample from at times, 3) This 30 day interval created a natural temporal stratification scheme to sample from, 4) Breaking up the clustering period into a smaller interval would cause more GPS locations to be classified into clusters incorrectly, as the true classification of GPS locations recorded near the end of the period is dependent on the temporal and spatial characteristics of GPS locations recorded up to 8 days into the start of the following period, and 5) Logistical restraints of clusters occurring on private land precluded immediate access.

The following protocol to investigate cougar GPS clusters in the field: within the randomly selected cluster, each cougar GPS location in the cluster was visited, and then walked by spiraling out a minimum of 20 m while using the GPS unit as a guide, and visually inspecting overlapping fields of view in the area for prey remains. Normally this was sufficient to detect prey remains and other cougar sign, (e.g., tracks, beds, latrines) associated with cougar. If prey remains were not detected within the 20 m radius, then the search was expanded to a minimum of 50 m radius around each GPS location. Depending on the number of locations, topography, vegetation type and density, a minimum of 1 hour and up to 3 hours per cluster to judge whether the cluster was a feeding site.

Basic habitat attributes, that may had a potential effect on the probability of detecting feeding remains, was recorded at every cluster visited. If evidence of feeding activities was detected (presence of carcass remains) at the investigation, an assessment was made to determine:

1. Species, sex, and age of individual prey item(s)
2. Characteristics to help determine whether the focal cougar actually killed the prey animal

As aforementioned, the complete dataset may not be retrieved via Globalstar satellite communication but through relatively more direct communication methods. Therefore, full recoveries of the data from the collar were only done in 6–24 month intervals depending on the cougar. Full recoveries of the GPS data set resulted in a backlog of GPS locations, interspersed throughout the full dataset, which were then added to the monthly downloaded data. Subjects whose collar was destroyed upon death (i.e. collision with vehicle) or suffered other major physical damage during inter- or intra-specific combat usually did not yield any recoverable data.

Full datasets of GPS locations were screened using three criteria to identify and remove suspected erroneous locations:

1) Locations that resulted in a movement vector between two consecutive locations greater than 12 km per scheduled fix acquisition interval (> 3-4 km/hr)
2) Locations with high PDOP values (> 10.0)
3) Locations where the elevation recorded by the GPS collar was drastically different than the elevation quantified by USGS digital elevation models for the coordinates given.

After full data retrieval and erroneous location screening, the GPS location data set for each cougar was run through the clustering algorithm script a second time for each subject over the entire lifetime that individual was monitored. Passing the data through the script this second time ensured that all locations ever recorded by the GPS collar were included, as well as ensuring that GPS locations recorded towards the end and beginning of a monthly sub-period were classified correctly.

Segment Objective 2) Develop spatial layers depicting human land-developments.

Identifying human developments that may be conceived as a risky habitat to a cougar can be difficult. Point locations of housing units, buildings, and other man-made structures are often proxies for the presence of humans and associated activities, while varying human densities can be mapped on the landscape to depict the potential intensity of human activity. To create a point location map of man-made roofed structures, heads-up digitization of USGS high resolution (0.6 m) aerial ortho-imagery (2008) was used to pinpoint the approximate center of all man-made roofed structures with at least two sides greater than 3.5 m across. All digitization was done within ArcMap 10.0 (ESRI, Redlands, CA) with the map scale set to 1:1,500. Three trained technicians were assigned a random subset of 2x2 km quadrats (~2400 total quadrats) superimposed over the study area along with a 2.5 km buffer of the perimeter. Quadrats were digitized in a randomized order to ensure that effort was distributed evenly. If the identification of any particular structure was questionable, USDA Farm Service Agency 1 m aerial photos (2007, 2009 and 2011 collection years) or other high resolution aerial imagery, if available, was consulted.

Using the digitized vector layer of structures, a Euclidean distance raster layer (10 m resolution) quantifying the linear straight line distance to the nearest digitized man-made structure was created with standard GIS processing tools. The quantity created for each raster cell is not dependent exclusively on the housing locations within the area digitized, but also can be influenced by housing locations just outside the study area, thus the raster cells calculated within the additional 2.5 km buffer were removed to ensure accuracy near the edges.

Measuring the spatial distribution of human activity/intensity can be rather difficult at fine scales fitting to the questions at hand. Land cover maps such as NLCD (National Land Cover Dataset) or GAP (Southwest Regional Gap Analysis Project) datasets usually utilize measures of non-permeable surfaces to quantify the intensity of human use at fine scales (30 m). These readily available datasets perform poorly when quantifying the distinction between areas of rural development and areas of low-density human development known as exurban development (Theobold 2005). A vast improvement over land cover data is the Spatially Explicit Regional Growth Model (SERGoM) (Theobold 2005), which produces a nationwide housing density layer utilizing census bureau housing unit counts (collected at the census block level) and the distribution of road density to predict the distributional of housing units within each census block.

Housing density was modeled for this project using an approach similar to SERGoM, but instead utilized density of man-made roofed structures rather than density of roads to allocate housing units across a census block. Man-made roofed structures may be rather numerous in rural and exurban areas, which are more likely than suburban/urban areas to have non-inhabited structures like outbuildings, garages and stables associated with a single housing unit. Additionally, local zoning regulations of the counties composing the study area only allow 1 housing unit per parcel, aside from parcels deemed multiple family units. Readily available parcel data was used to restrict the number of man-made roofed structures to just one point location per parcel. This restriction was only applied to parcels lying within census block groups where the housing unit density was fitting to the rural (>16.18 ha per housing unit) and exurban quantities (0.68 – 16.18 ha per housing unit). Census blocks containing suburban (0.68 – 0.1 ha per housing unit) and urban (<0.1 ha per housing unit) housing densities usually contained a high proportion of parcels deemed as multiple family housing which hindered applying the same restriction. This restricted man-made roofed structure point vector layer was then used for the input of a point density raster layer, which calculated the density of man-made roofed structures with a 100 m cell resolution. For each of these 100 m cells, the proportion of digitized roofed structures over the total count of roofed structures in the respective census block was calculated. This proportion was then multiplied by the total housing unit count of the block group to provide an estimate of the housing density for that 100 m cell. While this fine 100 m scale is an accurate depiction, it is likely not very useful in landscapes with low housing densities (rural and exurban), as it is likely that a 100 m cell would contain either no housing units or just 1 housing unit (i.e. measure of presence/absence). Using a cell size that is too large (1x1 km), may encompass an area with a mix of smaller high density residential and rural areas. An aggregation technique was used to average values of neighboring cells to new cell sizes ranging from 200 through 1000 m so that future work using this data as an input variable could choose the scale appropriate to the question at hand.

Segment Objective 3) Develop a model for depicting primary cougar prey distribution in relation to general habitat and human development.

In order to answer questions related to cougar selection of prey, a measure of fine-scale prey availability must be derived. Detailed spatial and temporal prey availability data is not available for the large spatial and temporal extent of the study area/period, as obtaining abundance estimates for even conspicuous animals is difficult in the exurban areas of the Front Range [i.e., deer (CDOW 2006)]. Therefore, camera trap units (Reconyx HyperFire, Holmen, Wisconsin) were distributed throughout the study area to sample photographic rates of potential cougar prey species across various landscape types over one annual period. Estimated photographic rates will be interpreted as the probability of encountering a particular prey species, rather than a density or abundance metric. Inferences on the encounter rate metric utilized with this design will restrict inferences to an experimental unit size equal to the camera's detection zone. Potential detection zone size is variable depending on the exact location and placement of the camera, but overall size is influenced by the length of the cameras detection radius (approximately 10 – 30 m) and the angular field of view (42°). While this may seem like a small coverage area, this high resolution was chosen as it fits the fine scale upon which cougar makes certain decisions regarding hunting and feeding locations, especially considering cougar are shown to select for edge habitats when killing deer (Laundre and Hernandez 2003). Sunquist & Sunquist (1989) suggest that most large stalking felid species, such as cougar (Banfield 2012) usually approach within 30 m of a prey item before attacking. Past work characterizing cougar hunting habits in relation to habitat edge, characterize "edge habitats" as a distance band 15-20 m from the interface of two habitat types (Altendorf et al. 2001, Holmes and Laundre 2006). These studies found significant differences in feeding site selection between the edge habitats and adjacent open or forested habitats. This small scale is also supported by anecdotal observations of cougar approaching within short distances prior to launching an attack (Robinette et al 1959, Wilson 1984, Branch 1995)

Encounter rates derived from infrared camera traps may be subject to heterogeneity across ambient temperatures, seasons, animal species and body mass, thus detection probabilities will be accounted for using a modified distance sampling technique (Rowcliffe et al. 2011), where probability of an animal triggering the camera is dependent on the location of the animal within the cameras detection zone. Accounting for detection probability within this detection zone will not only allow the comparison of encounter rates measured between sites but may eventually allow for the comparison among species.

To gather sighting data used to calculate encounter rates, camera traps were placed using a stratified random sample design of 25 m grid cells (n = 131). Sites are defined by single 25x25 m cells, delineated with the boundaries of the 25 m grid cells used in the BASINWIDE Colorado Vegetation Classification Project (CDOW 2003). Coincidentally, the 25 m dimension approximates the length of a cameras detection zone. Because there is potential to model a variety of species potentially preyed upon by cougar, each with differing movement and habitat selection patterns, sites chosen for surveys were randomly placed (Kays et al. 2010, Harmsen et al. 2010, O'Brien et al. 2010). This is particularly important in multi-species assessments, as placing cameras in habitats (i.e., trails) targeting certain species with low detection probabilities (as commonly done) may violate assumptions, thus causing biased results (Tobler et al. 2008). A stratified random design was utilized in which six major land-cover types, three housing density levels, and three levels characterizing the proximity to houses are represented (Table 1). Not all combinations of strata are present within the study area. Some of these categories may eventually be measured as continuous variables when included in final analysis, and thus these levels and strata are only used to guide the placement of cameras to ensure broad and even sampling across a range of possible habitat conditions. Final placement of cameras is shown in Figure 2.

Placement of the camera unit within the 25 x 25 m site was chosen by randomly generating a point location and azimuth (0-359º). In forested habitats, or habitats providing a stable structure for mounting a trail camera, the unit was placed on the tree/structure closest to the randomly generated point. For sites not providing a suitable mounting location, cameras were placed on a steel post driven into the ground. Some pruning of shrubbery/branches was permitted if maximum visibility was limited and if no more than 10% of the cameras detection zone was obstructed. If maximum visibility range of the camera sensor was limited, and pruning was not an option, the cameras direction was adjusted to a new randomly chosen azimuth. If no alternative azimuth was available because of complete 360 º obstruction, then the camera was moved to an alternative random location within the 25 m cell. Trail cameras were elevated ~50 cm from the ground to standardize the angle and viewing range of the infrared sensor and/or camera lens.

However, camera heights were slightly modified to accommodate snow accumulations and growth of low lying vegetation. Cameras were positioned so that the unit is parallel with the contour of the ground while the planar detection zone is perpendicular to the ground.

Camera units were programmed to trigger under one of two configuration settings. The primary configuration recorded 1 picture every second while the camera was being triggered. The alternate configuration recorded a burst of 5 pictures (1 picture/second once the burst initiated) upon triggering, but with a 30 second delay or "quiet period" between triggers. This alternate configuration was used if it appeared that the site would have especially high rates of triggering (e.g., from pedestrian trails, backyards, livestock enclosures). Care was taken to have cameras placed so that vegetation movements in the wind will not give false triggers, as false triggers will consume memory and battery life. Sites were checked to ensure proper camera functionality an average of every 4–6 months over the course of the deployment period (~average of 2.5 maintenance visits). All sites were checked at least once with a few sites checked up to 6 times. During these maintenance checks, memory cards were replaced, batteries swapped if needed, and new vegetation growth immediately in front of the cameras infrared sensor was carefully removed with small hand-held pruning shears to minimize disturbance to the site.

A General Linearized Modeling technique will be used to model the encounter rates of each particular prey species across un-sampled sites of the study area, given *a-priori* selected landscape covariate data such as major land-cover (BASINWIDE vegetation data set), elevation, aspect, hydrology, edge proximity, etc. Covariates with high predictive capabilities will be used to interpolate encounter rates at other non-sampled 25 m cells across the study area for each of the six most common Front Range cougar prey species [Mule deer, elk (*Cervus elaphus)*, raccoon (*Procyon lotor*), housecat (*Felis catus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*)]. Encounter rate (counts per unit time) will be initially defined using nightly counts, but may be defined using a longer time interval to ease computation. The final output of the prediction model shall be interpreted as the asymptotic rate of a stationary predator encountering a prey item at any given cell within the temporal and spatial extent of the study area and study period.

Segment Objective 4) Develop a thematic map of hobby livestock presence/absence

Formal knowledge on the distribution of hobby livestock of the Front Range does not exist. This will be countered by creating a thematic presence/absence map of all parcels of land containing hobby livestock items. Any parcel of land with the confirmed presence of hobby livestock items will be verified through roadside observations of all private land containing evidence of hobby livestock enclosures. Information regarding hobby livestock presence/absence in the individual parcels may be also gathered from:

- Knowledge from CPW staff working in the study area.
- Knowledge from collaborating agency staff in study area.
- Communications with local residence and livestock owners.
- Specific CPW wildlife/livestock conflict reports.
- Kill-site investigators' knowledge of vicinity of any visited cougar GPS location cluster.
- Road-side observations and personal landowner visitations.

Larger pastures inhabited by commercial stock (cattle/sheep/horses) will be denoted separately, as the amount of area utilized by livestock at any one time may be relatively small compared to the overall aerial coverage of the pasture at hand.

RESULTS

Segment Objective 1) Advance model-based methods for identifying feeding events/locations from GPS cluster data.

Monthly field investigations of GPS cluster locations commenced after the investigation of the November 2012 sub-period clusters. All data recorded prior to this time period, unable to be retrieved from the satellite uplink method, was recovered via hand-held communication device or by manual recovery of the collar unit upon recapture or death of the cougar. A total of 186,288 GPS locations were accumulated during this time period. A small percentage (0.3%) of the coordinates for these locations was erroneously recorded, reducing the number of useable points to 185,687. Of the collars where retrieval of data was capable via satellite (157,388 of the total), 16.4% of the data points were backlogged locations recovered directly from the collars long after cluster investigations had been completed. Future development of model-based methods directed at identifying feeding events using a training dataset of field investigated locations will need to address the discrepancy between GPS locations data sets used to direct field investigation efforts and GPS locations data sets used as input in the final model.

Current ongoing work includes: 1) Reclassifying final GPS location datasets, per individual cougar, using the clustering algorithm script, and 2) Sorting and processing field investigation data collected on clusters. Future work will include developing the statistical model to predict cougar feeding site locations from all GPS locations recorded using the clustering algorithm, collar activity/accelerometer data, and the training set of clusters visited in the field.

Segment Objective 2) Develop spatial layers depicting human developments.

A total of 156,565 man-made roofed structures were manually digitized. The Euclidean distance raster, developed at a cell size of 10 m, is summarized for the cells within the study area using the histogram shown in Figure 4. Approximately 50% of the cells were calculated to be less than 380 m from a structure. The resulting raster was classified into three natural quantiles (break points composed of equal amount of area): 0-190 m, 190-677 m, and 677-5394 m (Fig. 4a).

Results of the housing density model created from the man-made roofed structures layer and US census block group data are displayed using a 500 m cell size (Fig. 4). Approximately 70.3% of the study area can be described as having housing densities (housing units/ha) as rural (0-0.061 units/ha), 27% is described as exurban (0.061 – 1.47) and only 2.7% is described as suburban and urban (> 1.47). This composition measure is sensitive to where study area boundaries are drawn. When the results are compared alongside other datasets depicting intensities of human development, such as the NLCD and SERGoM, contrasts are easily observable (Fig. 5).

Segment Objective 3) Develop a model for depicting primary cougar prey distribution in relation to general habitat and human development.

The deployment of 131 cameras spanning November 2011 – January 2013 totaled 43,383 trap-nights. Cameras were fully functional on 41,740 of these trap-nights. Non-functional trap-nights resulted from 45 sites suffering 1-3 malfunctions over the course of the deployment. The most common cause of non-functionality ultimately occurred as a result of memory card space depletion. For 25 of these 45 sites, fast-growing vegetation during the summer months grew directly in front of the camera's infrared triggering sensors, leaves or culms were heated up by the sunlight and swayed in the wind. In certain conditions, memory cards with four gigabyte capacity could be filled within a few days. Other causes of the memory card filling up included large vehicles on roadways within the camera's detection zone, as well as sites being heavily frequented by non-target subjects such as humans, pets/livestock, and vehicles

(5 sites). Other cameras malfunctioned as result of insufficient battery life (5 sites), cameras being vandalized by animals (2 sites) or humans (1 site), and various mechanical/software malfunctions (7 sites).

After all cameras were removed, pictures were reviewed in two iterations to identify the species or triggering source. The first iteration consisted of viewing all raw images in the chronological order collected by a particular camera. Each picture was assigned one of the species in Table 2, or assigned to be triggered by one of the six other non-animal sources (Table 2). Counts of the individuals for each species visible in the photo were also made. Four technicians were utilized for the initial iteration of identification, which took place over the course of approximately 300-400 man hours. The second iteration was conducted by sorting images by the respective species or triggering source category. This enabled photos of each individual species/category to be compared side by side to other similarly identified images in order to scan quickly for potentially misidentified photos. A few thousand pictures (1.1%) initially identified in the first iteration were incorrectly or insufficiently identified ("unknown" categories) to species/triggering source. Photos where the identification of the species/triggering source was questionable or unknown were manipulated with readily available photo editing software using basic contrast, brightness, and mid-tone adjustment tools to increase the visibility of a subject. The effort of this second iteration consumed approximately 160 man hours. Incorrect or unknown classification of images usually resulted from animals appearing too far away from the camera, fast moving subjects that appeared blurry, photos being inadequately lighted, or by simple data entry error.

A total of 795,803 raw images were classified in each of the two identification iterations. This raw set was then reduced to ~297,000 images after removing the other triggering sources (e.g., wind, vehicles, and unidentifiable species). To standardize between cameras programmed with differing configurations, photos from cameras programmed with the continuous triggering configuration were rarified to impose a 30 second delay. Additionally, only the first photo from each 30 second trigger was included to calculate a total of 56,973 events. Counts for each species/triggering source and processing step are listed in Table 2.

The study area is composed of a myriad of private and public landowners, tenets and managers. The random placement constraint of this study made it necessary to obtain permission from 101 unique individuals/entities to allow one to several camera units to be deployed on their properties for the span of approximately one year along with permission to access the camera for multiple maintenance visits. In return for permission, each collaborator received digital media containing pictures collected by the camera deployed on their property along with a summary of the species and photo counts obtained.

Segment Objective 4) Develop a thematic map of hobby livestock presence/absence

Locations of hobby livestock enclosures are currently being documented by on the ground mapping while driving public roads. Approximately 20% of the study area has been mapped. Additional locations of enclosures, noted by technicians while conducting visits to GPS location clusters, are currently being geo-referenced.

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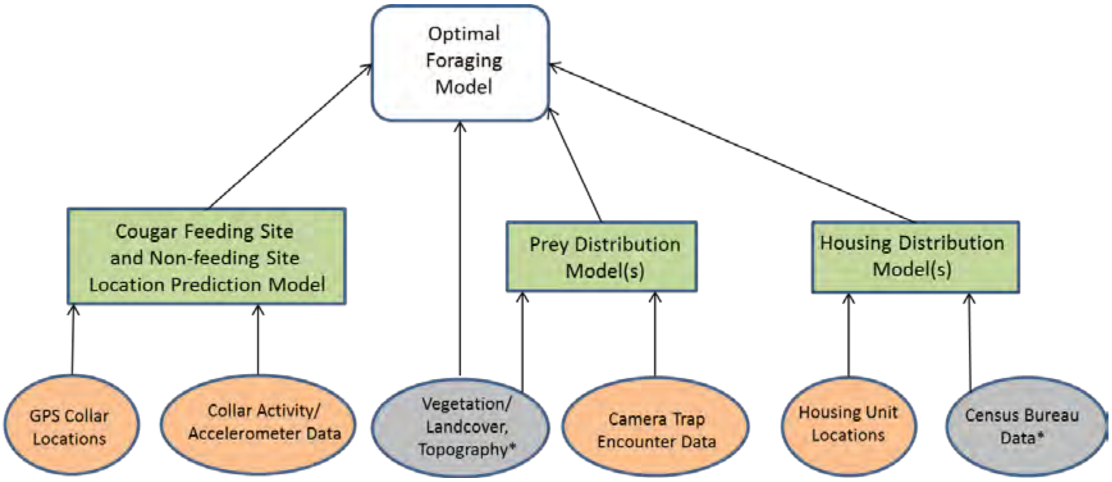


Figure 1: Schematic of the various inputs that will be utilized in the primary objective of developing an optimal foraging model that tests the selection of feeding site locations with respect to risks (housing distribution) and rewards (prey distribution) on the landscape. Research activities summarized in this annual report aimed at developing input datasets and input subsequent models.
*Input datasets gathered from readily available sources.

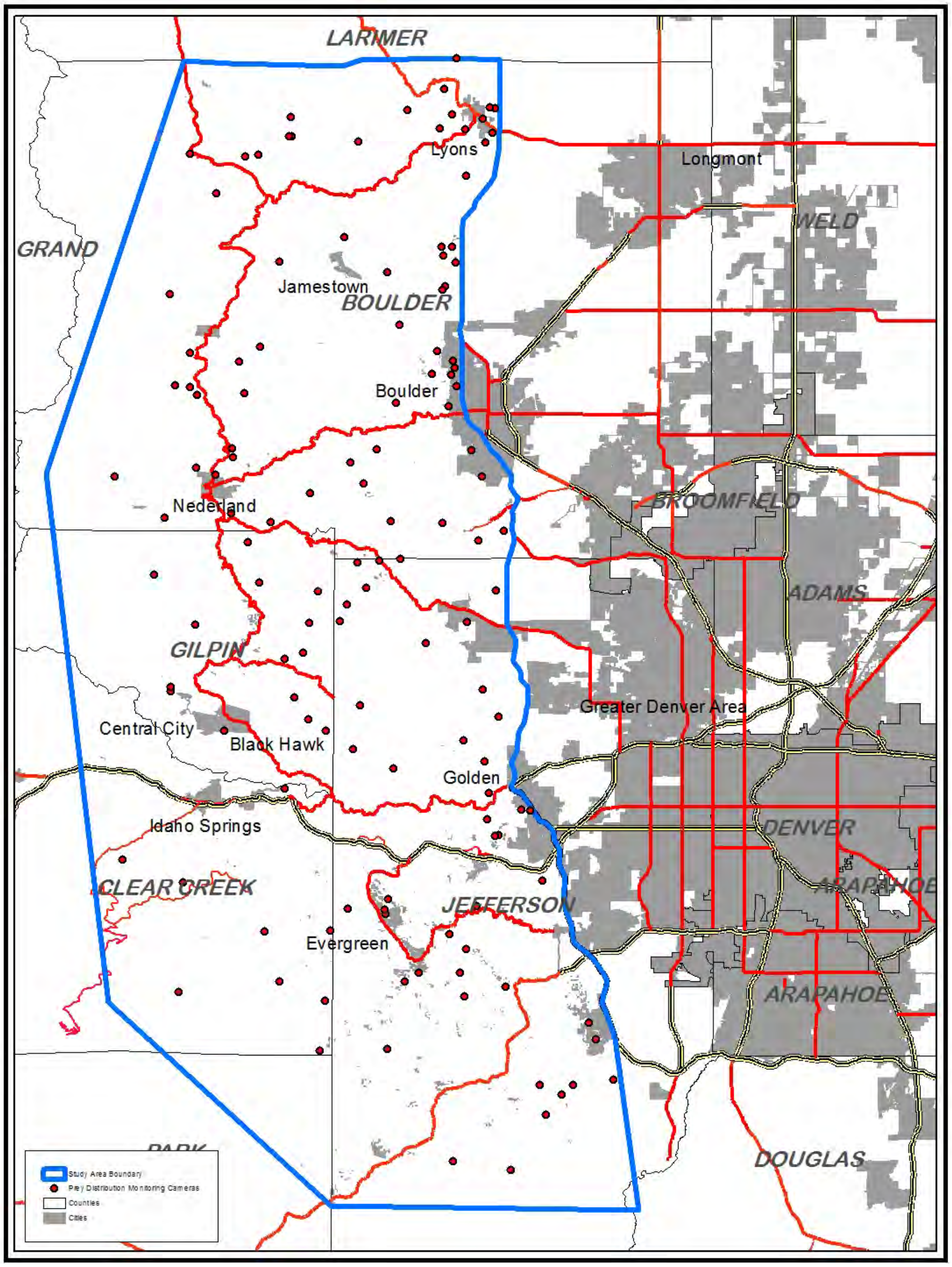


Figure 2: The 2,862 km^2 study area, delineated with the blue polygon, lies on a portion of the eastern slope of the Colorado Front Range. The study area encompasses the approximate home ranges for a sample of GPS collared cougar. Dots are prey distribution camera trap deployment sites.

Strata	Factor	Sub-Type	Description	# of Sites
Major habitat	DEC		Deciduous trees present	19
	GRS		Site dominated by grassland	20
	HEC		Site dominated by coniferous forest >8000 ft elevation	20
	LEC		Site dominated by coniferous forest <8000 feet in elevation	27
	SHR		Site dominated by scrub/shrub	20
	URB	Stream1	Site located in urban/suburban housing density levels and within 100 meters of a perennial stream	6
	URB	Stream2	Site located in urban/suburban housing density levels and 100-750 meters of a perennial stream	6
	URB	Stream3	Site located in urban/suburban housing densities and >750 m from a perrenial stream	6
	MIX		Site located in a mix of one of the major habitat classes	8
Housing Density	Rural		Housing density >16.18 ha/unit	67
	Exurban		Housing density 0.68-16.18 ha/unit	47
	Suburban/Urban		Housing density <0.68 ha/unit	18
Proximity to Dwelling	House 1		Site located < 200 m of house	61
	House 2		Site located within 200-700 m of house	50
	House 3		Site located >700 m from house	21

Table 1: Placement of the 131 cameras followed a stratified random sampling design across three major stratifications. These strata were chosen in order to spread out the cameras across a range of conditions, as well as to ensure adequate characterization of prey availability in relation to human activity.

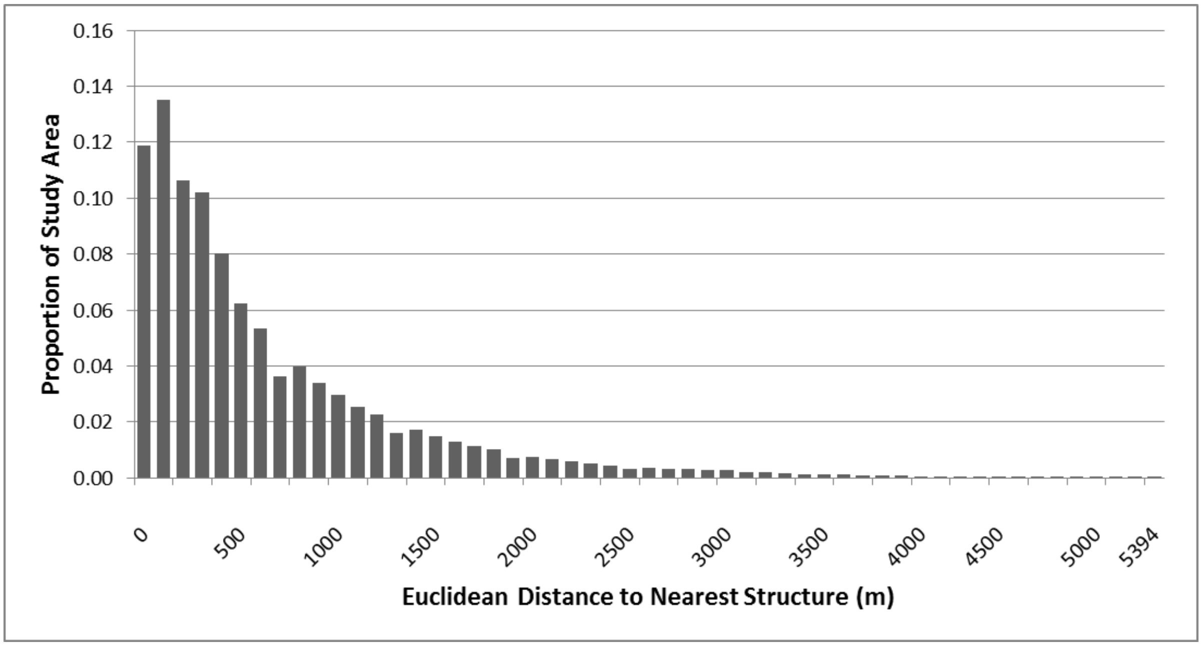


Figure 3: Histogram describing the composition of the study area, classified by the distance to nearest (Euclidean) digitized man-made roofed structure, at 100 m intervals. The maximum distance calculated was 5,394 m.

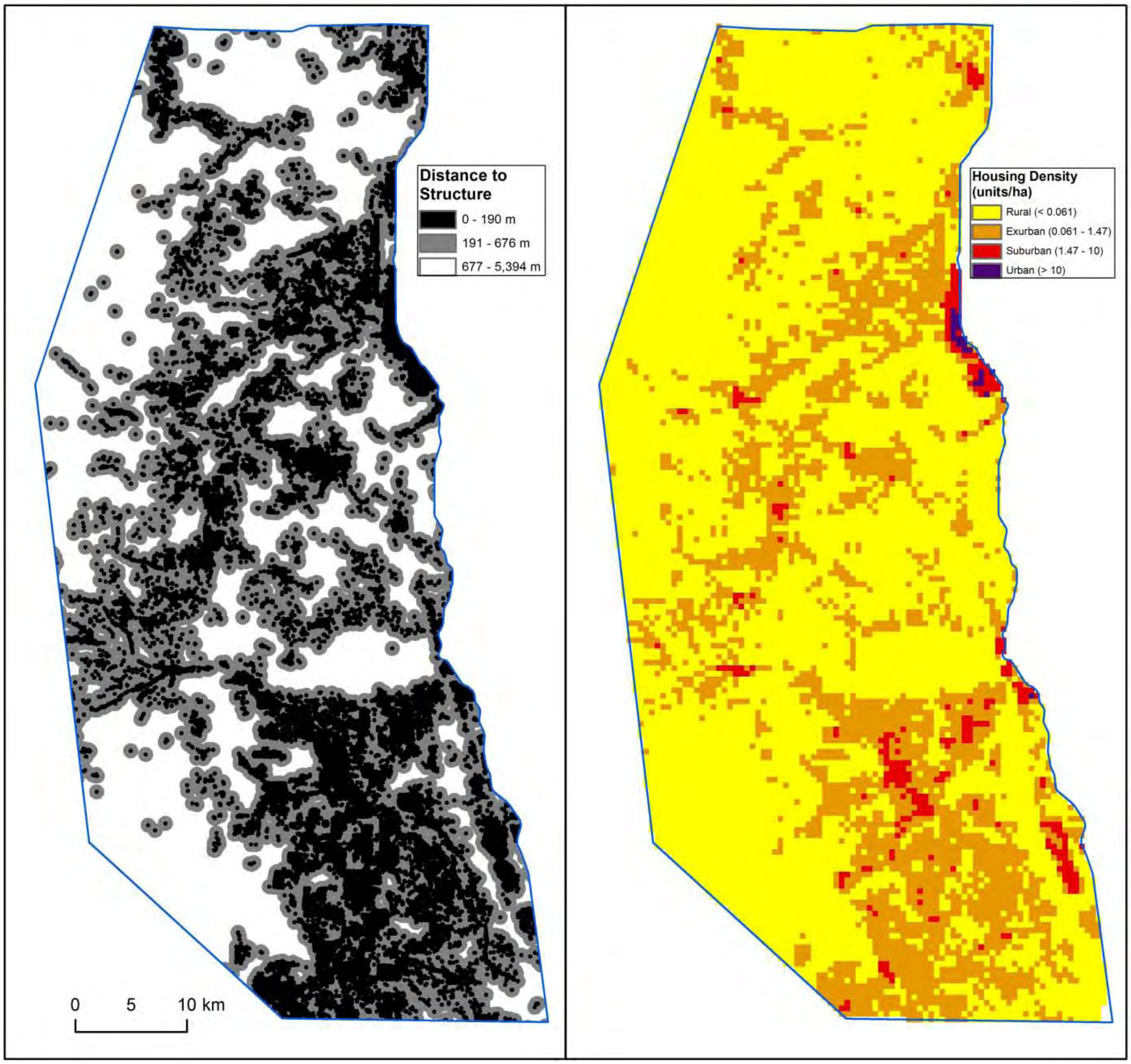


Figure 4: Left Pane – Nearest distance to man-made roofed structure (Euclidean distance) was classified into three quantiles of area (Euclidean distance intervals of 0-190, 191-676, and 677-5394 m). **Right Pane –** Results from the housing density model utilizing Census Bureau block group and the distribution of man-made roofed structures classified into four levels of housing unit density, aggregated to a cell size of 500 m.

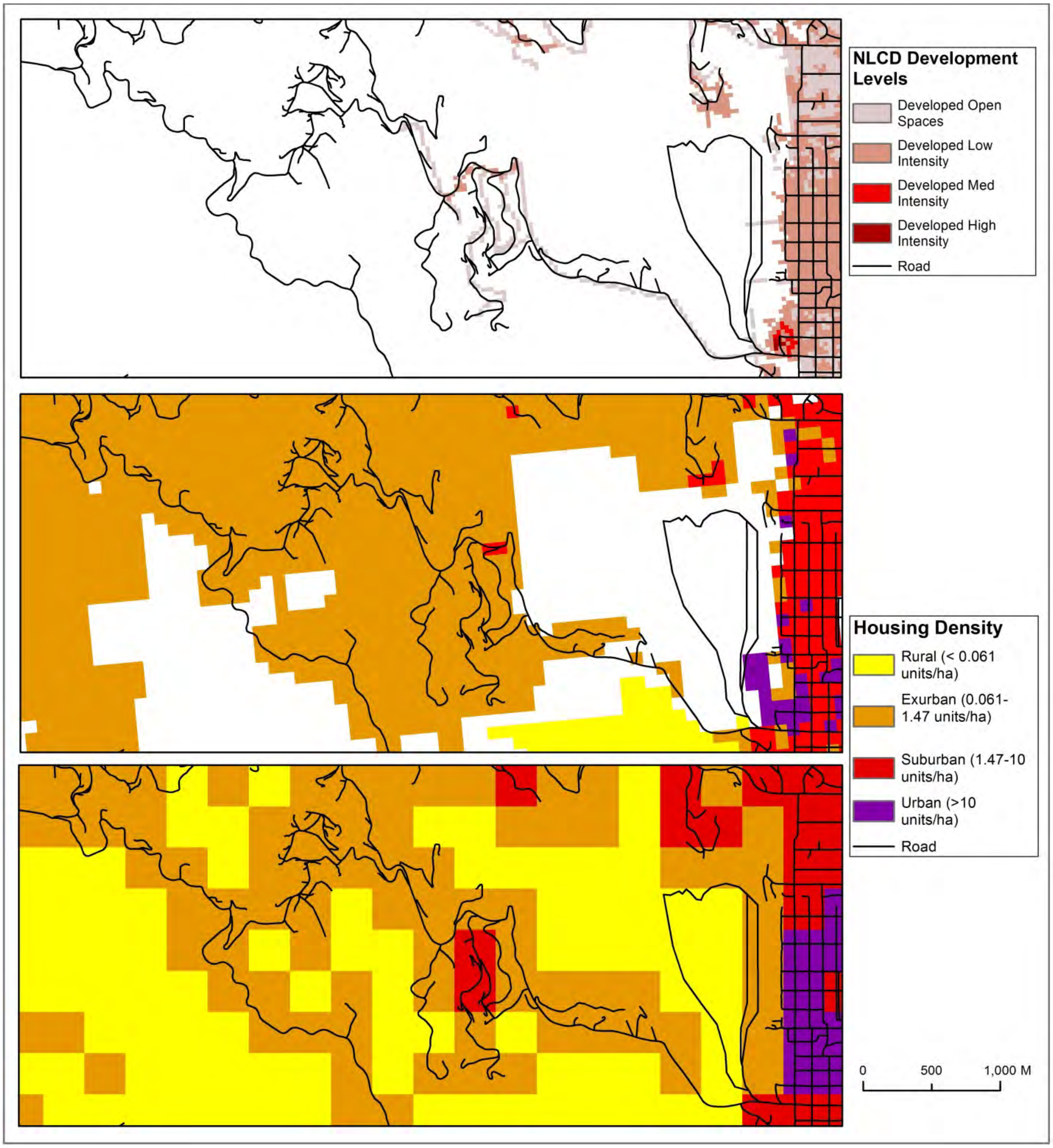
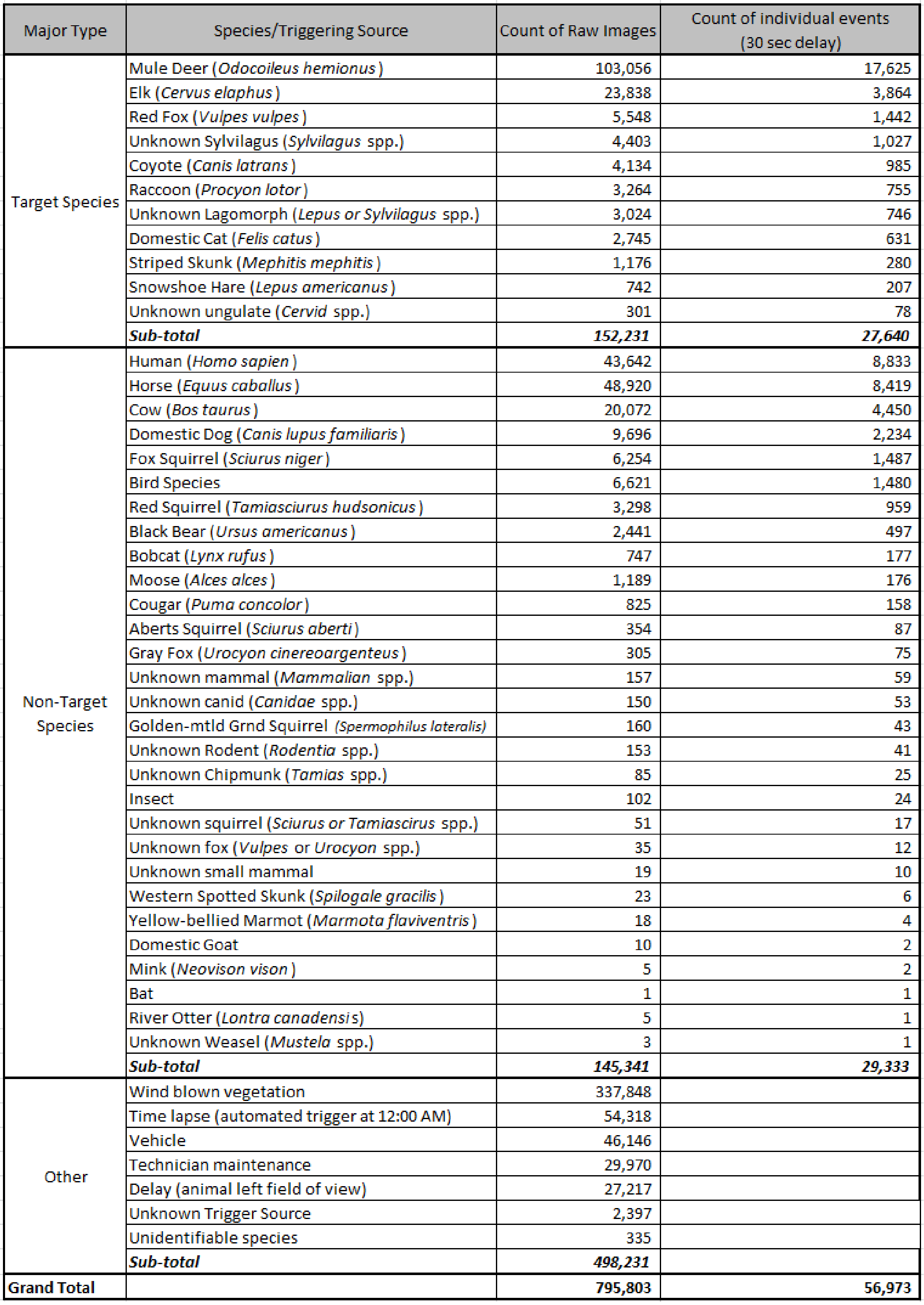


Figure 5: Comparison of three differing datasets depicting development intensity in the northwest vicinity of the City of Boulder, CO. **Top Pane** - The 2006 NLCD dataset data set was derived from the classification of permeable surfaces from Landsat Thematic mapper via satellite (USGS). **Middle Pane** - The 2000 SERGoM dataset utilized Census Bureau polygons depicting housing unit density and road densities to model the spatial distribution of housing density (Theobold 2005). **Bottom Pane** - The housing density model, aggregated to a cell size of 200 m, created in this project utilized the same Census Bureau data as SERGoM, but utilized man-made roofed structure densities to derive the spatial distribution of housing density.



Major Type	Species/Triggering Source	Count of Raw Images	Count of individual events (30 sec delay)
Target Species	Mule Deer (*Odocoileus hemionus*)	103,056	17,625
	Elk (*Cervus elaphus*)	23,838	3,864
	Red Fox (*Vulpes vulpes*)	5,548	1,442
	Unknown Sylvilagus (*Sylvilagus* spp.)	4,403	1,027
	Coyote (*Canis latrans*)	4,134	985
	Raccoon (*Procyon lotor*)	3,264	755
	Unknown Lagomorph (*Lepus or Sylvilagus* spp.)	3,024	746
	Domestic Cat (*Felis catus*)	2,745	631
	Striped Skunk (*Mephitis mephitis*)	1,176	280
	Snowshoe Hare (*Lepus americanus*)	742	207
	Unknown ungulate (*Cervid* spp.)	301	78
	Sub-total	***152,231***	***27,640***
Non-Target Species	Human (*Homo sapien*)	43,642	8,833
	Horse (*Equus caballus*)	48,920	8,419
	Cow (*Bos taurus*)	20,072	4,450
	Domestic Dog (*Canis lupus familiaris*)	9,696	2,234
	Fox Squirrel (*Sciurus niger*)	6,254	1,487
	Bird Species	6,621	1,480
	Red Squirrel (*Tamiasciurus hudsonicus*)	3,298	959
	Black Bear (*Ursus americanus*)	2,441	497
	Bobcat (*Lynx rufus*)	747	177
	Moose (*Alces alces*)	1,189	176
	Cougar (*Puma concolor*)	825	158
	Aberts Squirrel (*Sciurus aberti*)	354	87
	Gray Fox (*Urocyon cinereoargenteus*)	305	75
	Unknown mammal (*Mammalian* spp.)	157	59
	Unknown canid (*Canidae* spp.)	150	53
	Golden-mtld Grnd Squirrel (*Spermophilus lateralis*)	160	43
	Unknown Rodent (*Rodentia* spp.)	153	41
	Unknown Chipmunk (*Tamias* spp.)	85	25
	Insect	102	24
	Unknown squirrel (*Sciurus or Tamiascirus* spp.)	51	17
	Unknown fox (*Vulpes* or *Urocyon* spp.)	35	12
	Unknown small mammal	19	10
	Western Spotted Skunk (*Spilogale gracilis*)	23	6
	Yellow-bellied Marmot (*Marmota flaviventris*)	18	4
	Domestic Goat	10	2
	Mink (*Neovison vison*)	5	2
	Bat	1	1
	River Otter (*Lontra canadensis*)	5	1
	Unknown Weasel (*Mustela* spp.)	3	1
	Sub-total	***145,341***	***29,333***
Other	Wind blown vegetation	337,848	
	Time lapse (automated trigger at 12:00 AM)	54,318	
	Vehicle	46,146	
	Technician maintenance	29,970	
	Delay (animal left field of view)	27,217	
	Unknown Trigger Source	2,397	
	Unidentifiable species	335	
	Sub-total	***498,231***	
Grand Total		**795,803**	**56,973**

Table 2: The raw set of 795,803 images was identified to species or triggering source. Individual events, created by imposing a thirty second delay between consecutive photos, were identified to standardize counts made among sites with different trigger configurations.

Appendix IV

Front Range Cougar Research

Winters, 2011–2012 & 2012–2013

Predator-Prey Dynamics in Relation to Chronic Wasting Disease and Scavenging Interactions at Cougar Kill Sites

Colorado Parks and Wildlife

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June 30, 2013

Front Range Cougar Project

Predator-Prey Dynamics in Relation to Chronic Wasting Disease and Scavenging Interactions at Cougar Kill Sites

2013 Progress Report Submitted by:
Joe Halseth, Matt Strauser, and Mat Alldredge, Colorado Parks and Wildlife

Need:

The current Colorado Parks and Wildlife (CPW) cougar (*Puma concolor*) research on the Front-range is utilizing GPS radio collar technology allowing researchers to track cougar movements on a real time basis. With up to seven uploads a day, the roughly 20 current active project collars give researchers the ability to identify possible kill sites quickly, sometimes as soon as 6 to 12 hours after a kill is made. This provides the opportunity to explore previously un-researched facets of cougar behavior during the relatively short time interval from the point a cougar makes a kill, to the point at which it abandons the carcass. Feeding behavior, intraspecific kill site interaction, and scavenger competition can now be investigated.

Similar to Krumm et al.'s (2005) and Miller et al.'s (2008) cougar studies, which examined cougar selection of Chronic Wasting Disease (CWD) positive mule deer (Odocoileus hemionus), data can now be collected with a greater degree of efficiency. The study areas of each of the two prior CWD cougar projects lie within the more broad boundaries of the current Front-range cougar project, and a larger number of known cougars will increase sample sizes of CWD tissues from cougar killed mule deer. Additionally, much of the field work from the two previous studies is nearly a decade old which justifies another project to compare to past results. The ability to collect a potentially larger sample size will yield more accurate findings, identify gaps in need of further study, and/or detect developing trends in regards to possible temporal patterns.

The ongoing cougar project's available technology and resources, and the relatively minor additional project costs, provide the opportunity to initiate a camera study to explore cougar feeding behavior and scavenger interaction in the period immediately following a cougar kill. Site visitation of fresh cougar kills also allows for the collection of adequate tissue samples to test for CWD and further explore if cougars are selecting for CWD positive mule deer or other ungulates.

Background:

Cougar behavior and scavenger interaction:

Although there have been significant cougar research projects in the U.S. and Canada, only recent GIS advancements have allowed researchers the ability to monitor cougar movements and locations with dependable accuracy on a real-time basis. With GPS collar technology, researchers can collect data on kill sites, prey items, home ranges, den locations, preferred habitats, and a variety of other previously under-explored areas of cougar ecology and behavior.

This new technology initiated many projects that examined cougar feeding behavior. These projects collected extraordinary data documenting duration of kill site occupation, prey analysis, biomass consumption, and feeding patterns (Anderson and Lindzey 2003, Bauer et al 2005, Knopff et al 2010, Blecha and Alldredge unpublished data). However, actual behavior, feeding activity, consumption rates, and scavenger interactions has yet to be thoroughly documented. Placing cameras on fresh kill sites will identify any patterns of behavior that exist during the progression of feeding on a prey item and document interaction with competing scavengers and conspecifics. A goal of this proposed project is to document how often scavengers challenge cougars on fresh kills and how successful these competing scavenging species are at stealing the food item. Using time stamped photos from cameras, we will be able to determine the average time it takes for competing scavengers to arrive on site after a kill and the rate in which the scavenger species successfully displaces the cougar. Seasonal variation in scavenging rates of fresh carcasses will be analyzed, especially with regard to bear activity and changes in diet competition.

Basic cougar ecology suggests that with the exception of family groups and mating interaction, cougars are largely solitary animals (Seidensticker et al. 1973). On numerous occasions throughout the course of the ongoing lion project, researchers have documented two cougars on the same kill site. One can only speculate on their interaction. This proposed project also seeks to document behavior in such situations to observe if cougars are sharing kills or challenging one another for feeding opportunities.

CWD component:

Ongoing cougar research on the northern Front-range (Alldredge, unpublished data) as well as other significant cougar research (Logan and Sweanor 2001, Anderson and Lindzey 2003, Hornocker 1970) has shown that cougars, while predating on a wide diversity of prey species, select for deer and elk in higher proportions. Additionally, the northern Front-range has been identified as the epicenter of the Chronic Wasting Disease (CWD) epidemic, possessing the highest infection rates in the state (Miller et al. 2000). CWD is a naturally occurring prion disease effecting deer, elk and moose. Early stages of infection are difficult to recognize but advanced signs of CWD infected deer are more readily identified by humans, with symptoms including poor body condition, reduced coordination, excessive salivation, and increased isolation from other deer (Williams and Young 1980). Basic predation theories suggest that predators prey upon young, sick, and older individuals in greater proportion than fit, mature individuals. Optimal foraging theory predicts that predators ought to choose the most “profitable” prey (MacArthur and Pianka 1966, Schoener 1971, Pulliam 1974), which should be the largest prey available that can safely be killed. Thus, we might assume cougars can identify a deer in the later stages of CWD infection. Miller et al. (2008) speculated that cougars could have the ability to identify the most subtle changes in behavior or body condition in early stage CWD positive deer, causing them to be more vulnerable to predation.

While it is known that cougars prey on deer or other ungulates as a primary food source, only two studies have explored whether cougars are selecting for CWD positive deer (Krumm et al. 2005, Miller et al. 2008.) Krumm et al. (2005) found the percentage of CWD infected mule deer killed by cougars was significantly higher than hunter harvested deer in the same area. Miller et al. (2008) found infected deer were much more likely to be killed by cougars than uninfected ones. There is little information on cougar selection of CWD infected elk but this proposed study will document any CWD occurrence in cougar-killed elk.

It is the responsibility of CPW to utilize the best science when managing Colorado’s wildlife resources. Exploring cougar kill site behavior will address loss rates from scavenging/competition of fresh carcasses. This could provide insight on actual prey consumption and clarify an important variable in estimating the frequency of cougar deer and elk kills. Documenting feeding behavior has not previously been done in this proposed fashion and will provide invaluable information on basic cougar ecology and behavior. Collecting samples for CWD testing will provide a welcome opportunity to compare new data to the two previous studies and to existing (and evolving) CPW CWD data. Furthering our understanding of the relationships between predator/prey and disease dynamics will afford biologists better information in managing Front-range wildlife populations.

Objectives:

1. Document sharing and/or abandonment rates of cougars occupying kill sites in response to presence of other cougars and/or scavengers.
2. Document time from kill until presence of competing scavengers.
3. Document feeding patterns and length of individual feeding sessions.

4. Compare CWD infection rates from cougar-killed deer and elk to existing CPW CWD infection rates to determine if cougars are selecting for CWD positive deer and elk.

Methods:

Researchers will monitor cougar movements using GPS data on a GIS to detect possible kill sites as early as possible. After a location is deemed permissible and realistic to access, researchers will travel to the kill site area and navigate to the potential kill site location. Personnel will use a VHF signal to monitor cougar location during the approach to avoid contact. While some disturbance to cougars may be unavoidable if the animal is alerted upon researcher approach, precautions will be taken to avoid frequently forcing cougars off a kill. Past experiences, especially those associated with capture activities, on the Front-range cougar project have shown that a cougar is not likely to be affected if briefly disturbed at their kill. Ideally, the potential kill site will be approached between feeding sessions when the cougar is day bedded offsite. Initial kill site investigations are currently being conducted in the parent cougar project to establish the probability a kill site is detected by technicians at a later date. There have been no instances of abandonment. Additionally, many bait sites occupied by cougars are visited daily by technicians to switch memory cards in cameras, adjust location of placed bait carcasses, and/or refresh bait as needed to keep a cougar in the immediate area. Often times this is done for a series of days until researchers can attempt to conduct a capture. Even with these daily visits, patterns of bait site abandonment have not been observed. However, if these kill site visits and camera placements prove to disturb the cougar, and a pattern of kill site abandonment is observed, site visits and camera placement will cease

In the event a kill is found, a maximum of two cameras will be placed to document feeding activity and scavenger interaction. Multiple cameras will be used in the event the cached prey item is slightly moved and to monitor activity within a larger area. Cameras will be affixed to adequate stationary objects and camouflaged with vegetation to minimize sight manipulation and detection. The reconyx cameras currently used in the parent cougar project are 4x6 inches and emit a low glow instead of a flash during nighttime photographs. Cameras will be left in place up to two weeks after the cougar has left the kill site.

If the prey item is a mule deer or other ungulate, retropharyngeal lymph nodes and/or the medulla oblongata at the obex will be collected for CWD testing. Additionally, a lower incisor will be obtained for accurate age analysis. Krumm et al. (2005) collected 54 testable samples from cougar-killed mule deer in 42 months. Miller et al. (2008) observed 11 CWD positive collared deer succumbed to cougar predation at a rate nearly four times that of uninfected collared deer. With the large number of collared cougars in the current Front-range cougar project (n≈25), we predict the ability to collect a target sample size of 4-5 tissue samples per month. A large sample is necessary to determine if cougars are selecting for CWD positive deer, as the power to detect a 10% difference using binomial proportions is only 0.75 (n=200).

2012-2013 Progress:

Scavenging and Kill Site Interactions

Methods:

Timely approaches to kill sites have been successful, usually occurring within 24 hours of a cougar's first GPS location at a kill site. This allows technicians to evaluate the prey item to ensure the estimated time of death matches the carcass condition in order to rule out other possible causes of death (road kill, hunting loss, etc). Cougars are often onsite at the killsite upon approach but usually retreat as the researcher nears the site. There have been several situations where a cougar has been unwilling to move from a kill despite attempts to scare it off. In these situations technicians have left the area and if time allowed, returned at a later time.

There have been very few instances of abandonment (n~6) after a carcass have been visited and cameras placed. Four of these abandonments were due to the cougar occupying a second killsite and never returning to the first, and not likely a result of human visitation and camera placement on the first carcass.

Preliminary Results:

As of July 24, 2013 we have placed cameras at 175 cougar kill sites collecting approximately 320,000 raw photos. Identifying pictures is an ongoing effort with approximately 300,000 having been identified. Cameras have documented bears visiting 65 sites, roughly (37%) of the total sites. However, when calculating bear visitation at cougar feeding sites between March 15 and November 30, when bears are most likely outside of their dens, this figure increases to 41% as there have only been 20 camera placements between December 1 and March 15. After the 65 sites were identified to have pictures of bears, we further analyzed the photo sequence and when necessary, viewed archived cougar collar data. Of the 65 sites that contained a photo of bears, we consider 30 of these sites to be scavenging events, identified as the bear arriving after the cougar has finished and abandoned the carcass. At least 17 sites have been identified where bears have directly displaced the cougar and stolen the prey item. Another 18 events are considered possible stealing events where photos are deemed inconclusive or additional photo analysis and/or archived GPS data from the focal lion needs to be further analyzed.

Red fox (Vulpes *vulpes)* have been documented scavenging at 78, or 47% of the kill sites. Other scavengers documented have included striped skunk (*Mephitis mephitis)*, spotted skunk (*Spilogale gracilis)*, raccoon (*Procyon lotor*), ringtail cat (*Bassariscus astutus)*, grey fox (*Urocyon cinereoargenteus)*, coyote (*Canis latrans*), domestic dog (*Canis lupus familiaris)*, bobcat (*Lynx rufus),* golden eagle (*Aquila chrysaetos)*, red-tailed hawk (*Buteo jamaicensis*), great-horned owl (*Bubo virginianus)* and a variety of Corvidae bird species.

There have been at least 10 camera sites that have identified multiple cougars simultaneously occupying a kill site. These observations include a 'sharing' situation involving two cougar family groups and multiple sharing situations involving an adult male and female. Other interactions include two instances of female cougars stealing food items from other female and one instance of an adult male feeding on a prey item occupied by a female and three young kittens. There have also been several instances where non-focal cougars scavenge on the remains of prey items already consumed and abandoned by the focal cougar. These photo sequences are still in the process of being analyzed and field work is still ongoing.

CWD component

Methods:

There have been no problems with obtaining tissue samples to test for CWD from cougar killed ungulates except in rare situations where the testable tissues have been consumed by the cougar. Samples collected in the field are assigned a head tag and transferred to the Wildlife Health Lab in Fort Collins for testing.

Preliminary Results:

As of June 30, 2013 we have collected 113 CWD samples from cougar killed deer (n=108) and elk (n=5). 94 have been from adult deer (>1 yr) and 14 have been from fawns (<1yr). Of elk tested, four have been adult and one calf. Figure1 shows the breakdown of species, age and test results from within the broad boundary of the front-range cougar project.

Species/Age	# Tested	# Positive	% Positive
Adult Mule Deer	94	21	22.3
Fawn Mule Deer	14	1	7.1
Adult Elk	4	1	25
Calf Elk	1	0	0

Figure 1. Total CWD results

Deer DAUs 10 and 17 overlap the edges of the project boundary and DAU 27 falls entirely within the project boundary as shown in Figure 3. Figure 2 shows the sampling breakdown for the individual DAUs.

Deer DAU	# Tested	# Positive	% Positive
DAU 10	20	2	10
DAU 27	65	16	24.61
DAU 17	9	3	33.33

Figure 2. Adult CWD sampling breakdown by DAU

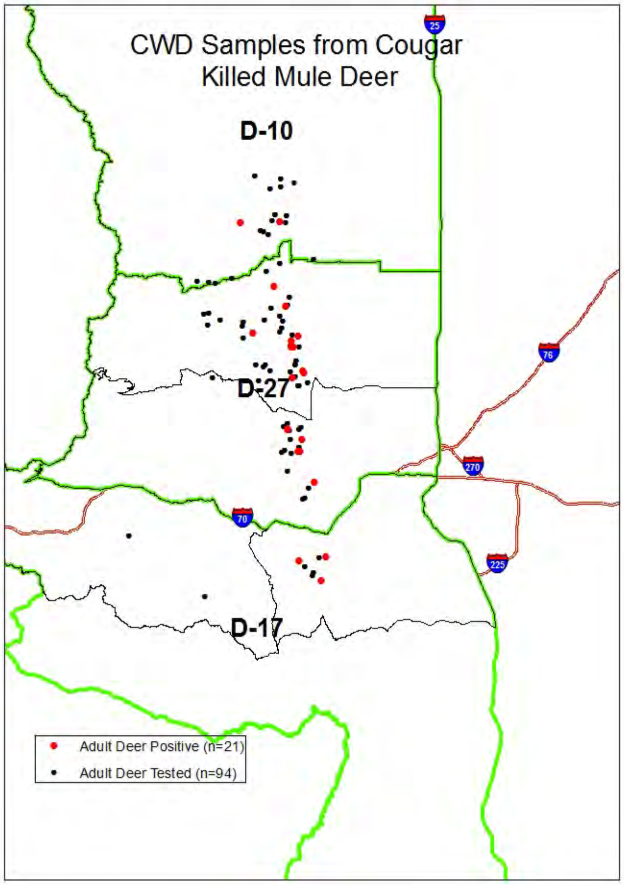

Figure 3. CWD sample distribution from cougar killed adult deer

A possible trend in the CWD sampling has been observed with CWD positives only occurring from mid-winter through spring (Figure 4). If this trend continues through the fall and winter of 2013, the total observed CWD prevalence found in cougar killed mule deer should decline from the currently observed values.

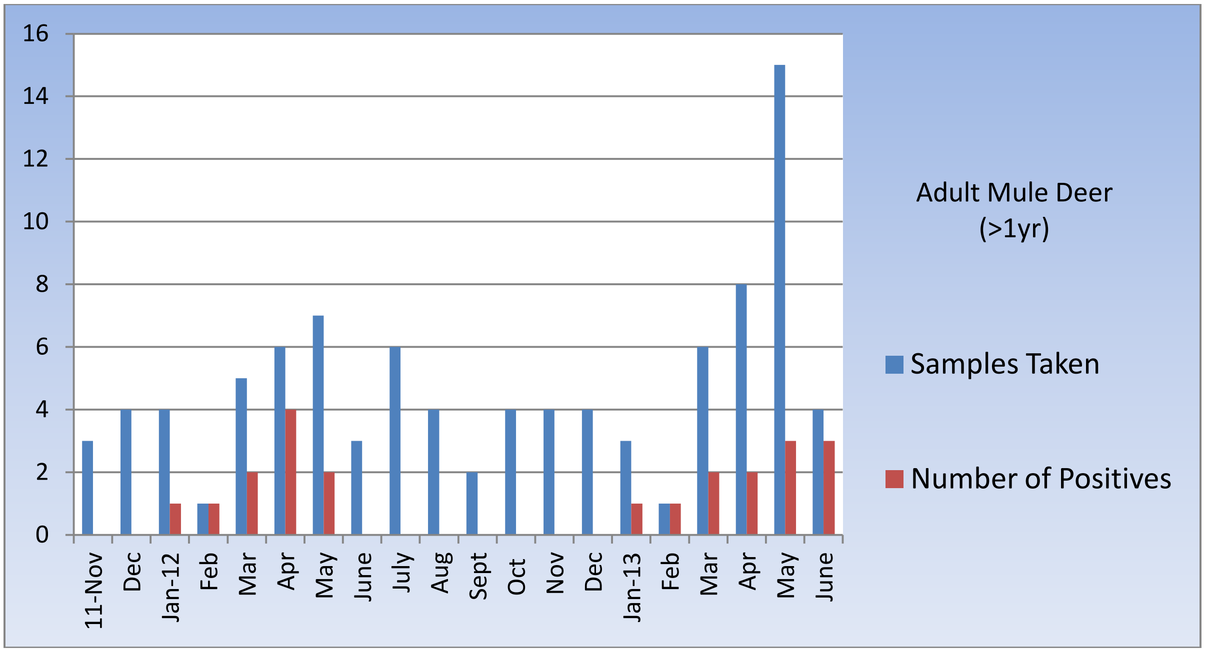

Figure 4. CWD occurrence in cougar-killed adult mule deer

Appendix V

Front-Range Cougar Research

Winters, 2011–2012 & 2012–2013

The Use of Lures, Hair Snares, and Snow Tracking as Non-Invasive Sampling Techniques to Detect and Identify Cougars

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Research Proposal

June 30, 2013

Introduction

To set harvest quotas, evaluate management practices, and understand the dynamics of predator-prey systems, it is desirable to have reliable estimates of population size. However, answering occupancy and abundance questions regarding carnivores has long been a challenging task (Kery et al. 2011). In general, carnivores are elusive and occupy large home ranges that often vary in size across the population (Anderson et al. 2004). As a result, it can be very difficult and expensive to obtain a representative sample that is large enough to produce a reliable estimate (Ruell et al. 2009). Despite the cost, it is essential that managers have accurate population estimates that can support management decisions (Dreher et al. 2007, Immell and Anthony 2008). Here, we focus on cougars (*Puma concolor*). In the state of Colorado, cougars are a game species and it is imperative that their population be responsibly managed. Wildlife personnel are also tasked with managing increasing cougar-human conflict in residential and recreational areas. Developers are pushing west into previously undisturbed habitat; pet loss complaints and depredation claims continue; and each year, municipalities acquire more land to be made available to the public.

Many things must be considered when estimating abundance such as the sampling method and the estimation procedure chosen. In wildlife studies, mark-resight methods are commonly used and estimates are generated by applying a suitable model like the Lincoln-Peterson estimator (Williams et al. 2002) or the Huggins model (Huggins 1989). As with any model, the assumptions must be addressed. Mark-resight models are bound by assumptions like closure and equal probability of capture and detection (Otis et al. 1978). But in wildlife studies, detection is often less than certain (<1) and variable across the population (Link 2003). Capture variation is also relative to the survey method(s), so how you choose to sample the population may depend on recognizing the sources of heterogeneity. For instance, if an animal was initially caught by a cage, it may not enter the trap a second time. In turn, one might consider using remote cameras or snow tracking as a means to resight previously captured animals.

Wild animals have been sampled by a variety of techniques either by their capture or through noninvasive means where direct human contact is not needed (Pauli et al. 2010). Due to carnivore ecology and behavior, trapping and handling practices are generally costly and difficult making noninvasive-genetic-sampling methods (NGS) an attractive alternative (Long et al. 2008). In addition, NGS has other benefits in that it minimizes stress and disturbance to the study animals; and when successful, it allows a larger sample size at a lower cost (Pauli et al. 2010). Herein, we will consider noninvasive methods.

Researchers have tested several noninvasive techniques, some quite creative, on a variety of carnivores to detect and count individuals. For example, track surveys can effectively verify occupancy or suggest general population trends, but are limited in their ability to produce accurate abundance estimates (Diefenbach et al. 1994, Sargeant et al. 1998, Wilson and Delahay, 2001, Hayward et al. 2002, Choate et al. 2006, Gompper et al. 2006). However, when track surveys are combined with the collection of genetic material, species identification can be confirmed (McKelvey et al. 2006) and/or individuals identified, allowing for abundance estimates using mark-recapture analysis (Ulizio et al. 2006). Cameras, lures, and/or hair snares have also been used to survey cougars (Long et al. 2003, Choate et al. 2006, Sawaya et al. 2011), lynx (McDaniel et al. 2000, Schmidt and Kowalczyk 2006), bobcats (Harrison 2006), ocelots (Weaver et al. 2005), multiple felids (Harrison 1997, Downey et al. 2007), and carnivore communities (Sargeant et al. 1998, Long et al. 2007, Ruell and Crooks 2007, Castro-Arellano et al. 2008, Crooks et al. 2008). Though dozens of lures have been tested along with several novel hair-snaring devices, results have been variable, suggesting no single method is superior above all others.

With regard to cougars, the potential of NGS has not been realized. Inconsistent results have left the techniques needing further testing and refinement. In past studies involving attractants, almost all have primarily used scents. Few surveys have incorporated auditory calls despite the fact that felids may exhibit a greater response to auditory cues than to olfactory stimulus (Chamberlain et al. 1999). Further testing of this component is needed to assess whether calls will attract cougars to sites. Furthermore, John Weaver (Turbak 1998) described a hair-snaring device that consisted of a board with a scent-lure-covered carpet pad pierced with nails and secured to a tree. McDaniel et al. (2000), Harrison (2006), McKelvey et al. (2006), Schmidt and Kowalczyk (2006), Long et al. (2007), and Sawaya et al. (2011) tested similar mechanisms on a variety of felids. These designs snagged hair part of the time though the quality of the hair and whether or not the hair was from the target species was inconsistent. Modifications in snare designs are needed to improve the reliability of the hair snagged, thus increasing the likelihood of obtaining a usable sample.

Barbed wire is an alternative hair-snaring mechanism to traditional scratch-pad designs. Barbed wire has long been used to collect hair samples from grizzly and black bears (Woods et al. 1999, Mowat and Strobeck 2000, Poole et al. 2001, Boersen et al. 2003, Belant et al. 2005, Boulanger et al. 2006, Dreher et al. 2007, Kendall et al. 2008, Settlage et al. 2008, Proctor et al. 2010). Ebert et al. (2009) used barbed wire to snag hair from wild boar, and Belant et al. (2007) obtained hair from white-tailed deer. We could not find a study that used barbed wire in an attempt to snag hair from a felid species. However, we collected hair suspected to be cougar from a barbed-wire fence during a snow-tracking survey.

Snow tracking is another NGS method that has been implemented in a variety of cougar studies. Seidensticker et al. (1973) applied winter tracking to evaluate movement patterns relative to kill sites, reproductive status, and topography and vegetation. Hemker et al. (1984) used snow tracking to locate cougar sign needed in population estimation. Snow tracking can also be used to facilitate DNA sample collection where hair or scat found along a track can be genotyped to yield an individual identification (McKelvey et al. 2006, Ulizio et al. 2006). Sawaya et al. (2011) reported winter tracking cougars under favorable conditions returned hair samples 80% of the time after tracking on average 1.09 km. However, because success is largely dependent upon optimal snow conditions and timing after snow fall (Squires et al. 2004), this method may only be effective in specific geographic regions. Its utility has not been tested on the Front Range.

Winter tracking may prove useful as a secondary method of detection in mark-resight surveys. Utilizing multiple detection methods can reduce problems with bias due to the capture variation that arises when a single survey method is used (Noyce et al. 2001). For example, individuals that develop trap shyness to established sites can be detected alternatively via track surveys. Wildlife managers have used additional resources, such as animals collected during hunter harvest, as another ‘occasion’ in a detection history of a capture-recapture analysis (Garshelis and Visser 1997, Diefenbach et al. 2004, Nicolai et al. 2005, Dreher et al. 2007). Applying a secondary collection method, alternative to capture, can also reduce costs (Pauli et al. 2010) as the capture and handling of carnivores is often of great expense to federal and state agencies (Long et al. 2003, Immell and Anthony 2008).

Eliminating or accounting for genotyping errors is essential in satisfying the assumption of known identity in mark-recapture models. Failure to do so can result in an over or under estimation of abundance depending upon the type of error (Lukacs and Burnham 2005). Hair and scat collected using NGS methods typically have a low quality and quantity of DNA (Broquet et al. 2007). Inherently small quantities of DNA are susceptible to sample contamination and degradation in the field and in the laboratory (Taberlet and Luikart 1999). The resulting poor DNA samples may fail to amplify or display genotyping errors by allelic dropout or false alleles exhibiting false homozygotes and heterozygotes respectively (Buchan et al. 2005). Ernest et al. (2000) report an 8% allelic dropout rate during fecal amplification compared to a < 1% error rate in blood and muscle assays. Strict data collection and laboratory protocols can minimize genotyping errors (Taberlet et al. 1996). When possible, errors can be observed by comparing NGS results to more reliable profiles generated through blood and tissue analyses (Ernest et al. 2000, Mills et al. 2000, Mondol et al. 2009). If errors are found, it may be necessary to run multiple tests on a single sample (Taberlet et al. 1996).

DNA can be used to both confirm species and identify individuals (Woods et al. 1999, Kéry et al. 2011). For our purposes, cameras should confirm species identification. Individuals are typically identified using nuclear DNA as it has a high level of variability needed to differentiate individuals (Menotti-Raymond and O’Brien 1995). Menotti-Raymond et al. (1999) developed a genetic linkage map for the domestic cat containing 253 microsatellite loci. These loci can be used in the analysis of other felids. How many and which microsatellites are used depend upon the degree of genetic diversity between individuals in the population sampled (Woods et al. 1999). Menotti-Raymond et al. (1999), Culver et al. (2000), Ernest et al. (2000), Anderson et al. (2004), and Mondol et al. (2009) reported between 7 and 12 loci with a high degree of variability was adequate to express enough heterozygosity to differentiate individuals in their respective studies.

In summary, many attempts have been made to realize NGS methods capable of producing reliable responses. Up until now, results have been mixed. It was our goal to develop noninvasive field methods that reliably detected and identified cougars (Chapter 1) and estimate the probability of detection given the most effective survey method (Chapter 2). We also aimed to address the closed mark-recapture model assumptions and investigate potential sources of capture variation (Chapter 3). Finally, we hoped to evaluate if snow tracking as a means to locate genetic material was a useful tool given the snow conditions on the Front Range (Chapter 4).

Chapter 1. The development of a noninvasive method to sample cougars

It is impossible to know when, where, or how the first animal was studied. What was the question and how was it answered? Since then, the resolutions to countless scientific inquiries have and continue to expand the knowledge base that cultivates how we study wild animals. For example, advancements in genetic techniques, in many cases, have dictated the quality and quantity of the sample needed. Before the advent of the polymerase chain reaction (PCR) (Mullis and Faloona 1987), genetic variation could be observed via protein electrophoresis or by assessing the restriction fragment length polymorphisms (RFLP) of mitochondrial DNA (mtDNA), but the amount or type of tissue needed for these techniques usually necessitated the sacrifice of the study animals (Avise et al. 1979, Brown and Wright 1979, Lewontin 1991). Alternatively, PCR can amplify a minute quantity of DNA extracted from sources such as a single spermatozoid or a hair follicle (Taberlet et al. 1996). Since preservation is often of interest in many wildlife studies, causing unnecessary harm is objectionable.

Animals are physically sampled via a variety of techniques but the current trend, when possible, is to move away from methods that require the capture and handling of the animal and towards a more noninvasive-sampling protocol. Large carnivores are not an exception and using noninvasive methods (NGS) to sample them is appealing for several reasons. For example, a carnivore's elusive nature and large home range size can make capturing it difficult and cost prohibitive (Long et al. 2008). In addition, NGS techniques generally cause less stress and disturbance to the study animals (Pauli et al. 2010).

A variety of NGS methods have been developed to address specific research questions and in many instances the resolution requires obtaining a physical sample. For example, a track survey can effectively verify occupancy or suggest general population trends but is limited in its ability to produce an accurate abundance estimate (Sargeant et al. 1998, Choate et al. 2006, Gompper et al. 2006). Many models used in abundance estimation are bound by the assumption that all animals are strictly identifiable (McClintock et al. 2009). Without having prior knowledge of an individual, which is often the case (Van Dyke et al. 1986), it is extremely difficult to verify a unique identity by tracks alone. Remote cameras can distinguish conspecifics with unique markings like tigers (*Panthera tigris*) (Karanth and Nichols 1998) but an animal with a uniform pelage such as a cougar (*Puma concolor*) cannot be individually identified with certainty via photographs alone. Since, aside from identical twins, nuclear DNA is unique to each member of the population (Hartl and Jones 2005), obtaining genetic samples, for example, by following tracks, can yield the individual genotypes needed to estimate abundance (Dreher et al. 2007, Sawaya et al. 2011). Furthermore, NGS techniques and appropriate laboratory methods can determine sex, paternity, and other measures of relatedness (Long et al. 2008), estimate age (Pauli et al. 2011), and give dietary information (Hopkins et al. 2012).

DNA is frequently extracted from blood and tissue but scat, feathers, and hair are typically the source of DNA collected via NGS techniques (Taberlet and Luikart 1999). At present, we focus on the collection of hair. A commonly used NGS method to obtain hair is to apply an attractant to a hair-snaring device (Long et al. 2008). Dozens of lures and novel hair snares have been tried on a variety of carnivores, including cougars, but results have been variable. One challenge seems to be achieving a consistent and significant response. Sawaya et al. (2011), Choate et al. (2006), and Long et al. (2003) used scent lures and reported having detected five, zero, and zero cougars in their respective studies. A sample size of five can confirm species presence but is not adequate to address precise population questions. We know of no study that has confirmed a technique capable of eliciting multiple, regular responses in cougars. Past studies have placed emphasis on scent lures (Long et al. 2003, Choate et al. 2006, Sawaya et al. 2011) but felids might exhibit a greater response to auditory cues (Chamberlain et al. 1999) suggesting that cougars may be attracted to an auditory stimulus such as a predator call.

Currently, there are challenges to using hair as a DNA source. For example, the scratch pads generally used to sample felids (McDaniel et al. 2000, Weaver et al. 2005, Harrison 2006, McKelvey et al. 2006, Schmidt and Kowalczyk 2006, Long et al. 2007, and Sawaya et al. 2011) tend to snag shed hair which might not have a follicle. In addition, hair has less extractable DNA than tissue and blood (Taberlet and Luikart 1999). Goossens et al. (1998) recommended obtaining ≥ 10 plucked hairs to minimize the chance for genotyping errors in the lab but acknowledged that this quantity is probably species specific. Regardless, improvements in hair-snaring techniques are needed to ensure that individuals are genotyped accurately.

Our objective was to find a NGS technique that could reliably sample cougars. We used previously captured cougars marked with unique ear tags and monitored via collars equipped with global positioning system (GPS) technology in our assessment. When possible, ear tags confirmed a cougar's identity in photographs but when ear tags were not visible, GPS location information indicated an individual's presence at a site. We assessed scent lures, auditory calls, and three hair-snare designs at 68 randomly established sites. As the season progressed, we altered the sites based on photographic evidence and the presence or absence of hair. Here we emphasize cougar responses to the attractants and the hair-snaring devices we employed.

Study Area

The study area was located on the Front Range, Colorado, USA in Boulder and Jefferson counties. Though interspersed with private parcels, the majority of the 400 km² study area was comprised of city and county open space properties west of the city of Boulder and between the town of Lyons to the north and Interstate 70 to the south. The elevation ranged from approximately 1650 m to 3000 m. The average monthly precipitation during the study was 31.5 mm and the average monthly temperature was -0.5 °C using climate data collected at 17 National Oceanic and Atmospheric Administration (NOAA) weather stations in or near the study area. The dominant canopy species included ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), and Rocky Mountain juniper (*Juniperus scopulorum*). The understory vegetation included mountain mahogany (*Cercocarpus*), Gambel's oak (*Quercus gambelii*), serviceberry (*Amelanchier alnifolia*), three-leaf sumac (*Rhus trilobata*), and bitterbrush (*Purshia tridentata).* Besides cougars, we observed other medium to large-bodied mammals in the region such as elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), black bears (*Ursus americanus*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), bobcats (*Lynx rufus*), ring-tailed cats (*Bassariscus astutus*), an American marten (*Martes Americana*), and on occasion, unleashed domestic dogs (*Canis lupus familiaris*).

Methods

From February to April, 2012 and November, 2012 to April, 2013, we tested attractants and hair snares as a noninvasive-sampling method for cougars at lure sites. We selected the sites by first dividing the 400 km² study area into four 100 km² quadrats. Each quadrat was comprised of twenty-five 4 km² parcels. We randomly chose 4 – 6 parcels in each quadrat over four sampling periods using the spatially balanced points function in ArcGIS® 10.0 and placed one site within each parcel (n = 68). We selected the exact site location to avoid areas with human activity, to inhabit specific landscape features (ridgelines, saddles, drainages, canopy cover, and tree line edges), and to comply with restrictions imposed by city and county officials. The sites were active an average of 31.6 days for a total of 2,149 survey nights (Table 1).

We assessed scent lures and auditory calls by establishing four types of sites that varied by whether they included a scent lure, a call, neither, or both (Table 1) and tested hair-snaring techniques at sites with the requisite attractant. When possible, the attractants were assigned randomly so that each quadrat had at least one of each site type. We tested three scent lures in succession. As the study progressed, the lack of cougar response to Pikauba® then Canine Call® prompted us to try beaver (*Castor canadensis*) castoreum. We applied the lure to a scratch pad that consisted of a board (14 cm x 14 cm), cotton batting or a carpet swatch, and a piece of metal altered to snag hair (a design similar to that conceived by J. Weaver [Turbak 1998]) (Fig. 1). Scratch pads were nailed to a tree at an average height of 55 cm. We used a predator call with a distressed fawn sound set to play a five second recording with a 30 second interval as the auditory attractant (Wasatch Wildlife Product® FurFindR®). These calls were equipped with light sensors rendering them dormant during daylight hours. The calls were initially secured to a tree in plain view at a height of ~2.5 m but after the first sampling period, the calls were lowered to ground level and concealed in brush or rocks. We also tried a scratch pad with catnip (*Nepeta cataria*) and a visual lure (aluminum pie pan or compact disc) at each site but discontinued their use after the first sampling period due to a lack of cougar response. Finally, we added a small piece of mule deer meat to all sites as a consistent component since one hair-snaring device required bait.

In addition to the scratch pads, we tried two other hair-snaring techniques. First, we tested a device described as a metal mesh cube (25 cm edge) open on one end with a 0.1 – 0.2 kg piece of meat wired in the back (Fig. 2). To snag hair, we attached a 20 cm spring and a 13 cm barrel cleaning brush. The snares were secured to trees and the height was altered relative to cougar response (0 – 95 cm). Second, we constructed stick cubbies to conceal the predator call hidden in the back (Fig. 3). In the entry way, we placed one or more of the following: two or four pronged barbed wire, a cable with a roller (15 cm long ¾"PVC pipe) coated with a sticky substance (Tree Tanglefoot®), or a barrel cleaning brush and varied the height based on cougar response. At the end of the study, the average height of the wire and roller was ~ 28 cm. To further entice a cougar to enter the cubby, we added a 0.1 – 0.2 kg piece of meat and suspended a feather inside the cubby. Finally, we documented cougar activity through photographic evidence obtained via infrared motion-sensor cameras (Reconyx® PC85 Rapidfire® or PC800 Hyperfire®) programmed to take five photos in rapid succession when triggered. All sites were checked weekly and as necessary, hair samples were collected, baits and scents were replenished, and new batteries were placed in cameras and calls.

Hair samples were collected via a strict protocol that included using sterile tweezers to remove the hair. We considered the hair on each barrel brush, roller, or individual barb a discrete sample (Poole et al. 2001, Dreher et al. 2007) and placed the hair from each in a separate paper envelope. The barbs and brushes were re-sterilized by fire (Kendall et al. 2008, Settlage et al. 2008), contaminated rollers were replaced, and tweezers were cleaned with bleach water. The hair was stored with a desiccant at room temperature until the samples were processed (Taberlet and Luikart 1999).

We are currently processing the samples at the USGS Fort Collins Science Center, FORT Molecular Ecology Lab. When possible, we are extracting DNA from > 15 hairs using Qiagen DNeasy® Tissue Kits (Qiagen Inc., Valencia, CA). We are amplifying the DNA by polymerase chain reaction (PCR) using a M13-tailed forward primer as described by Boutin-Ganache et al. (2001). We are genotyping each sample using 10 microsatellite primers shown to have high variability in cougars (Ernest et al. 2000, Sinclair et al. 2001, Anderson et al. 2004) and analyzing each loci via GeneMapper®. We are assessing genotyping error by comparing genotypes of blood and tissue samples previously collected by CPW with those of hair samples. DNA from blood and tissue samples were first extracted by personnel at the CPW Foothills Wildlife Research Facility then genotyped using the same microsatellite loci at the USGS lab.

Detections (site visits) were counted as per cougar per night and confirmed with photos. An individual marked cougar that returned multiple times within a single night (dusk till dawn) was counted as one detection. In addition, we assumed that an unmarked cougar documented multiple times within the same night was the same animal and its activity was tallied as one detection. We considered females with dependent kittens as a single detection but adults traveling together were counted separately. We programmed the time lapse on each camera to take a photo at 00:00 and 12:00. We assumed the camera was functioning properly if our activity triggered the camera and if the time lapse photos were present. If a cougar visited the site, it would be photographed unless it visited the site from the opposite side and never entered or exited through the entryway. Because undocumented visits were possible, the total detection count was conservative.

We used photographs to verify the most effective lure and snare combination by quantifying the number of times the appropriate response was observed. Specifically, the cougar had to respond to the attractant in a manner such that a sample could have been acquired. For example, the beaver castoreum may have attracted a cougar to the site but if the individual was not motivated to rub against the scratch pad, the combination ultimately was ineffective. Likewise if the cougar did not enter the cubby or did not attempt to take the bait, the hair-snaring devices associated with each method were futile. Finally, assessing cougar response to each combination revealed possible incidental detections (i.e., the cougar was not attracted to the site but appeared to coincidentally walk past the camera).

Results

We observed 57 detections by 14 independent marked adults, an unknown number of unmarked cougars, and one known sibling group. Marked adults accounted for 34 of the 57 detections, unmarked cougars comprised 21 detections, and the known sibling group visited twice. We documented five detections at sites with just bait, 12 at sites with bait and a scent, 15 at sites with bait and a call, and 25 at sites with all three components (Table 1). Detections did not occur at all sites but were observed at 24% of sites with bait, 28% of sites scent, 50% of sites with calls, and 59% of sites with all three. Likewise, the sites did not detect an equal number of unique, marked animals. Of the 14 known adults, two were detected at sites with bait, three were documented at sites with scent, seven were photographed at sites with calls, and nine visited sites with all three.

We used photos to observe a cougar's response to the various lure-snare combinations. Of the 37 detections at sites with the scent, a cougar rubbed the scratch pad only twice. Of the detections at sites with just bait, a cougar attempted to get the bait during three of the five site visits. Cougar response to calls could only be verified once the sites had evolved to hide the call in a cubby, which occurred after the first sampling period. Of the 23 detections (that occurred after period one), a cougar responded to the call by entering the cubby 16 times.

The hair snaring technique was modified many times throughout the study. We did not obtain hair from the metal-cube snare as cougars showed little interest in the bait wired in the back. We did however obtain hair on the two occasions when a cougar rubbed against the scratch pad with beaver castoreum. In addition, we obtained a hair sample 14 of the 16 occasions a cougar passed by the snaring devices to enter the cubby. The hair samples are currently being processed.

Discussion

The optimal sampling technique to both attract a cougar to a site and obtain a genetic sample proved to be concealing an auditory call within a stick cubby. A four-pronged strand of barbed wire and a cable with a sticky roller most effectively snagged hair (Fig. 4). This technique required three responses: that the cougar be attracted to the site, that it enter the cubby through the entry way preferably passing under the wires, and that the hair-snaring mechanisms trapped hair. We established 24 sites with calls hidden in cubbies and recorded 23 site visits. Once at the site, the cougar did not always enter the cubby (16/23). However when the cougar did enter, we almost always obtained a hair sample (14/16).

Photographs also suggest a greater interest in calls than scents. During the first sampling period, the calls were secured higher in a tree to broadcast the sound further. Photos documented cougars looking up towards the calls and/or attempting to climb the tree. On several occasions, photos showed cougars playing with or carrying away the calls. Sites with calls also attracted more individual animals. Thirteen of the 14 marked animals were detected at sites with calls. In contrast, photos provided little support for cougar interest in scents. Many scratch pads seemed to be ignored during a cougar visit. In addition, we only recorded the cheek rubbing response characteristic of felids (Reiger 1979) on two occasions during the 37 site visits at sites where a scratch pad was present.

Despite the lack of photographic evidence, we cannot ignore the possible effect of adding a scent. We documented more site visits at sites with both scents and calls (25) than at sites with only a scent (12) or only a call (15). We tested three scents. We chose Pikauba® due to its positive effects on lynx (G. Merrill personal communication) but despite several cougar visits, we did not observe a rubbing response. Next, we tested Canine Call® (K. Crooks personal communication) but again, no rubbing response was observed. We then chose beaver castoreum (K. Logan & L. Sweanor personal communication). Both rubbing responses that we observed were in response to scratch pads with the castoreum. We suggest that including a scratch pad with beaver castoreum at each site adds little expense and effort but could yield more detections and possibly a few more hair samples.

Besides scents and calls, we included bait at each site and we acknowledge the possible confounding effect this may have had. Because baiting with ungulate carcasses has been used with success in capture efforts (M. Alldredge unpublished data), we knew that cougars were attracted to carrion. We designed a hair-snaring device that required bait but limited the size of the bait to 0.1 – 0.2 kg. During the first sampling period, we tested this mechanism at every site but our observations indicated that cougars did not elicit the response necessary to obtain a hair sample. In subsequent sampling periods, we discontinued testing this device but chose to use bait in a different way. We added bait to the cubbies each week to further entice the cougar to enter. The bait was accessible and it was often scavenged by non-target animals like foxes or squirrels but we hoped the natural deer scent would remain in the leaf litter. To maintain consistency, a small piece of fresh bait was also placed near scratch pads. It too was often scavenged. We continued placing sites with just bait to serve as a control to address any confounding effect. Bait probably contributed to attracting a cougar as we observed five detections at sites with just bait but adding a scent and/or a call yielded more site visits. Also, we were not able to obtain hair samples at sites with just bait.

We incorporated randomization into our study design when possible but many things were considered when selecting the exact site location. The 4 km^2 grid cell was randomly chosen but we were obliged to abide by restrictions stated in our permits such as raptor nesting closures and chose to avoid residential areas and highways. Attracting large carnivores to neighborhoods or causing traffic related deaths was not desirable. After considering the topography of the rest of the grid cell, we chose areas where animals might naturally move but also complimented our attractants. For example, we might choose to put a site with just a scented scratch pad along a canyon rim or along the bottom of a drainage. However, we might place a site with a call high up on a hillside so that it would broadcast into the drainage and to the other side. Thus in theory, any cougar moving along that drainage had the potential to be detected even if it passed through several private parcels to get to the site. Furthermore, applying prior knowledge of animal movements such as placing the sites along known travel routes or at scrape sites can increase the probability of obtaining a sample (Schmidt and Kowalczyk 2006, Ruell and Crooks 2007, Reppucci et al. 2011). We chose not to use the previous movements of the GPS-collared animals to test if this noninvasive-sampling technique could be applied in an area where there were no existing data for the resident cougars.

Despite the many trials and tribulations of investigating noninvasive-sampling methods, our data suggest that predator calls used with a cubby-snare design have the potential to be a consistent and reliable method to sample an unknown population of cougars. We observed cougars of varying ages, males, females, and females with kittens. The effort required to conduct this study was dictated by the battery life of the cameras and calls and by the necessity of collecting the hair sample before it was contaminated with hair from another cougar. We monitored the sites once a week which was adequate to maintain functional electronics but a more frequent schedule might have yielded fewer contaminated samples. This study was also conducted in the winter to avoid the potential negative influence of bears but snow further limited access and increased the time necessary for us to navigate to the sites. Also, heavy snow events buried the cubbies filling in the entry way and muffling the calls.

Management Implications

The trend in sampling animals is to move away from capture and handling and towards a more noninvasive-sampling method thus reducing the financial burden to managing agencies and minimizing stress and disturbance to the study animals. Noninvasive sampling via lure sites has other advantages in that, in theory, they can be distributed about the study area incorporating the random component necessary to reduce bias in study design. Historically, inconsistent responses to the attractants (usually scents) have required the sites be placed along known travel routes for cougars to be detected. We have found that randomization in site placement can be incorporated when using an auditory call with a cubby and that these sites will sample many different individuals throughout the population despite the elusive nature and large home-range sizes typical of cougars.

Randomization is critical to obtaining an unbiased estimate of population size and population estimation is often a top priority of managing agencies. Population estimates influence harvest quotas, guide management practices, and aid in understanding the dynamics of predator-prey systems. In wildlife studies, mark-recapture methods are commonly used to generate population estimates by considering the capture histories for each individual over two or more occasions. Since cougars will visit the call sites multiple times, a capture history can be determined and subsequently be used to yield a population estimate.

Capture histories require the tracking of genotypes obtained when the DNA in the hair is processed but hair can yield more than just a unique identification. Hair can provide dietary information by comparing the stable isotopes within it to those that comprise potential food sources (Hopkins et al. 2012). In addition, age can be determined by evaluating the telomere length of the DNA (Pauli et al. 2011). Laboratory techniques will continue to progress but without first obtaining the hair sample, these advancements are futile.

Table 1. This table summarizes the 68 lure sites and includes the number of each site established, the average period each site was active, the total number of survey days, the total number of detections, the number of sites with detections, the percentage of sites with detections, and the number of different marked cougars that were detected at each site type (*several cougars were detected at multiple site types).

	No. of sites	Avg. days active	Total days active	Total No. of detections	No. of sites w/ detections	% of sites w/ detections	No. of different marked cougars
Bait only	17	31.6	538	5	4	0.24	2
Bait & scent	18	33.3	600	12	5	0.28	3
Bait & call	16	29.0	464	15	8	0.50	7
Bait, scent, & call	17	32.2	547	25	10	0.59	9
Totals or Averages	68	31.6	2149	57	27	0.40	14*

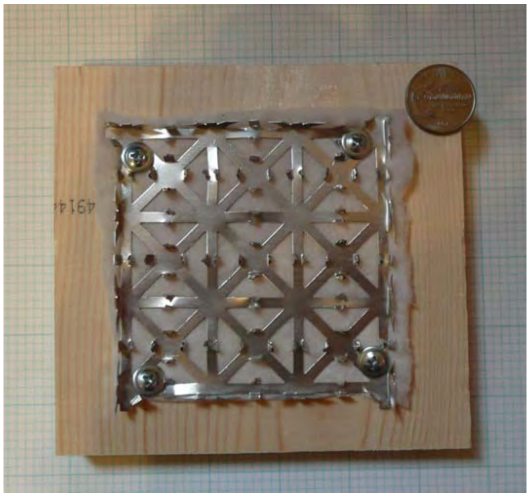

Figure 1. Catnip, Pikauba®, Canine Call®, or beaver castoreum was applied to each scratch pad.

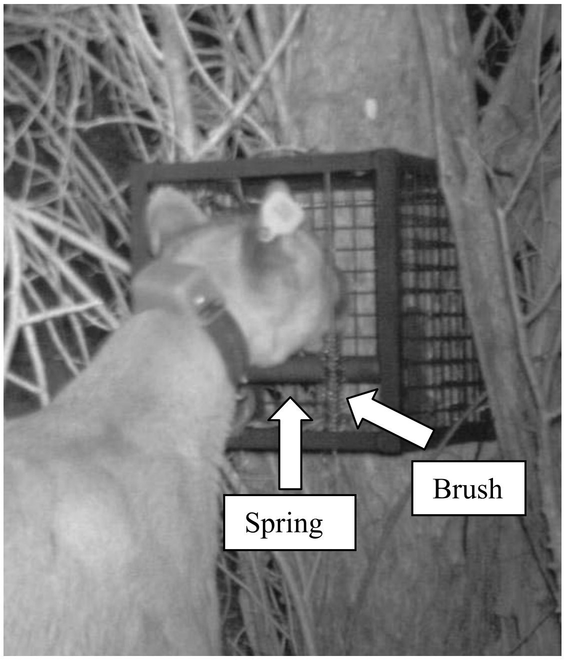

Figure 2. Bait was wired in the back corner. In attempting to obtain the bait, the cougar would flex the spring catching hair and contact the barrel brush.

Figure 3. Stick cubbies were constructed to conceal the auditory call secured in the back. Hair-snaring devices, such as barbed wire, barrel brushes, and/or a cable with a sticky coated roller, were stretched across the entry way. A feather was suspended in the cubby and a small piece of bait was added each week.

Figure 4. A four-pronged strand of barbed wire and a cable with one or more rollers coated with Tree Tanglefoot® most effectively snagged hair. The final height of the wires was approximately 28 cm.

Chapter 2. Imperfect detection and a noninvasive hair-snaring technique

In wildlife studies, the probability of detecting (p) an animal is usually less than certain (<1) (Link 2003). Within a survey, all the reasons for this may not be known. p may be consistent across the population or it can vary by: site, individual animal, or attributes like age and sex. Unequal detection must either be incorporated into the analytical approach or eliminated through study design. Equal detection is probably not the case with cougars on the Front Range. Trap response (a positive or negative behavioral response to the trapping event) is one potential source of variation (Pollock et al. 1990). For example after the first few visits, it is possible that a cougar will lose interest in a site upon discovering that the distressed fawn call and deer scent is not a real animal. This 'trap shy' response can create positive bias in a population estimate (Williams et al. 2002). Mowat and Strobeck (2000) recommended reducing capture disparity by moving the sites throughout the field season. Moving the sites to new locations may also keep the sites novel and continue to provoke curiosity. Furthermore, selecting new locations is likely to accommodate the activity patterns of more animals increasing the likelihood that all individuals will come in contact with the sites and reducing animal-specific heterogeneity (Boulanger et al. 2006).

We tested various attractants and hair-snaring mechanisms and found the most effective combination to be an auditory predator call concealed within a stick cubby with barbed wire and a sticky roller to snag hair (the methods and results are detailed in chapter 1 of this report). We established lure sites with cubbies and predator calls in two study areas and used previously captured and GPS collared cougars to estimate the probability of detecting a cougar given its availability in the study area and to each site. Colorado Parks and Wildlife currently has two active cougar studies where cougars are captured and marked: the Front Range Cougar Research Project led by M. Alldredge and the Uncompagre Plateau Puma Project led by K. Logan. GPS and VHF location data as well as blood and tissue samples were collected via the efforts of personnel for each project. These location data were used to determine availability and the blood and tissue samples were genotyped and will be compared to the genotypes of hair samples we collected noninvasively. We have completed the field component of this study and are currently conducting the analysis and processing the hair samples that we collected.

Study Area

We sampled cougars in two study areas in Colorado, USA, one on the Front Range and one on the Uncompagre Plateau. The 1,270 km² study area on the Front Range was located in Boulder, Jefferson, and Gilpin counties. This area was bordered to the east by Highways 36 and 93, to the west by the Peak to Peak Hwy, to the north by the Boulder county line, and to the south by Interstate 70. Though interspersed with private parcels, much of this land was public and managed by Boulder City, Boulder County, Jefferson County, Colorado Parks and Wildlife, the Bureau of Land Mangement (BLM), and the US Forest Service (USFS). The lure sites on the Front Range spanned in elevation from 1,690 to 2,868 m. The average monthly precipitation during the study was 25.4 mm and the average monthly temperature was -0.2 °C using climate data collected at 29 National Oceanic and Atmospheric Administration (NOAA) weather stations in or near the study area. The dominant canopy species included ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), Rocky Mountain juniper (*Juniperus scopulorum*). The understory vegetation included mountain mahogany (*Cercocarpus*), three-leaf sumac (*Rhus trilobata*), bitterbrush (*Purshia tridentata*), Gambel's oak (*Quercus gambelii*), and serviceberry (*Amelanchier alnifolia*). Besides cougars, we observed other medium to large-bodied mammals in the region such as elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), black bears (*Ursus americanus*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), bobcats (*Lynx rufus*), ring-tailed cats (*Bassariscus astutus*), an American marten (*Martes Americana*) and on occasion, unleashed domestic dogs (*Canis lupus familiaris*).

The 536 km² study area on the Uncompagre Plateau was located west of the city of Montrose in Montrose and Ouray Counties. Exact boundaries were determined by historical deer and elk winter range data (CPW unpublished data) and location data for resident cougars (K. Logan unpublished data). The sites ranged in elevation from 1,704 m to 2,479 m. The average monthly precipitation during the study was 22.3 mm and the average monthly temperature was -1.3 °C using data collected at six NOAA weather stations in or near the study area. The vegetation was predominantly pinyon-juniper woodlands with Gambel's oak, serviceberry, and mountain mahogany understory and some mix of ponderosa pine at higher elevations and sagebrush (*Artemisia tridentata*) at lower elevations. This area is comprised largely of public lands managed by the BLM or the USFS. Similar to the Front Range, we observed other mammals such as elk, mule deer, coyotes, red foxes, bobcats, ring-tailed cats, and domestic dogs.

Methods

From November, 2012 to April, 2013, we placed lures and hair snares across both study areas. In total, we established 148 sites. Each site was active an average of 28.5 days (ranging from 20 – 36 days) for a total of 4,214 sampling nights. Specifically on the Front Range, we sampled cougars over four sampling periods, where the sites were active an average of 28.4, 29.9, 27.7, and 28.1 days respectively for a total of 2,679 sampling nights. On the Uncompagre Plateau, we sampled cougars over three sampling periods where the sites were active an average of 29.8, 29.0, and 26.4 days respectively for a total of 1,535 sampling nights.

Site placement varied by study area. In general, we selected site locations by first overlaying a grid with 4 km² cells. On the Front Range, grid cells were randomly selected without replacement using the spatially balanced points function in ArcGIS® 10.0 in accordance with a stratified sampling design which partitioned the study area north to south along an altitudinal gradient. Colorado Parks and Wildlife (CPW) monitors a higher density of collared animals in the eastern half of this area so we concentrated most of our effort in the lower strata. We established 15 – 19 sites in the eastern strata and six sites in the western strata per sampling period (n = 94). On the Uncompagre Plateau, we did not stratify the study area but simply applied the same spatially balanced points function in ArcGIS® 10.0 to select 18 sites per sampling period (n = 54). In both study areas, we selected the exact site location to inhabit specific landscape features (canyon rims, canyon bottoms, ridgelines, saddles, drainages, canopy cover, and tree line edges) to comply with research permit restrictions like raptor nesting closures, and to avoid areas with human activity. In general, we avoided residential areas and highways to evade negative human interactions and traffic related mortality to the cougars. Access limitations due to winter snow conditions also influenced site placement.

The site components were consistent in both regions. We applied the technique found to be most effective in Chapter 1 of this report. This method utilized auditory predator calls (Wasatch Wildlife Product® FurFindR®) with a distressed fawn sound set to play a five second recording with a 30 second interval at night only. The calls were concealed within a stick cubby and snaring devices were placed in the entry way. As the season progressed, modifications were made to the snaring technique based on cougar responses. In general, the sites included a four-pronged strand of barbed wire and a cable with a roller (15 cm long 3/4"PVC pipe) coated with a sticky substance (Tree Tanglefoot®) stretched at an average height of ~ 28 cm. To further entice a cougar to enter the cubby, we added a 0.1 – 0.2 kg piece of deer meat and suspended a feather. In addition, we added a scratch pad hair snare similar to that devised by J. Weaver (Turbak 1998) with beaver (*Castor canadensis*) castoreum at select sites. We documented cougar activity through photographic evidence obtained via infrared motion-sensor cameras (Reconyx® PC85 Rapidfire® or PC800 Hyperfire®) programmed to take five photos in rapid succession when triggered. All sites were checked on average every seven days and as necessary, hair samples were collected, baits and scents were replenished, and new batteries were placed in cameras and calls.

To minimize the possibility of sample contamination and degradation, we conformed to the same protocols for sample collection outlined in Chapter 1. We removed hair using sterile tweezers and re-sterilized the barbs by fire (Kendall et al. 2008, Settlage et al. 2008). Contaminated rollers were replaced. We considered hair on a single barb as one sample and placed each in a separate paper envelope. Paper envelopes were then put in a plastic bag with a desiccant and stored at room temperature (Taberlet and Luikart 1999).

Hair samples are currently being processed at the USGS Fort Collins Science Center, FORT Molecular Ecology Lab. Taberlet et al. (1996) suggested that to achieve a correct genotype at a 99%

confidence level, 8 U template DNA is needed (1 U is equivalent to the DNA content of 1 diploid cell). Therefore when possible, we are extracting DNA from ≥ 10 hairs (Goossens et al. 1998, Boersen et al. 2003) using Qiagen DNeasy® Tissue Kits (Qiagen Inc., Valencia, CA). Samples are being genotyped using 10 microsatellite primers shown to have high variability in cougars (Ernest et al. 2000, Sinclair et al. 2001, Anderson et al. 2004). We are amplifying the DNA by polymerase chain reaction (PCR) using a M13-tailed forward primer as described by Boutin-Ganache et al. (2001) and analyzing each loci via GeneMapper®. To assess error, we are comparing the results with archived blood and tissue samples collected by CPW during capture. If possible, we will re-process hair samples shown to contain error at ≥ 1 allele.

We will assess imperfect detection and estimate study-wide and site-specific detection probabilities (p) using the location information for cougars previously captured and equipped with GPS collars. To estimate p, a total count of available animals (A) is needed. An individual's availability must first be appropriately defined for the estimate to be unbiased. We will base availability on GPS locations located within the study area or within a circular buffer zone around a site. The radial distance of the buffer will be determined by collar error due to fix rates and the incidence missed fixes and will be specific to each study area. It will not be possible to know an animal's exact location at all times resulting in potential error in determining availability. For example, if an individual was not detected but spent time in the study area or passed within the buffered region without recording a fix, the availability value would be low resulting in a high p estimate. Positive bias would also result if the same individual was detected but never considered available. This can be troublesome as a positively biased estimate for p applied in population estimation will result in a negatively-biased abundance estimation. We will determine the distance the collar error becomes negligible by increasing the buffer zone until all animals detected can also be considered available. For animals not detected, we will connect successive locations with a straight line. If this line passes through any part of the study area or buffer zone, we will count the animal as available.

On the Uncompagre Plateau, the collars were programmed to record a location twice daily, 07:00 and 19:00 but the incidence of missed fixes was high for some collars. We observed the average success rate for the ten deployed GPS collars to be 69% (range 38% – 89%). When considering availability study wide, we determined a cougar was available if it recorded a location at least once that day within the study area boundary. But on average, collars failed to record both daily GPS data points 13% of the time (range 0% – 34%). To address the gaps in the location data, we assumed availability based on the location of the individual prior to and after the missing data. For example, if the cougar was clearly in the study area the day before and the day after the void, it was considered available all days.

Cougar availability was also considered relative to each site. We cannot be certain of the exact travel route between two GPS data points so we assumed all movement between points to be linear. Cougars can also move a great distance in a short amount of time. In addition, the closest recorded location was often far from the detection site due to a programmed fix rate of twice daily and a high probability of missing fixes. In order to make sure all cougars detected could be considered available via location data, we established a buffer with a 4 km radius around each site. As a result, there was much overlap between buffers of adjacent sites. This meant a cougar could be available to be detected at multiple sites from a single location. A cougar was considered available if it recorded a location at least once a day within the buffer zone. We accounted for missing data in the same manner as described above.

Two cougars were individually marked and fitted with collars equipped with VHF. Their locations were estimated aerially throughout the season and found to be in the study area at least part of the time. Though one of these individuals was detected three times, these cougars were not used in the detection probability analysis as they had too few data points to determine availability.

We will consider the availability of cougars on the Front Range in a similar manner, study wide and site specific. Here, the GPS collars are programmed to record seven data points per day (1:00, 4:00, 7:00, 11:00, 15:00, 19:00, and 22:00). The incidence of missed data points will be considered when establishing an appropriate buffer radius.

We will use the available animals (A) and the number detected (n) to estimate the detection probability (p) for each site (*i)* via the simple binomial model,

$$\hat{p}_i = \frac{n_i}{A_i}$$

(Williams et al. 2002). This model is bound by 2 assumptions: the fate of all cougars is known and each detection is an independent event (Williams et al. 2002). We met these assumptions as GPS collars allowed us to know the locations and fates of the study animals and sites were placed such that one site should not have influenced the activity at another.

We will estimate the average p for all sites in each study area, where *x* is the number of sites (94 or 54),

$$\hat{\bar{p}} = \frac{\sum_{i=1}^{x} \hat{p}_i}{x}$$

(Thompson 2002) and the sampling variance per site,

$$\hat{var}\,(\hat{p}_i) = \frac{\hat{p}_i(1 - \hat{p}_i)}{A_i}$$

(Williams et al. 2002).

The variance across all sites will be estimated using a variance components approach. Total variance [$\hat{var}\,(\hat{p})$] is comprised of two components: process variation ($var\,(p_i) = \sigma^2$) and sampling variation [$var\,(\hat{p}_i|p_i)$] (Burnham and White 2002). Sampling variation is the variation associated with the sampling and estimation procedure. Our variance estimate will consider process variation only and be derived by subtracting the estimated average of the sampling variances across all sites from the total variance.

$$\sigma^2 = \hat{var}\,(\hat{p}) - E[var\,(\hat{p}_i|p_i)]$$

(Gould and Nichols 1998),

where

$$\hat{var}\,(\hat{p}) = \frac{\sum_{i=1}^{x}(\hat{p}_i - \hat{\bar{p}})^2}{(x - 1)}$$

(Link and Nichols 1994),

and

$$E[var\,(\hat{p}_i \mid p_i)] = \frac{\sum_{i=1}^{x}\left(\frac{\hat{p}_i(1 - \hat{p}_i)}{A_i}\right)}{x}$$

(Williams et al. 2002).

Confidence intervals at an alpha level of 0.05 will be constructed using a test-statistic from the student's *t* distribution with degrees of freedom 60 > 120 (1.99) (Ott and Longnecker 2010) and the standard deviation ($\sqrt{\sigma^2}$) obtained by subtracting the sampling variation,

$$\hat{\bar{p}} \pm (1.99) \times \hat{SD}(p)$$

(Williams et al. 2002).

Initial Results

We are currently conducting the analysis and processing the hair samples but we do have some preliminary results.

Front Range

We observed 98 detections by 14 independent marked cougars, two sibling groups, and an unknown number of unmarked animals. Independent marked adults accounted for 38 of the 98 detections, the sibling groups were detected three times, and the unmarked cougars comprised the remaining 57 detections (Table 1). Many of the independent, marked adults were observed multiple times. Two cougars were detected five times, two were detected four times, five were counted three times, no cougar was observed twice, and five were observed once. Also, four of the independent adults observed were females with kittens. The probability of a cougar entering the site given that it was detected was higher for unmarked animals than for marked individuals (0.860 > 0.605). The probability of obtaining a sample was approximately the same for both marked and unmarked cougars given that the animal entered the site. The number of detections was similar for the first, second, and third sampling periods (27, 30, and 25) but declined during the fourth sampling period (16) (Table 2). The probability of a cougar entering the site given that it was detected was similar during all sampling periods. We collected 52 hair samples though eleven samples may have included hair from multiple cougars as more than one cougar visited and entered the site over the seven day period between our site checks. After period one, we modified the hair-snaring technique. As a result, the probability of obtaining a sample given that the cougar entered the site approximately doubled for the remainder of the study.

Uncompagre Plateau

We observed 18 detections by seven uniquely marked cougars (Table 3) and no unmarked cougars. Many of the cougars were observed multiple times. One cougar was detected for each of three, four, and five occasions. Two cougars were detected twice and two were observed once. Eleven marked cougars used the study area but no cougar was in it the entire time. The time spent ranged from 2 – 98 days (out of a possible 102 days). The four cougars not detected were available ≤ 18 days (range 2 – 18). Those detected were available ≥ 31 days (range 31 – 98) which translates to being in the study area ≥ 30% of the duration of the study. The probability of detecting a marked cougar during the study given that it used the study area at least part of the time was 0.64 and on average we detected 1.25 unique individuals per week. This summary includes the two cougars harvested within the first few weeks of the study and the five cougars fitted with GPS collars mid-study. Detections were observed during all three sampling periods and seven hair samples were collected (Table 4). Availability was also considered relative to each site but the 4 km buffer needed to accommodate the fix schedule and error rate resulted in an extremely large area around each site with much overlap between sites and was too large to be informative. But it should be noted that no cougar recorded a data point within 4 km of 15 of the 54 sites.

Table 1. This table compares the Front Range detections of previously marked to unmarked cougars. *One sample could have hair of both a marked and an unmarked cougar as several samples could have hair from multiple cougars. The prevalence of this was dependent upon how often the sites were checked and samples were collected.

	No. of Detect.	No. of Enter	Enter/ Detect	No. of Samples	Samples/ Enter
Marked	38	23	0.605	21	0.913
Sibling Group	3	2	0.667	2	1.000
Unmarked	57	49	0.860	40	0.816
Tot/Avg.	98	74	0.755	*52	*0.703

Table 2. This table summarizes the Front Range site detections per sampling period and includes the number of detections, the number of times the cougar entered the site, and the number of samples obtained. The table also includes the probability of a cougar entering the site given that it was detected and the probability of obtaining a sample given that it entered the site. The hair-snaring technique was modified after the first sampling period. *The average does not include the first sampling period.

	No. of Detect.	No. of Enter	Enter/ Detect	No. of Samples	Samples/ Enter
Period 1	27	20	0.741	8	0.400
Period 2	30	23	0.767	19	0.826
Period 3	25	20	0.800	16	0.800
Period 4	16	11	0.688	9	0.818
Tot/Avg.	98	74	0.755	52	*0.815

Table 3. This table summarizes cougar availability on the Uncompagre Plateau including the number of days each cougar was in the study area (days available), total number of detections per cougar, and the proportion of time spent in the study area per sampling period (1,2, & 3) and total (T). Bold, italicized values indicate the cougar was detected at least once during that time period. *M180 was not equipped with a GPS collar thus availability could not be determined.

Cougar ID	Days available	No. of detections.	Avail (1)	Avail (2)	Avail (3)	Avail (T)
F95	8	0	0.00	0.00	0.25	0.08
F96	60	1	***0.66***	0.14	1.00	***0.59***
F111	98	2	***0.89***	1.00	***1.00***	***0.96***
F129	31	2	0.00	***0.31***	***0.63***	***0.30***
F137	92	4	***0.89***	***1.00***	***0.81***	***0.90***
F152	10	0	0.29	0.00	0.00	0.10
F171	69	1	0.83	***0.83***	0.34	***0.68***
F181	58	5	0.00	***1.00***	0.72	***0.57***
M179	18	0	0.51	0.00	0.00	0.18
M183	2	0	0.00	0.00	0.06	0.02
*M180	Unk	3	***Unk***	***Unk***	Unk	***Unk***

Table 4. This table summarizes the Uncompagre site detections per sampling period and includes the number of detections, the number of times the cougar entered the site, and the number of samples obtained. The table also includes the probability of a cougar entering the site given that it was detected and the probability of obtaining a sample if it entered the site.

	No. of Detect.	No. of Enter	Enter/ Detect	No. of Samples	Samples/ Enter
Period 1	6	3	0.500	2	0.667
Period 2	9	7	0.778	5	0.714
Period 3	3	0	0.000	0	0.000
Tot/Avg.	18	10	0.556	7	0.700

Chapter 3. Investigating potential sources of variation in detection at lure sites

Mark-resight methods are commonly used to estimate abundance in wildlife studies. Populations are estimated using data obtained over two or more occasions via one or more sampling procedures. For example, animals may be initially counted and marked when physically captured and subsequently counted when detected at a lure site. The Lincoln-Peterson estimator is a simple, two-period, closed mark-recapture model, used to estimate abundance (N) by the relationship:

$$\frac{m_2}{n_2} = \frac{n_1}{\hat{N}}$$

where m_1 individuals are marked at occasion one and released and n_2 individuals are counted on occasion two with m_2 marked animals (Williams et al. 2002). But assumptions like closure and equal probability of capture restrict the use of the Lincoln-Peterson estimator (Williams et al. 2002).

Closed mark-recapture models maintain 4 primary assumptions (Otis et al. 1978). The first assumption of geographic and demographic closure (no immigration, emigration, births or deaths) is of fundamental importance in the analysis of mark-recapture data under closed models (Stanley and Burnham 1998). This assumption is likely to be violated in most field applications (Kendall 1999). Consequently, complex models have been developed to test for closure violations (Stanley and Burnham 1998) and to estimate the parameters responsible (Kendall 1999).

No tag loss and accurate individual identification are also assumptions of closed mark-recapture models (Otis et al. 1978). Survey design and sample processing methods influence the degree to which these assumptions are violated. For example, it is highly unlikely that a cougar with two ear tags and a GPS collar will lose all three identifiers. But when sampling hair, misidentification through genotyping error is possible, potentially biasing population estimates. False genotypes result in population over-estimation and multiple individuals assigned the same genotype produce under-estimates (Lukacs and Burnham, 2005). These assumptions are less likely to be violated when potential sources of tag loss are remedied during initial planning and strict sample collection and laboratory protocols are followed.

We are most interested in the fourth assumption, equal capture or detection. The factors that influence an animal's response to a sampling procedure are often not homogenous throughout the population thus violating the assumption. Models can accommodate some variation by grouping attributes with similar values, for example, separating males and females because females are detected at a higher rate than males. Otis et al. (1978) considered other sources of capture variation and presented three models (and all combinations thereof). Model M_t considers variation between sampling occasions. The second primary model, M_b, accommodates a behavioral change due to trap response, 'trap happy' or 'trap shy'. Failure to consider capture variation due to a behavioral response can lead to biased population estimates where a 'trap happy' response can negatively bias estimates and a 'trap shy' response will create positive bias (Williams et al. 2002). Finally, model M_h assumes heterogeneity amongst individuals. Unmodeled heterogeneity may overstate precision and include bias (Link 2003).

Accounting for individual heterogeneity has long plagued researchers (Link 2003) but some estimation procedures seem to be robust. Burnham and Overton (1978) describe a jackknife estimator that can provide some robustness in population estimation where heterogeneity in capture probabilities is present. However, because the jackknife estimator is not a maximum likelihood estimator, the sources of variation cannot be evaluated by comparing models using likelihood ratio tests or through model selection criteria (Akaike's Information Criterion, AIC) (Williams et al. 2002). Pledger (2000) fit finite mixture models in addressing capture heterogeneity by maximum likelihood, thus allowing for model comparisons. Finite mixture theory groups individuals into two or more mixtures and considers the probability that an individual is in one mixture (π) and the probability that an individual is in the other mixture ($1-\pi$), though it is not possible to discern to which group an individual belongs. Huggins (1989) described a maximum likelihood approach that will accommodate individual capture covariates when deriving the abundance parameter. Sources of heterogeneity modeled as covariates can then be evaluated through likelihood ratio tests and model selection criteria. Huggins (1989) suggested that the asymptotic properties of his estimators were normal in large sample sizes. However, in the case of small samples, which are common in most wildlife studies, his simulations showed a skewed distribution. In response, he described a conditional bootstrap method that can be applied to overcome problems of nonnormality thus producing reasonable confidence interval estimations.

Much is already known about cougar behavior to suggest that capture variation is possible and likely (C. Anderson personal communication). Resident adult home-range sizes vary between season (Seidensticker et al. 1973), sex (Dickson and Beier 2002, Anderson et al. 2004), and female reproductive status (Hornocker 1969). Males generally occupy larger areas than females (Anderson et al. 2004), but female home-range sizes are more variable (Hornocker 1969). Movements differ among behaviors such as hunting, feeding, and mating (Beier et al. 1995). Scrapes suggest a pattern in how cougars travel (Hornocker 1969) indicating that cougars do not occupy all parts of their home ranges equally. In addition, females with small kittens will be less mobile and confined to a smaller area (Seidensticker et al. 1973). Activity also varies relative to time of day, peaking in the evening hours (Sweanor et al. 2008). Finally, transients create another dynamic in the population that must be considered (Lindzey et al. 1994).

From November, 2012 – April, 2013, we used attractants and hair-snaring mechanisms to survey a population of cougars. Based on the limited success described in past studies, we anticipated few, if any, detections. However, we observed 115 site visits including multiple detections of the same individuals making this an ideal opportunity to explore possible sources of capture variation.

We will consider several variables relative to each detection (Fig. 1). Many cougars were previously captured by CPW and at the time of capture, age, sex, and if possible, reproductive status (with kittens or without) were noted. Photographic evidence at the sites also aided in determining the reproductive condition of females. Using photos, we logged the time of the detection (day, dusk, night, or dawn) and the presence of multiple adult cougars. We also considered general site specific aspects (ridgeline, drainage, or saddle). Finally, we assigned a behavior to each animal found to be available (feeding, traveling, mating, or denning) via GPS location data.

The sources of variation will dictate which analytical procedure to apply and greatly influence future sampling designs. For instance, we would expect a relatively small sample size when surveying cougars and acknowledge the potential to have a large quantity of factors that may contribute to capture variation. In this case, the Huggins model, which considers relationships as covariate and applies a bootstrap procedure, may be an appropriate estimator. But if we find that detection is equal across the population, the Lincoln-Peterson estimator may be adequate, given that the other assumptions are satisfied.

At this time, it is not our intention to estimate the population size. Our efforts are simply to explore possible sources of capture variation. Therefore, we reserve the possibility of investigating additional variables post hoc. When possible, we will apply information we gain from our exploratory investigations to testing models with simulated data. We will use program MARK (White and Burnham 1999) and compare model fit via model selection criteria (Akaike's Information Criterion, AIC, Stanley and Burnham 1998).

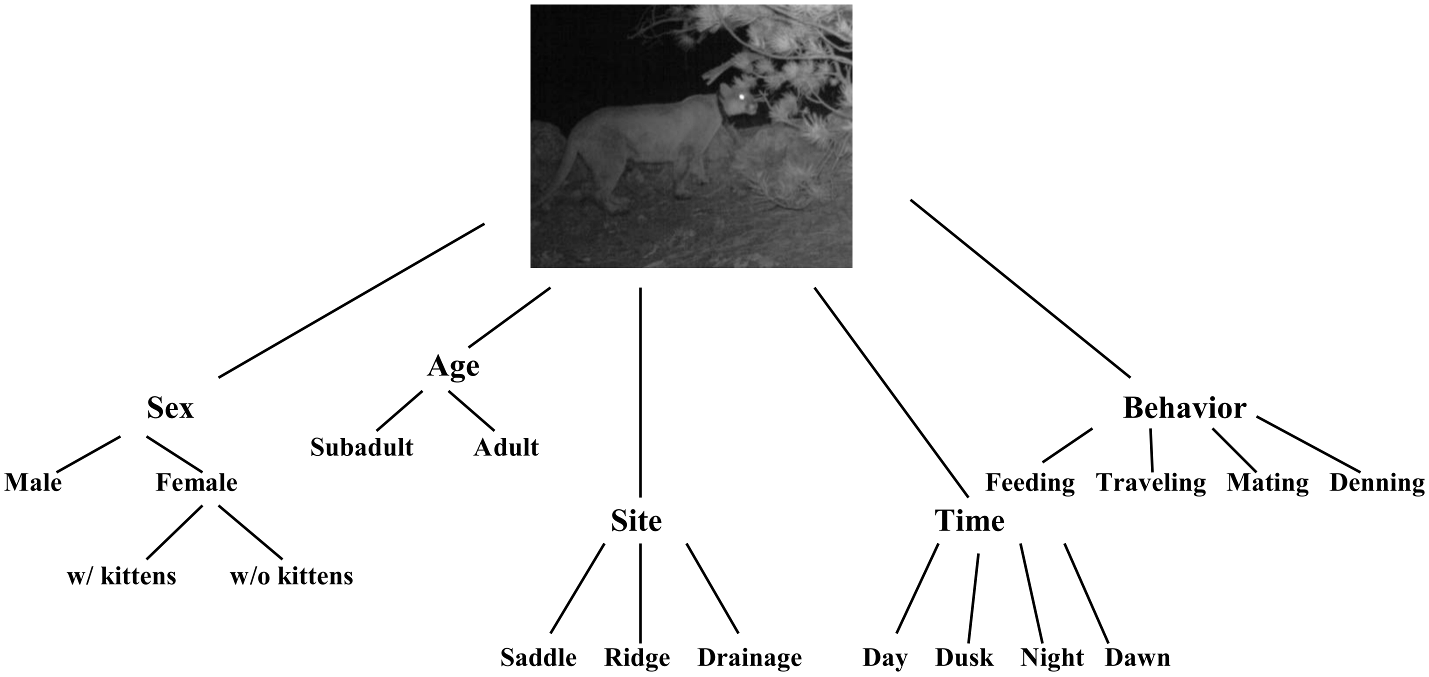

Figure 1. Variables we considered in the detection process.

Chapter 4: The utility of snow tracking on the Front Range

We evaluated the utility of snow tracking as a means to obtain genetic material given the terrain and snow conditions on the Front Range. In February, 2012, we located and followed tracks from known cougars collecting hair and scat samples found en route. The samples will be processed and evaluated based on the successful genotyping of individuals. We found that many variables contributed to the condition of the track and to the quality and quantity of genetic material available. We had planned to snow track from November 2012 – April 2013 but did not have the necessary snow conditions.

Methods

Our initial objective was to investigate the ability to find a genetic sample relative to the time after a snow fall event and the age of the track. On the first day after it snowed, we would randomly choose five cougars whose track would be surveyed on day 1, 2, 3, 4, or 5. On the second day, we would choose four more animals to be surveyed on day 2, 3, 4, or 5. We would continue this trend for five days (Table 1). For example, on day three, we would survey three tracks: a one-day old track, a two-day old track, and a three-day old track.

Our interest also lay in determining the distance we needed to travel to obtain an adequate sample. We would use GPS collared cougars to locate tracks and to evaluate genotyping success by comparing DNA from hair and scat samples with archived DNA from blood and tissue collected during capture. We would follow the track 1 – 2 km, collect all hair and scat found (differentiating between hair found on the surface of the snow, snagged on brush, or in day beds), assess which samples were genotyped successfully, and determine the average minimum distance we needed to survey before an individual could be identified.

Table 1. Schematic of a five-day sampling period following a snow-fall event considering tracks that are 1 – 5 days old.

Days after snow Track age	1	2	3	4	5
1	1	1	1	1	1
2		1	1	1	1
3			1	1	1
4				1	1
5					1

Results and Discussion

Though limited, we had the snow conditions needed to snow track in February and March of 2012 but not from November, 2012 to April, 2013. During the first season, we located multiple hair samples and two scats by following tracks on average 1.25 km but only within 1 – 2 days after a snow fall. Snow conditions were not conducive to tracking over the full five day survey period we had described. Many factors, such as temperature, wind conditions, aspect, snow depth, canopy cover, and vegetation type, contributed to our ability to find and follow a track and to the quality and quantity of genetic material found. In addition, our initial study plan dictated we would follow a track for 1 – 2 km. However, we often lost the track on dry ground or encountered private property boundaries and could not continue.

We also struggled with determining which cougars to survey and where to start. We used the GPS collared animals monitored by CPW to efficiently locate the tracks but needed to randomly choose a starting point and a direction of travel (forward or backward). Our study area was a mosaic of private parcels and public open space. Cougars available to be surveyed needed to have moved a considerable distance across public land shortly after it snowed. We found that, on any given day, only ~¼ of the collared cougars were traveling on public land. Consequently the morning after a snowfall, we were limited to 4 – 6 possible tracks to pursue.

We encountered other logistical challenges while tracking. Snow conditions on sunny, exposed, south-facing slopes, deteriorated rapidly thus ending our progress by mid-morning the first day. Conversely, tracks remained in good condition for several days in north-facing, wooded areas. We had difficulty tracking where more than one cougar was present, especially females with multiple kittens. We also encountered males following in the tracks of the females we were surveying. Not knowing for certain which cougar left the sample was problematic to our initial objectives. In addition, other species like deer would travel over cougar tracks making tracking difficult and obscuring genetic material.

We recognize that inconsistent snow conditions may deem winter tracking to be an inefficient field method in some regions. However when the appropriate snow conditions persisted, we could find hair and scat by following tracks but only within a day after it snowed, preferably first thing in the morning. Snow conditions on the Front Range did not allow for a five-day sampling period. We have not yet processed the samples to determine if the hair and scat we collected contain enough DNA to genotype without error.

Conclusion

We have completed the field component of our study which included a brief pilot season from February – April, 2012 and a longer season from November, 2012 – April, 2013. We used previously captured and GPS collared cougars from two on-going research projects, one led by M. Alldredge on the Front Range and the other led by K. Logan on the Uncompagre Plateau. We established lure sites and tested various scent lures, auditory predator calls, and hair-snaring techniques. We found the most effective combination to be an auditory call concealed in a stick cubby with barbed wire and a sticky roller to snag hair. We are currently conducting the analysis but our initial results reveal a high number of detections by a variety of cougars where many individuals were detected multiple times. We are evaluating the probability of detecting a cougar given that it is in the study area or within a designated buffer zone around each site. We will also address mark-resight model assumptions and assess potential sources of capture variation. In addition, we are currently processing the hair samples and we will assess genotyping errors by comparing our results with the genotypes from blood and tissue samples previously collected. Finally, we evaluated snow tracking as a means to locate genetic material on the Front Range and found that when snow conditions were optimal, we could find hair and scat samples by following tracks. This research is scheduled to be completed in December, 2013.

Timeline

February, 2012 – April, 2012	Pilot Season
November, 2012 – April, 2013	Main Field Season
April, 2013 – August, 2013	Hair Sample Processing
April, 2013 – December, 2013	Data Analysis

Lures were tested (Chapter 1) during the pilot and main field seasons. The detection probability (Chapter 2) and capture variation (Chapter 3) were considered during the main field season. Snow tracking efforts (Chapter 4) were conducted during the pilot and main field seasons and dictated by snow conditions. This work is scheduled to conclude in December, 2013.

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Colorado Parks and Wildlife
July 2012 – June 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	7210	:	Customer Services/Research Support
Task No.:	1	:	Library Services
Federal Aid Project No.	N/A		

Period Covered: July 1, 2012 – June 30, 2013

Author: Kay Horton Knudsen

Personnel: Kay Horton Knudsen, Chuck Anderson, Eric Bergman

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ABSTRACT

The Colorado Parks and Wildlife (formerly Colorado Division of Wildlife) Research Center Library has existed for several decades in the Ft. Collins office. A library housed in the Denver office was moved to Ft. Collins many years ago. Early librarians, Marian Hershcopf and Jackie Boss, can be credited with the physical organization of the Library including seven decades of Federal Aid reports, almost 50 years of Wildlife Commission reports and a unique book and journal collection.

Jackie Boss retired in April 2007 and the Library was temporarily closed to all services. Kay Horton Knudsen was hired as the new Research Center Librarian and began employment on August 30, 2008. The goal, as stated by a former supervisor, was to reopen the Library and expand the electronic and digital capabilities of library services to the entire Agency.

Chuck Anderson became the Mammals Research Team Leader in April 2013. His duties include supervision of the Research Center Library. Eric Bergman and Chuck Anderson served as Acting Mammals Team Leaders from July 2012-April 2013.

A progress report and current status of the Library are detailed below.

WILDLIFE RESEARCH REPORT

COLORADO PARKS AND WILDLIFE RESEARCH LIBRARY SERVICES

KAY HORTON KNUDSEN

PROJECT NARRATIVE OBJECTIVE

Provide an effective support program of library services at minimal cost through centralization and enhancement of accountability for Colorado Parks and Wildlife employees, cooperators and wildlife educators.

SEGMENT OBJECTIVES

1. Continue to improve and modernize library services.
2. Continue to develop, improve, and implement the CPW Research Library web-site.
3. Continue to serve the research information needs of the staff of CPW.

SUMMARY OF LIBRARY SERVICES

The Research Center Library celebrates its fifth full year of operation since reopening in 2008. Work continues on website features, filling literature research requests and taking a more long-term view on improving Library services. Following the merger with State Parks, the librarian reached out to the Parks biology staff to assist with their information retrieval needs.

Major projects this year were an upgrade of the federated search feature for the Library website, digitization of CPW publications and continued contact with staff statewide to meet their bibliographic research needs. Since the Library serves as a historic archive for CPW publications, each meeting with staff also includes a request to be included in the dissemination of white papers, journal articles and internal reports. Day-to-day duties continue to be responding to research and document retrieval requests, cataloging newly acquired material and digitizing internal CPW reports.

EOS International is the vendor for the integrated library system. It was decided to initially purchase the basic modules (a hosted system with library catalog, circulation, cataloging and serials control.) The Library website was released to CPW staff in March 2009. The next module purchased from EOS was Indexer – this feature allows for full-text searching of PDFs linked to bibliographic records. The Knowledge Builder and Classification Management modules purchased earlier did not live up to expectations or usage and were dropped in 2012.

In addition to the catalog of books and reports housed in the Ft. Collins Library, the Library website also gives CPW staff access to research databases. Current subscriptions include BioOne, four of EBSCO's specialty databases (Environment Complete, Fish and Fisheries Worldwide, Wildlife and Ecology Studies Worldwide and CAB Abstracts), SORA (Avian journals), ProQuest Dissertations and Theses and the JSTOR Life Sciences collection. The decision was made in late 2011 to discontinue the print subscriptions to many of the major journals. Online access to the journals was retained and continues as the primary usage point for staff. This online subscription often includes the publisher's full-text online archives. Backfiles of major wildlife and aquatic journals were purchased when necessary to expand the full-text capability. CPW staff statewide are authenticated through WildNet and WildPoint (intranet) eliminating the need for individual usernames and passwords.

A federated, or integrated, search feature for the Library website was on the wish-list from day one. Federated searching combines access to the Research Library catalog, all of the third-party databases listed above, as well as most of the online journals into one all-in-one search. EBSCOHost's Integrated Search (EHIS) was the first version available in spring 2011. The entire federated search industry is evolving and the librarian continued to work with EBSCO staff to resolve problems and maintain links to all resources. In late 2012, as negotiations continued on a contract for 2013, EBSCO staff agreed to upgrade the Research Library to their Discovery service. Using more advanced indexing and metadata management, Discovery provides faster access to all resources. Of course, the installation of any new product also brings a long period of trial and testing and this proved to be the case during the winter and spring of 2012/2013. However the problems were resolved and the new Discovery "All-in-One" search feature was introduced to the CPW staff in April 2013. So far, the product seems to be well-received by Library website users.

The next major project envisioned at the reopening of the Library was the digitization of CPW publications. An HP printer/scanner with optical character recognition software was purchased, installed and tested in 2010. The *Outdoor Facts* and much larger *Special Reports* collections were the first document series to be digitized. The resulting PDFs are attached to bibliographic records for each title within the series and are available via the Library catalog for download by CPW staff throughout the state. In late 2011, Federal Aid staff in Denver donated a large collection of Terrestrial Federal Aid reports to the Library. It was decided to use these for the next digitization project. With the help of a work-study student from Colorado State University, several decades of early reports have been scanned and uploaded to the Library catalog.

Other projects in the Library this year included: 1) processing journal subscription renewals and updates to include full-text online access, 2) organizing Aquatic Federal Aid reports from the 1950s-1970s, 3) continuing to add links to PDF formats into the catalog's bibliographic file, 4) printing and cataloging the Data Analysis Unit (DAU) reports, 5) continuing to gather the transition and merger documents for the combined Parks and Wildlife agency in order to maintain a historic record in the Library collection, and 6) distribution and cataloging of the Mammals, Avian and Aquatics annual reports.

The librarian attended the following conferences and workshops: 1) Colorado Association of Libraries annual conference in Keystone, October 2012, 2) Google User's one day workshop at CSU, January 2013, 3) data curation workshops at CSU and 4) Science Boot Camp for Librarians, 3-day workshop at University of Colorado-Boulder in June 2013. There was also the opportunity throughout the year to participate in several online "webinars" sponsored by various vendors and library agencies to expand knowledge on trends in the library field.

With expanded library services, the number of requests for documents or research assistance has grown. The Library website provides more full-text resources than ever before, however there are also more abstract-only indexes. The librarian has a near 100% success rate in providing material requested by CPW staff. The Library is not open on a walk-in basis to the general public but the librarian does assist the Help Desk at the Denver office with questions they receive. CPW employees generally request journal articles or items from the Library collection; outside researchers (consultants and out-of-state natural resources employees) most often want a copy of a CPW publication. The chart below shows the number of reference questions and document requests handled by the librarian each month during the past 5 years. Please note that one request from a CPW staff member may be for multiple journal or book titles. It is also interesting that the current record for number of requests per month was set in April 2013.

	2008-09		2009-10		2010-11		2011-12		2012-13	
July			20		45		28		37	
Aug	15		25		34		52		44	
Sept	21		30		37		53		48	
Oct	33		38		41		42		39	
Nov	14		28		46		52		51	
Dec	28		32		34		52		49	
Jan	33		62		48		64		46	
Feb	30		43		43		43		54	
Mar	35		36		46		36		53	
Apr	24		23		30		42		**70**	
May	13		17		51		53		65	
June	20		26		27		36		35	
TOTAL	266		380		482		553		591	

As of June 30, 2013, the Research Library held 18,762 titles and 24,718 items (these are the multiple copies of a title) and had 162 registered patrons (CPW staff). Usage statistics for the research databases are given below. These are the total number of sessions; multiple searches were probably performed during each session.

American Fisheries Society package	435
BioOne	1063
Canadian Science Publishing (2 titles)	185
EBSCOHost databases	383
EBSCO All-in-One (Jan-June 2013)	335
Ecological Society of America package	145
JSTOR	1560

Prepared by ____________________________
Kay Horton Knudsen